COSNER
V.
UMATILLA COUNTY

LUBA NO. 2011-070, 2011-071, 2011-072

Local File Number
Text Amendment, #T-10-042

CONSOLIDATED RECORD

VOLUME 5 of 8, Pages 2442 - 3327

Renewable Northwest Project

64.

April 14, 2011

Umatilla County Board of Commissioners
Department of Land Use Planning
Attention: Tamra Mabbot
216 SE 4th Street
Pendleton, OR 97801

Dear Board of Commissioners,

In an effort to inform the decision of the Board of Commissioners regarding the proposed amendments to Umatilla County Development Code (UCDC) 152.615 and .616 (HHH), the Renewable Northwest Project has gathered what we believe represents rigorously researched scientific information regarding wind turbine operation, safety, and economic impact on local communities. The attached documents present diverse research and multiple literature reviews that address the economic benefits, impacts to property values, potential health effects, mechanical safety considerations and setback standards, and sound associated with an operating wind facility. There are many more resources available regarding each of these subjects and we have selected those which represent the best currently available science.

Like so many other rural Oregon counties, the health of Umatilla's communities is founded on the responsible use of its abundant natural resources. Among those natural resources, Umatilla County has the potential to harvest biomass, solar, and wind-generated energy. Along with the hydro-system that helps keep our energy costs among the lowest in the nation, responsible development of Oregon's other renewable resources will help revitalize the State's economy and achieve energy independence. Statewide over $5.4 billion dollars has been invested through the renewable energy development industry. Of this, over $4.5 billion dollars have been invested by the wind energy sector alone. With over 350 MW of operating projects in Umatilla County, our analysis shows that the economic benefits have disproportionately and favorably benefitted Umatilla residents through property taxes, job creation, and support industries over other Oregon counties. These economic benefits include Strategic Investment Programs (SIPs), an estimated $500 million in capital investments, $1.4-3.5 million[i] paid in annual royalty payments to private landowners and $1.7[ii] million in property tax payments.

Our experience demonstrates that in addition to the annual benefits associated with property tax payments, renewable energy facility development and operation helps rural communities diversify their economic activities. Wind turbine operation is compatible with many

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agricultural activities, enabling local landowners to benefit from the reliable secondary source of income provided through annual lease payments. Improvements in service roads enable county emergency response units to respond faster to dangerous situations. Wind energy construction and operation also create permanent jobs and economic opportunities for the businesses and local contractors they support, as well as the result of school improvements and county services from increased economic activities stimulated by renewable energy development.

If the Board of Commissioners adopts the recommendations made by the Planning Commission to the *Wind Power Generation Facility siting standards* (HHH), it is our opinion that further development of wind farms in Umatilla County will be greatly impaired. Passing these standards as they are currently proposed will likely also threaten a portion of the 203 MW of approved wind projects and an additional 400 MW of renewable energy that is currently in permitting. This would greatly diminish the future economic opportunities that could be realized through renewable energy development. And while our aim is not to offer statements on residents' concerns, our goal is provide these reports to ensure that the Board of Commissioners has the best available information at hand as you reach your final decision on the HHH amendments.

We appreciate the opportunity to provide the Board of Commissioners with these comments and to directly address concerns related to renewable energy. If you have any questions about these documents or desire additional information, please don't hesitate to contact RNP. Thank you for your efforts to responsibly develop wind energy in Umatilla County.

Sincerely,

Lauren J Prince

Lauren Prince
Policy Associate
Renewable Northwest Project
917 SW Oak Street
Portland, Oregon 97205

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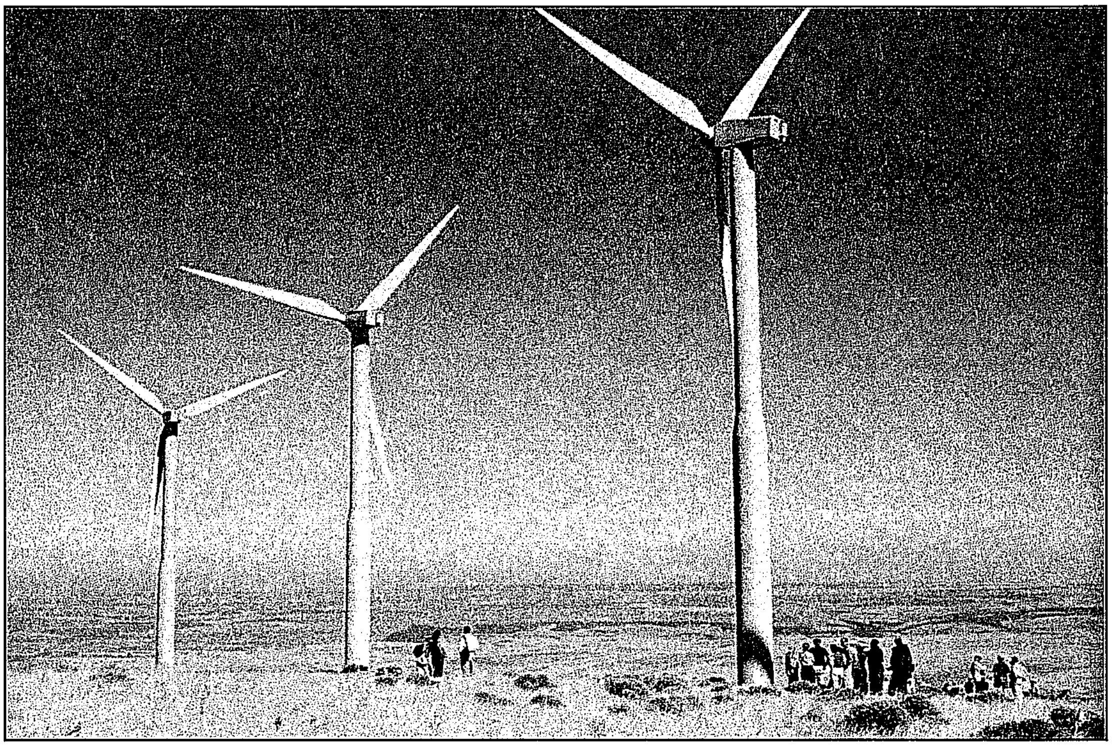
[i] Costanti, Mike and Beltrone, Peggy. US Department of Energy and National Renewable Energy Laboratory. *Wind Energy Guide for County Commissioners*. November, 2006. Available from: http://www.nrel.gov/docs/fy07osti/40403.pdf.
[ii] Direct communication with Umatilla County Assessor.

Renewable Northwest Project

Materials submitted to
UMATILLA COUNTY BOARD OF COMMISSIONERS
April 14, 2011

Review of Scientific Literature Regarding Wind Power Generation Facility Siting

submitted for the Board of Commissioners Work Session
regarding amendment to Conditional Use Section 152.616 (HHH)
of the Umatilla County Development Code



Compiled and submitted by
Renewable Northwest Project
917 SW Oak St, Ste 303
Portland, OR 97205

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Renewable Northwest Project

RNP Members

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American Wind Energy Assoc.
Blattner Energy
Bonneville Environmental Foundation
BP Wind Energy
Calpine
Center for Energy Efficiency & Renewable Technologies
CH2M Hill
Citizens' Utility Board
Climate Solutions
Clipper Windpower
Columbia Energy Partners
Columbia Gorge Community College
David Evans & Associates
E.ON Climate & Renewables
Element Power
Environment Oregon
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enXco, Inc.
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Tonkon Torp LLP
Vestas Americas
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Washington Environmental Council
WashPIRG
Western Resource Advocates
Western Wind Power

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Section 1

RNP WHITEPAPERS

Document List

- *Renewable Energy & Economic Development: Real Examples from Oregon.* March, 2011.
- *Windfall from the Wind Farm: Economic Development in Sherman County.* July, 2006.
- *Renewable Energy Fact Sheet.* October, 2005.
- *Wind Power.* November, 2006.
- *About the Oregon Renewable Energy Act, SB 838: Powering Oregon's Future.* August, 2007.
- *Vansycle Ridge Wind Farm.* July, 1999.
- *Stateline Wind Energy Center.* January, 2003.

Renewable Energy & Economic Development

Real Examples from Oregon March 2011

OREGON'S RENEWABLE ENERGY LEGACY
Economy, Community & Environment

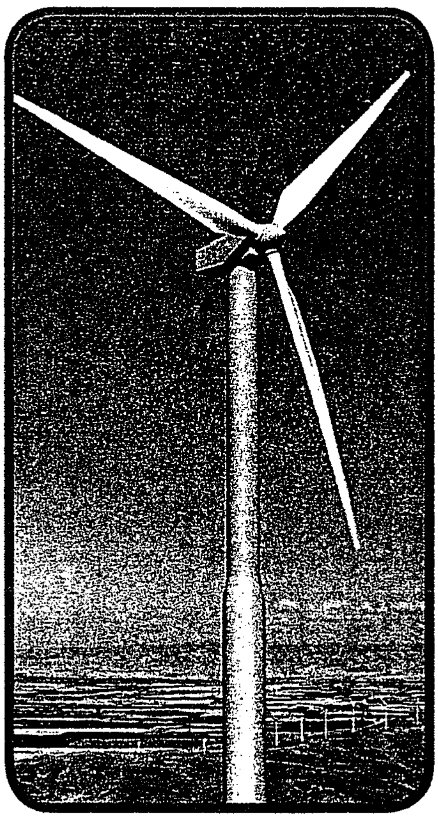
The renewable energy sector has made a leading investment in Oregon's economy. It is "the" answer to job creation – through direct project related jobs, secondary impacts and manufacturing supply chain involvement. The breadth of benefits – economic and environmental - spans rural and urban communities throughout our state.

JOB CREATION & STATEWIDE ECONOMIC RECOVERY

The renewable energy sector has invested over $5.4 billion throughout Oregon so far,[1] with much of that investment benefitting rural communities blessed with abundant natural resources capable of generating clean, renewable energy.

As a result of Oregon's supportive policies and incentives – like the Renewable Energy Standard, Business and Residential Energy Tax Credit programs – our state is cultivating a thriving clean energy economy through the businesses and industry clusters we have attracted.

- **Oregon ranked #2 in the 2010 U.S. Clean Energy Leadership Index**, surpassed only by California in the 2010 rankings from Clean Edge.[2]
- **Oregon has become the U.S. solar manufacturing capital, employing 1,700 people now and projected to grow to 2,350 by the end of this year.**[3]
- **Since 2001, Oregon has seen more than $143 million invested in residential and commercial solar projects, employing hundreds of installers.**[4]
- **Oregon has cultivated a robust wind industry cluster.** Wind companies have made over $4.5 billion in investment in Oregon to date.[5] Leading wind energy developers and manufactures, such as Iberdrola Renewables, Vestas, Horizon Wind and Element Power, have a major corporate presence in the state because of Oregon's commitment to the industry.
- **Geothermal energy is also primed for growth.** With federal cost share programs, over $120 million has been invested in geothermal exploration, research, and project development since 2009.[6] At least 75 megawatts will be coming online in the short term.
- **Other renewables are building for the future.** With the state's rich natural resources and Pacific coastline, the biomass and wave energy industries are also looking at Oregon as a prime location for investment.



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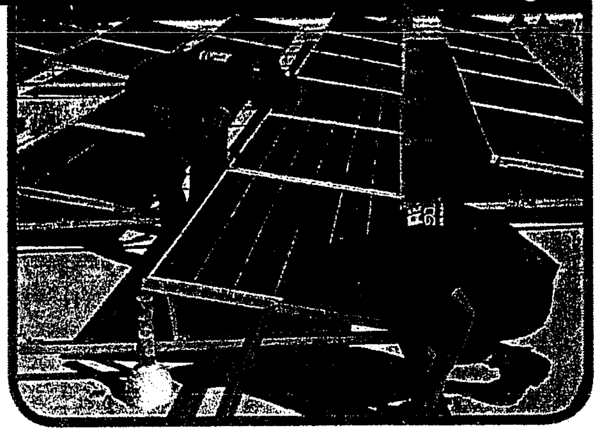


OREGON ENERGY, OREGON VALUES

Oregon and the Northwest house the nation's leading customer voluntary renewable power programs. Despite recession conditions, power customers in Oregon and the Northwest opted into utility renewable power programs at record levels.[7]

Polls indicate that voters view clean energy as a high priority. A 2011 poll of residents in Oregon, Washington and Idaho found that 79% of the rural population and 87% of the urban population would support wind energy development even if turbines were in view from their home.[8]

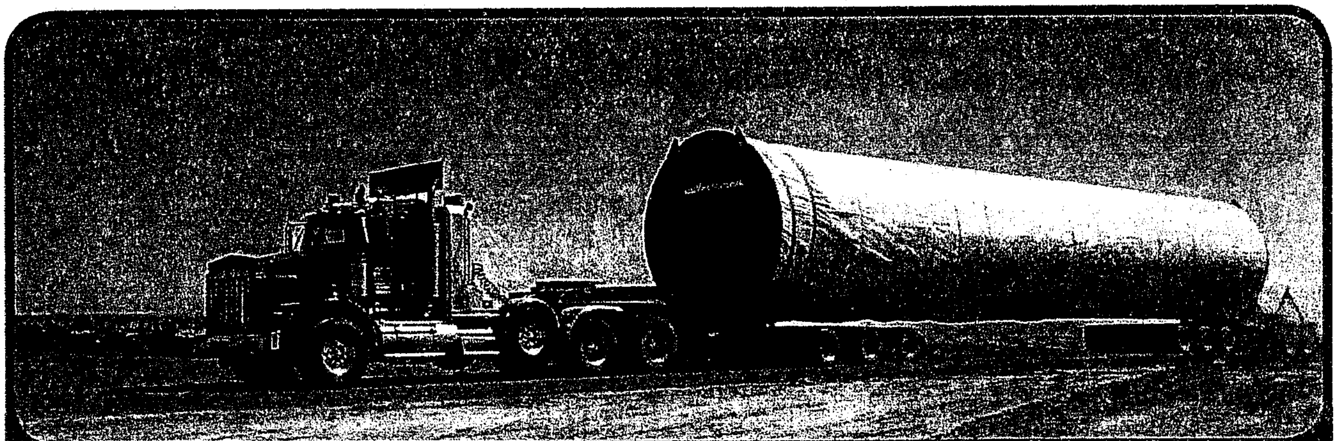
IN RURAL OREGON, FARMERS, RANCHERS & COMMUNITIES REAP NEW HARVEST

Imagine a rural county that's hit by hard times. Farmers struggle, young generations leave without local opportunity, schools and services suffer due to lacking funds. Citizens worry about their families, bank accounts and future. Now imagine that county's **annual revenues increasing from about $315,000 in 2002 to $10 million in 2010.** Imagine that county providing **more than $1 million to county residents** through the Sherman County's Resident Compensation Program, which pays $590 to heads of households as a means of sharing surplus revenue – literally money in their pockets. Imagine **creating about 80 jobs in a county with 1,800 people** and a high school graduating class of about 25.[9] This is the real-life win-win-win story of Sherman County, Oregon and wind power development. Oregon's rural communities have long harnessed natural resources for economic stability and a valued way of life. Renewable energy has expanded these options.

POLICIES TO SUPPORT CLEAN ENERGY VISION AND VALUES

Clean energy is the best economic recovery opportunity for Oregon's communities and workforce. Strong policies have brought great economic benefits to Oregon. The state can continue to lead the nation and build the clean energy economy if there is continued political will to support it. Now is the time for Oregon to push forward as a leader more than ever.

Download this fact sheet with references at http://www.RNP.org/node/RNP-reports-and-fact-sheets



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Windfall from the Wind Farm

Renewable Northwest Project

Economic Development in Sherman County

Rural counties and landowners in the Pacific Northwest are harvesting a new crop. Large, utility-scale wind energy projects can add to a county's tax base and support essential services such as schools and fire departments. These projects also can generate revenue for individual farmers as well as local and regional businesses. Wind turbines are compatible with farming, occupy little land and can pay farmers many times what they earn per acre harvesting crops.

Sherman County is a prime example of a rural community that is harnessing its wind resource and reaping the benefits. A report from the Renewable Northwest Project titled "Windfall from the Wind Farm; Sherman County, Oregon" details the economic development benefits to the county and to Oregon businesses resulting from the first phase of the Klondike Wind Farm. Revenue from the wind farm is helping to diversify this historically single-engine economy that is under increased stress from low wheat prices and decreasing harvests.

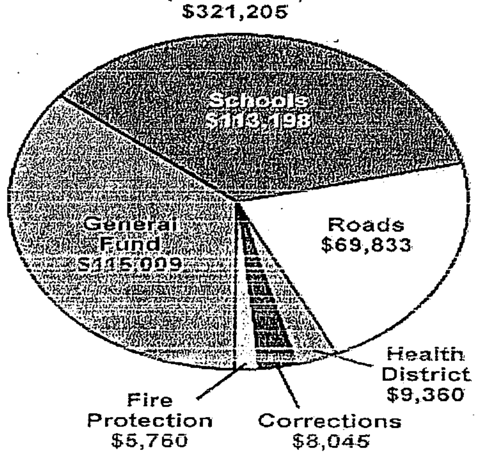
PPM Energy, an energy company based in Portland, Oregon owns the Klondike Wind Farm. The first phase of the project, which came on line in 2001, consists of sixteen wind turbines that can generate up to 24 megawatts (MW) of electricity. A second phase, consisting of an additional 50 turbines, was completed in 2005. The total capacity of both phases totals 99 MW; enough to power approximately 25,160 homes in the Pacific Northwest.

The project is located on land cultivated for wheat farming and removes less than 25 acres of land from production. While the physical footprint of the wind farm is small, the economic benefit is substantial.

Property Tax Benefits

During its first year of operation, Phase I of the Klondike Wind Farm Phase I generated $321,205 in property tax revenue for Sherman County. In 2005, the wind farm generated $362,442 in property tax revenue. This amount represents just over 10 percent of the county's total property tax base. The figure below illustrates how the county is using this new revenue to support a variety of essential services. According to the county tax assessor, the first phase of the project is expected to generate approximately $250,000 in property taxes each year over its 20 to 30 year lifetime. "Wind power helps to diversify the economy. It's another crop we can harvest and it helps fill gaps in the county budget," says County Judge Mike McArthur.

Tax Revenue Contribution from Klondike Wind Farm (2002-2003) $321,205



Landowner Benefits

Farmers in Sherman County who lease their land to wind developers receive annual royalty payments of between $2,000 and $4,000 per year for each turbine sited on their property. For comparison, each turbine sits on only a half an acre of land, enough to earn less than $100 per year if used to cultivate winter wheat. According to Lee Kaseberg, a local wheat and wind farmer, the turbines are compatible with farming operations. "Put them

> ***"Wind power helps to diversify the economy. It's another crop we can harvest, [and[it helps fill gaps in the county budget."***
>
> -Mike McArthur
> County Judge

up, we can farm around them easily," declares Kaseberg. Four workers periodically maintain the turbines and access them via new roads that were built as part of the project. A neighboring farmer, John Hilderbrand, adds, "The new roads allow easier access to my fields. Plus, the turbines make money in the winter when I can't work my land."

Other Local Benefits

A variety of local and regional businesses took part in the planning, development and construction of the wind farm including many Oregon businesses from Canby, Hood River, Portland and Wasco. Approximately 80 to 100 workers were involved in the construction of Phase I alone and local establishments experienced a boom as these workers patronized local motels, restaurants and grocery stores. Occupancy rates skyrocketed at the Tall Winds Motel in Moro, at motels in the towns of The Dalles and Biggs Junction, and at the RV park in Wasco. Workers also bought gasoline from the local Hardware Co-op. The owners of the Lean-to Café, one of the few restaurants near the project, added on to their building with profits from increased business associated with the wind farm construction. The restaurant owners also plan to build a new motel and buy a mobile kitchen to serve the needs of working crews as the project expands. Due to the quality wind resource and supportive local community, PPM Energy recently quadrupled the size of the Klondike Wind Farm with a second phase and Portland General Electric is buying all additional 75 megawatts from Phase II.

"The turbines make money in the winter when I can't work my land."
-Lee Kaseberg, wheat and wind farmer

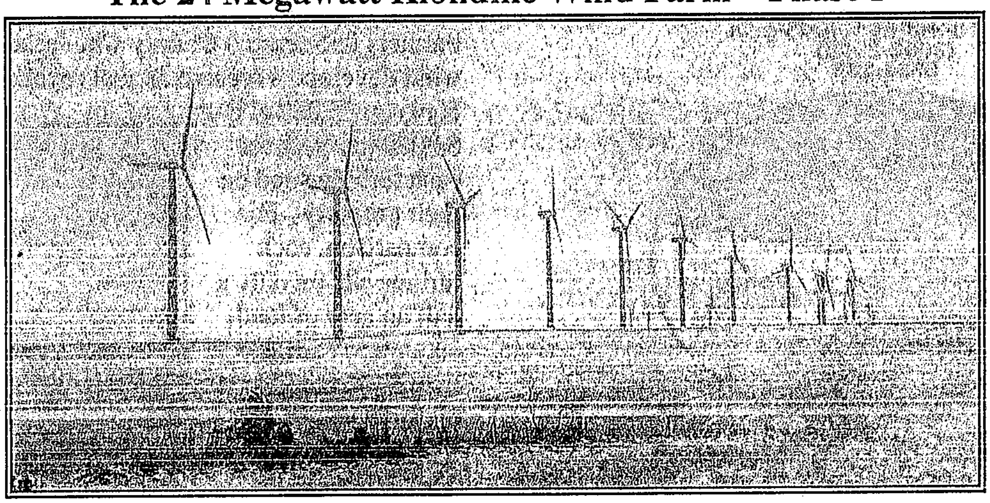
Environmental Assessment

The environmental assessment for this project revealed minimal impacts to habitat and wildlife. The project does not disturb any natural habitat since it is built completely on tilled farmland. Due to a lack of trees and water sources, the local environment is not well suited to host many native or migratory birds. A one-year, post construction study found minimal impact on birds and the turbines have had no effect on local deer and antelope populations.

Conclusion

Although Phase I of the Klondike Wind Farm is small relative to other utility-scale wind projects, it is providing a valuable economic development opportunity for Sherman County. The planning and construction phases stimulated local and regional businesses. In its operational phase, the project is generating tax revenue for the county and royalty payments for individual landowners. Large wind power projects are a viable way for rural counties with strong wind resources to diversify their economies and for local farmers to preserve their cherished way of life.

The 24 Megawatt Klondike Wind Farm – Phase I



These 16 turbines from the first phase of the Klondike Wind Farm project support the local economy by paying county property taxes and royalties to landowners.

Renewable Energy
FACT SHEET

Renewable Northwest Project

What's wrong with the electricity system?

Generating electricity is a significant source of air pollution and a major cause of carbon dioxide, smog, acid rain and habitat destruction. About 40% of the electricity consumed in the Northwest comes from burning fossil fuels, such as coal and natural gas. These and other conventional methods of electricity generation emit pollutants that harm human health, degrade ecosystems and contribute to global warming. Shifting our electricity system towards reliance on clean, domestic resources such as wind, solar, and geothermal power can help preserve our air and water quality, strengthen security in homegrown energy, and bring economic benefits to our region.

Is there renewable potential in the region?

The Northwest is blessed with an abundance of renewable resources. With the region's varied climate zones and geology, we have enough potential solar, wind, and geothermal resources to satisfy at least 40% of our nation's electricity needs*. Furthermore, remarkable improvements in renewable technologies continue to reduce costs and help expand the potential of the region's already large renewable resource base.

* Resource potential from *Renewable Energy Atlas of the West* was compared to latest data electricity consumption data from DOE/EIA to calculate this percentage.

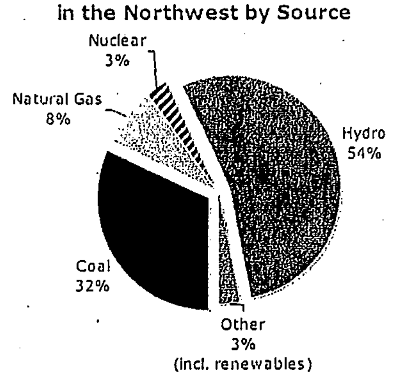
Are there renewable energy projects operating in the Northwest?

There are currently nine utility-scale wind plants serving customers in Oregon, Washington, Idaho, and Montana, with 5 more wind projects under construction and over 2 dozen in development in the region. There are also five proposed geothermal projects and a growing number of commercial-scale solar projects, the largest of which is a 172 kilowatt system located at the Pepsi bottling plant of Klamath Falls in southern Oregon. By the end of 2005, operating wind plants in the Pacific Northwest and Wyoming will produce 380 average megawatts of power, or enough energy to power all the homes in the city of Portland for a year.

What are the environmental benefits of renewables?

Solar, wind, and geothermal resources do not create the pollution associated with fossil fuels, such as mercury, sulfur oxides, nitrogen oxides, and particulates. Renewable energy reduces the environmental impacts of power generation.

Electricity Consumption in the Northwest by Source



What are the economic benefits of renewables?

Renewable energy keeps family-wage jobs and dollars in the region, unlike gas-fired generating plants, which create a fraction of the jobs and send millions of dollars outside the region to pay for fuel. Many wind power projects add significantly to the local tax base and farmers get lease income from turbines on their property. These are significant economic benefits for rural areas in the Northwest. Solar, wind, and geothermal plants have no fuel costs and therefore eliminate the uncertainty and expense of fuel prices increases. They lower our dependence on imported fuel supplies, diversify our energy portfolio and stabilize electricity rates for the long run.

What can I do?

By participating in green power programs offered by utilities, consumers use their electricity dollars to bring clean resources online in the Northwest even faster. Many Northwest utilities offer a renewable energy power option to their customers. By participating in these green power programs, utility customers can push the market toward new, clean resources. Investing in energy efficiency upgrades, solar water heating, and small-scale wind or solar power generation systems also has positive impacts. These steps will help to protect the environment of the Pacific Northwest, strengthen its economy, and create long-lasting jobs.

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Renewable Energy FACT SHEET (cont'd)

Who's purchasing Renewable Energy in the Northwest?

These are just a few of the many Northwest businesses and organizations making significant clean energy purchases:

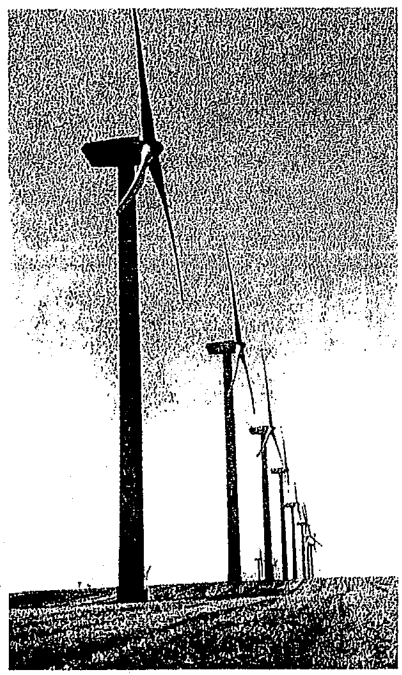
Bainbridge Graduate Institute
Batdorf & Bronson Coffee Roasters
Burley Design Cooperative
Cascade Bookkeeping
Cascade Business News
Cascade Credit Counseling
CH2M Hill
City of Bend
City of Corvallis
City of Portland
City of Walla Walla
Contemporary Family Dentistry
Corvallis Chamber of Commerce
Cozmic Pizza
David Evans & Associates
Downtown Bagel Sphere
Ed's Tire Factory
Emerald Valley Kitchen
EPA, Region X
Eugene Coin & Jewelry
Eugene Friends Meeting Hall
Evergreen State College
Fairchild Air Force Base
FedEx Kinko's
First Alternative Coop
First Unitarian Church
Foot Zone
Forcum Speck Attorneys
Foxy Dog
Global Energy Concepts
Harlequin Beads & Jewelry
Hewlett Packard
Hood River Cinemas
Hood River County
The Joinery
Kettle Foods
Morning Glory Bakery & Café
Mt. Bachelor Village
Nike
Norm Thompson
Pacific Winds Music
Palmer Homes
PCC Natural Markets
Peak Sports
Phoenix Day Spa & Salon
Phoenix Organics Garden Center
Port of Portland
Rainbow Valley Design & Construction
Red Barn Natural Grocery
Robnett's Hardware
Russell Development Co.
Scholz Family Fabricators
Schwartz Chiropractic Clinic
Sera Architects
Seven Stars Childcare
Soundpeace
Staples
Starbucks
Stoel Rives LLP
The Stone Medical
Trout Unlimited
Valley View Winery
Walla Walla Valley Chamber of Comm[illegible]
Western Washington University
Whitman College
Wild Oats Natural Marketplace
Xanterra Parks & Resorts
Xantrex

Environmental Benefits of Green Power:

- Clean energy resource - no air, water or ground pollution
- Purchasing a 100 kWh block of wind for one year is equal to planting 1/3 acre of trees or not driving 1,800 miles
- Participation can develop *new* renewable resources
- Renewable energy projects keep good paying jobs and dollars in the region

These Organizations Support Renewable Energy in the NW:

Audubon Society of Portland
Bonneville Environmental Foundation
Central Oregon Environmental Center
Citizens' Utility Board of Oregon
Climate Solutions
Corvallis Environmental Center
Fair and Clean Energy Coalition
Friends of Opal Creek
Friends of Trees
Montana Environmental Information Ctr.
MontPIRG
Natural Resources Defence Council
Northwest SEED
NW Energy Coalition
Oregon Environmental Center
OSPIRG
Physicians for Social Responsibility
Renewable Northwest Project
Resource
Sustainable Solutions
WashPIRG
3E Strategies



For More Information:

U.S. Department of Energy, Energy Effciency and Renewable Energy Green Power Network:
www.eere.energy.gov/greenpower/

Northwest Seed:
www.nwseed.org

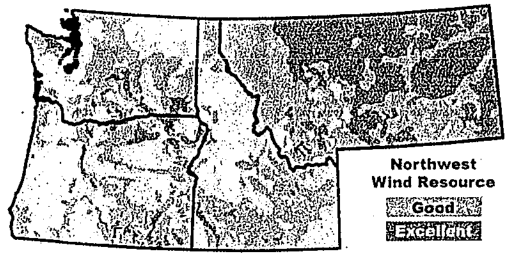
Renewable Northwest Project:
www.rnp.org

Database of State Incentives for Renewable Energy
www.dsireusa.org

Renewable Northwest Project

Wind Power

Renewable Northwest Project



WIND ENERGY IN THE NORTHWEST		
	Potential	Installed Capacity*
Oregon	7,991 aMW	886 MW
Washington	7,078 aMW	1165 MW
Idaho	5,594 aMW	75 MW
Montana	116,438 aMW	164 MW
Resource type	Variable, predictable	
Capacity factor		28-36%
Real levelized cost (2006$)		4-7 ¢/kWh
Construction lead time		1-3 years

*Installed capacity as of February 2008.
MW= Megawatts (capacity),
aMW = average MW;
Sources: see endnote 1.

POTENTIAL

As the above table shows, the Pacific Northwest has the potential to generate over 137,000 aMW of electricity from wind power. This is enough to provide nearly four times the current electricity consumption in the region. The majority of the region's potential wind resources are in Montana, which alone has enough potential wind resources to supply one quarter of the electricity needs of the United States.[2]

Nearly 2,300 MW of nameplate wind power capacity is currently generated at Northwest wind farms and projects currently in development could triple that figure over the next several years.[3] Texas leads the United States in wind development with over 4,350 MW of currently installed capacity each. California, has nearly 2,500 MW of installed capacity and Colorado, Minnesota, and Iowa are also making rapid investments in wind power, with over 1,000 MW currently in service in each state.[4]

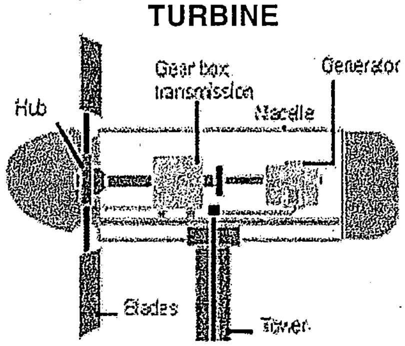
Between 2001 and 2007, the U.S. wind generating capacity expanded at a remarkable rate of 49% per year on average. By the end of 2007, the U.S. had over 16,800 MW of wind capacity online, enough to power over 1.5 million homes for the entire year![5]

However, Europe currently remains far ahead of the U.S. in wind development, with 56,535 MW of wind capacity online as of the end of 2007.[6]

COST

Advances in technology and increased experience have made wind power competitive with many traditional sources of electricity, especially when factoring in risk factors for traditional generation resources such as fuel volatility and future environmental regulation. The price of wind-generated electricity has decreased approximately 90% from the early 1980s; modern wind farms now generally have levelized costs in the range of 4-7 cents per kilowatt-hour over the life of a project (including federal tax credits) making them competitive with many new coal or natural gas facilities. Costs for individual projects vary and depend on the strength and consistency of the wind, financing terms, and transmission infrastructure. All else being equal, the cost effectiveness of wind farms generally increases with the turbines' capacity factor, the size of the turbines, and number of turbines installed.[7]

ANATOMY OF A WIND TURBINE



Source: see endnote 8

"Montana ... alone has enough potential wind resources to supply one quarter of the electricity needs of the United States."

ECONOMIC BENEFITS

Tapping our domestic wind resources brings a host of economic benefits. Since the strongest wind resources are often located in rural areas, rural counties and landowners can benefit from wind power. Wind farms are capital intensive, infusing money into the local economy during construction phases and paying property taxes to the host county and royalties to local landowners during operation. At the 24 MW Klondike Phase I Wind Farm in Sherman County, Oregon, the wind project contributes 10% of the county's property tax base. Wind turbines are also compatible with rural land uses like farming and ranching and can provide extra income to property owners via power sales or royalty payments. On average, landowners make between $2,000 and $7,000 annually for each modern wind turbine located on their land.

In contrast, a natural gas plant drains an estimated $200,000-$350,000 per MW of capacity out of the regional economy annually for fuel imports. Additionally, wind energy produces 27% more jobs per kilowatt-hour than coal plants, and 66% more jobs than natural gas plants.[9]

Wind energy is clearly a homegrown energy source that strengthens the economy and increases the nation's energy security.

HOW IT WORKS

Turbine blades, modeled after airplane wings, rotate due to a pressure differential caused by air moving over the surface of the blade. The blades cause a rotor to turn, which drives an electrical generator. Turbines can adjust so that they always face toward the wind.

Wind turbines can be designed to operate either at variable speeds or at a single, fixed speed. The variable speed designs are more complex but they convert wind power into electricity more efficiently.

Most wind turbines are designed to use wind blowing anywhere from 8 to 56 mph. Sizes for new U.S. utility-scale turbines for onshore sites range from 850 kW to 2.5 MW and turbines rated 3.5 MW and larger are being used in offshore wind projects.

System Integration

While variable, wind energy can be integrated into a utility system using existing load-matching capabilities for a minimal cost of less than half a cent per kWh.[10] Weather forecasting can predict wind power output with a fair degree of confidence. Additionally, multiple wind sites in different locations can be combined to create a relatively stable power supply curve.

Environmental Impacts

Wind turbines generate electricity without producing any pollutant emissions. In contrast fossil fuel plants emit toxic mercury, nitrous oxides that cause smog, sulfur dioxide that causes acid rain and large quantities of carbon dioxide, the main greenhouse gas. Although wind is one of the most benign power sources, if not properly sited, it too may have environmental impacts. Wildlife and avian impacts are often the greatest concern. New tower, blade and turbine designs and careful siting help minimize environmental impacts.

Incentive Programs

The federal production tax credit offers an important tax credit to new wind production. Each state in the region offers several additional incentives for wind development, from residential projects to utility-scale developments. Oregon, for example, provides personal and business tax credits and low-cost financing for renewable energy projects, while Washington provides small wind turbine owners a strong production incentive and grants sales tax exemptions for renewable energy equipment. Idaho offers a residential tax deduction and a sales tax exemption for renewable energy systems as well as low-interest loans for small-scale wind installations and state-backed bonds for utility-scale wind projects. Finally, Montana offers corporate income and property tax incentives and a residential tax credit for renewable energy installations. Additional incentives are offered as well.

More Information

National Renewable Energy Laboratory: www.nrel.gov/wind/

Northwest SEED: www.nwseed.org

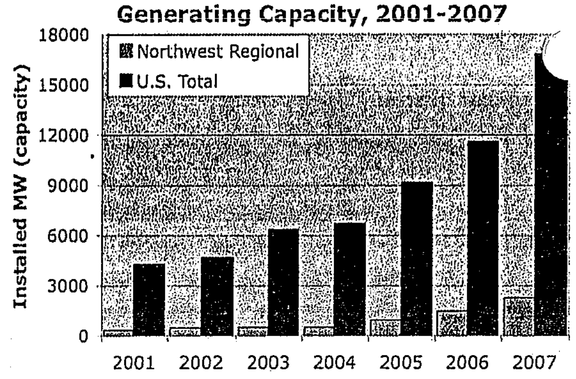
National Wind Technology Center: www.nrel.gov/wind/

Renewable Energy Research Laboratory Fact Sheets: www.ceere.org/rerl/about_wind/

American Wind Energy Association: www.awea.org

DSIRE: Database of State Incentives for Renewable Energy: www.dsireusa.org/

Northwest and U.S. Wind Generating Capacity, 2001-2007



Source: see endnote 11.

Sources and Notes:

[1] Wind potential from *Renewable Energy Atlas of the West*, Land and Water Fund of the Rockies, et al. (July 2002).

-Installed capacity from "Renewable Energy Projects Serving Northwest Load", Renewable Northwest Project (RNP) (Feb 19, 2008), www.rnp.org/Projects/projectlist.php, accessed 2/19/08.

-Capacity factor from *Fifth Northwest Electric Power and Conservation Plan*, Northwest Power and Conservation Council (NWPCC) (May, 2005). See Appendix I.

-Levelized costs include transmission and integration costs and the federal Production Tax Credit.

[2] 2005 Northwest consumption from NWPCC, *op. cit.* note 1.

-2004 total U.S. electricity generation from *Annual Energy Outlook 2006*, Energy Information Administration (Feb. 2006). See Table A8.

[3] Installed capacity and projects in development from RNP, *op. cit.* note 1.

[4] "U.S. Wind Energy Projects". American Wind Energy Association (AWEA) (Jan 16, 2008). www.awea.org/projects/ accessed 2/19/08.

[5] Annual growth figures from "Wind Power, U.S. Installed Capacity", AWEA, www.awea.org/faq/instcap.html, accessed 2/19/08. 2007 year-end installed capacity from "Installed US Wind Power Capacity Surged 45% in 2007", AWEA (Jan 17, 2008).

[6] "Statistics", European Wind Energy Association, http://www.ewea.org/index.php?id=180, accessed 2/19/09.

[7] Cost trends from "The Economics of Wind Energy", AWEA (Feb 2005). Levelized costs include transmission and integration costs and the federal Production Tax Credit.

[8] Graphic from "Renewable Energy", New South Wales Department of Energy, Utilities and Sustainability. http://www.seda.nsw.gov.au/ren_wind_body.asp, accessed 9/27/06.

[9] Natural gas fuel cost assumes a 55% efficient combined cycle plant with a 90% capacity factor using natural gas at $4-$7/mmBtu.

-Jobs figures from "Wind Energy for Rural Economic Development", US Department of Energy, EERE (2003).

[10] *Wind Taskforce Report*, Western Governor's Association (March 2006)

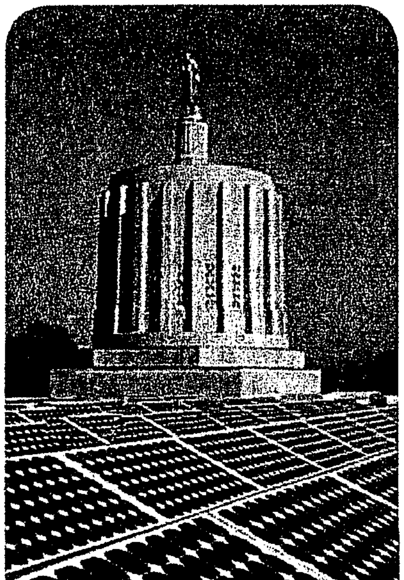
[11] U.S. from AWEA, *op. cit.* note 5, NW from RNP, *op. cit.* note 1.

About the Oregon Renewable Energy Act

SB 838: Powering Oregon's Future

The Oregon Renewable Energy Act (SB 838) was signed into law on June 6th, 2007. The Act establishes a Renewable Energy Standard that requires Oregon's largest utilities to acquire 25% of their electricity from renewable energy sources by 2025. Smaller Oregon utilities must meet targets of 5% or 10% by 2025.

A remarkably diverse range of stakeholders supported the effort and the bill received bipartisan support in the legislature. "[The Oregon Renewable Energy Act] will encourage the growth of a new industry in Oregon providing new jobs in rural Oregon," said Senator Jason Atkinson (R-Grants Pass), the bill's co-sponsor. Upon it's passage, Governor Ted Kulongoski hailed the Act as "the most significant environmental legislation ... in more than 30 years that will stimulate billions of dollars in investment - creating hundreds, if not thousands, of jobs in both urban and rural Oregon."



"[SB 838] is the most significant environmental legislation ... in more than 30 years that will also stimulate billions of dollars in investment - creating hundreds, if not thousands, of jobs in both urban and rural Oregon."

Ted Kulongoski, Governor of Oregon

Benefits for Oregonians:

SB 838 ensures more clean energy for Oregon

Oregon has an abundance of clean, renewable energy resources and SB 838 will create a stable market for new renewable energy development. The Oregon Renewable Energy Act is expected to support the development of **1,500 average megawatts (aMW) of new renewable energy**, enough energy to meet the needs of 1.25 million average Pacific Northwest homes.

SB 838 increases Oregon's energy independence

Developing our own, homegrown renewable energy resources will make Oregon more self-reliant and increase our energy independence. **More than half of the electricity consumed in Oregon comes from volatile and risky fossil fuels** and hundreds of millions of dollars leave the state's economy every year to import coal and natural gas. SB 838 will change that picture by keeping more of our hard-earned money and good-paying jobs in Oregon's communities.

SB 838 strengthens Oregon's economy

Communities across Oregon will receive a tremendous economic boost from the renewable energy development spurred by SB 838. Renewable energy development will bring billions of dollars of new economic activity to both rural and urban Oregon. **Just one year's worth of wind energy development brought nearly $1.4 billion in new capital investment to the region and supported nearly 1400 jobs.**[1]

SB 838 guarantees a cleaner energy future

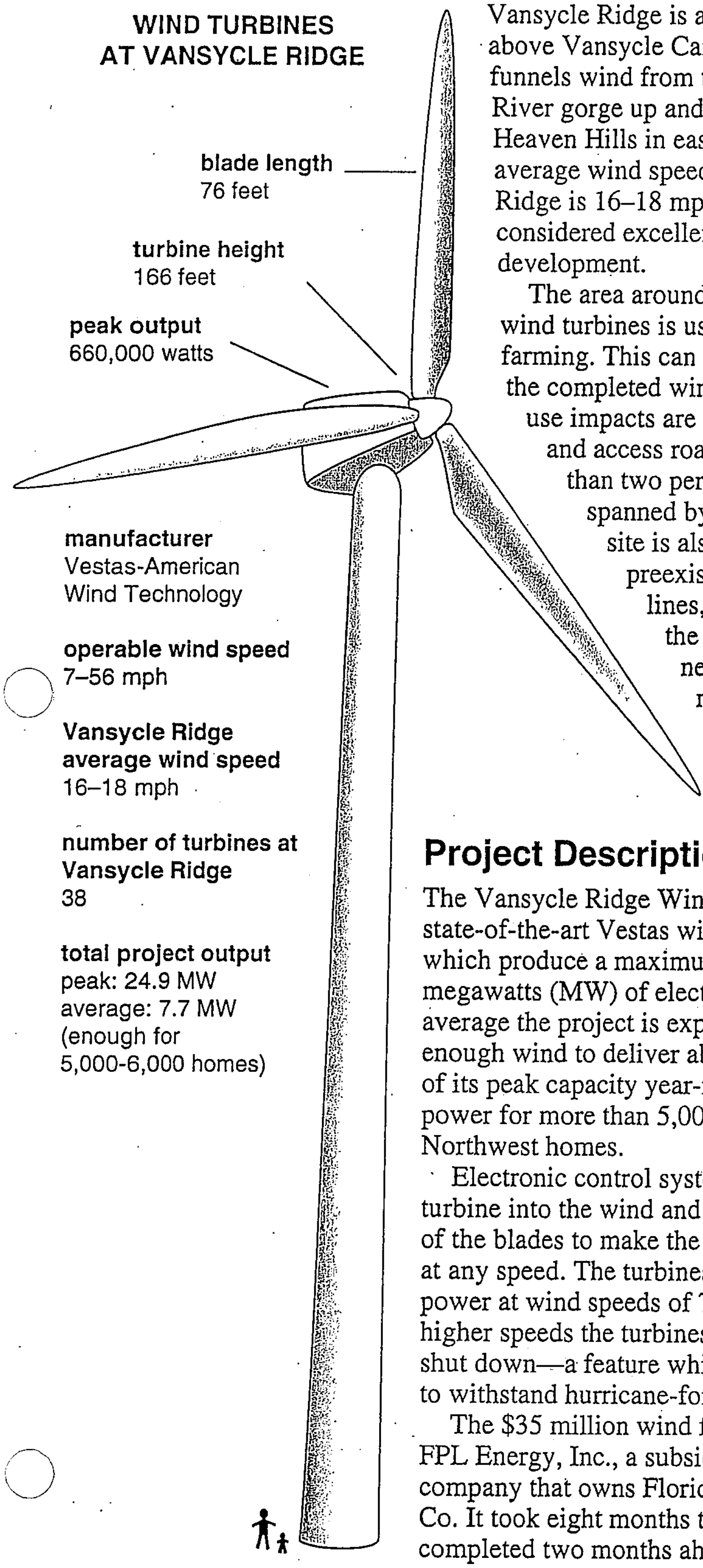
Global warming has emerged as the most significant threat facing Oregon's environment, and rising temperatures are already threatening the places we know and love, from Cascades to the Oregon coast. **SB 838 is Oregon's most significant step yet to rein in global warming pollution in Oregon.** Renewable energy also generates clean electricity, free of the smog, acid rain and toxic mercury pollution that spews from fossil fuel power plants.

1. "Wind Power and Economic Development: Real Examples from the Pacific Northwest." Renewable Northwest Project (January 2007). http://www.rnp.org/Resources/.

August 9th, 2007

Vansycle Ridge Wind Farm

The Vansycle Ridge Wind Farm is Oregon's first commercial facility to generate electricity using wind. It is located near Pendleton and began operation in November 1998.



Project Location

Vansycle Ridge is a crest of land above Vansycle Canyon, which funnels wind from the Columbia River gorge up and over the Horse Heaven Hills in eastern Oregon. The average wind speed at Vansycle Ridge is 16–18 mph, which is considered excellent for wind farm development.

The area around the project's 38 wind turbines is used mostly for farming. This can continue beneath the completed wind farm, so land-use impacts are minimal; turbines and access roads occupy less than two percent of the area spanned by the project. The site is also close to preexisting transmission lines, which reduced the need to install new cables and minimizes the amount of power lost during transmission.

Project Description

The Vansycle Ridge Wind Farm uses 38 state-of-the-art Vestas wind turbines, which produce a maximum output of 24.9 megawatts (MW) of electricity. On average the project is expected to receive enough wind to deliver about 30 percent of its peak capacity year-round—enough power for more than 5,000 average Northwest homes.

Electronic control systems point each turbine into the wind and adjust the pitch of the blades to make the best use of wind at any speed. The turbines can generate power at wind speeds of 7–56 mph. At higher speeds the turbines automatically shut down—a feature which allows them to withstand hurricane-force winds.

The $35 million wind farm was built by FPL Energy, Inc., a subsidiary of the company that owns Florida Power & Light Co. It took eight months to build, and was completed two months ahead of schedule.

Environmental Effects

The Vansycle wind project was planned carefully and underwent extensive review to minimize its environmental impact. Early biological studies indicated that the site receives little use by birds or other vulnerable species, and the wind farm's operators continue to monitor the impact of the facility on avian and bat species. The project uses tubular towers and buried cables instead of lattice bases and pole-mounted cables, in order to avoid adding new perching places for birds. As a clean power source, the project also eliminates some of the need for fossil fuel electric plants in the region. If natural gas or coal were used to generate the same amount of power, they would emit 30,000–80,000 tons of carbon dioxide per year, as well as air pollutants and acid rain precursors. Wind power produces no air emissions.

Economic Profile

The Vansycle Ridge Wind Farm is owned by FPL Energy, Inc., a major developer of renewable energy sources in the U.S. Wind power typically costs slightly more than traditional coal and natural gas facilities, but the gap is narrowing every year. The wind farm is operated under a contract with Portland General Electric, which will buy 100 percent of the power for the first 30 years of the project's life. The power from the Vansycle project is currently integrated into PGE's general resource portfolio.

Like other renewable energy projects, the Vansycle wind farm benefits the local and national economy. It pays royalties to the farmers who own the underlying land, without disturbing their farming practices, and it pays taxes to local governments. It also increases local economic activity by hiring people to build, operate and maintain the wind farm and roads. The project's turbines were built by Vestas-American Wind Technology, a company based in North Palm Springs, California.

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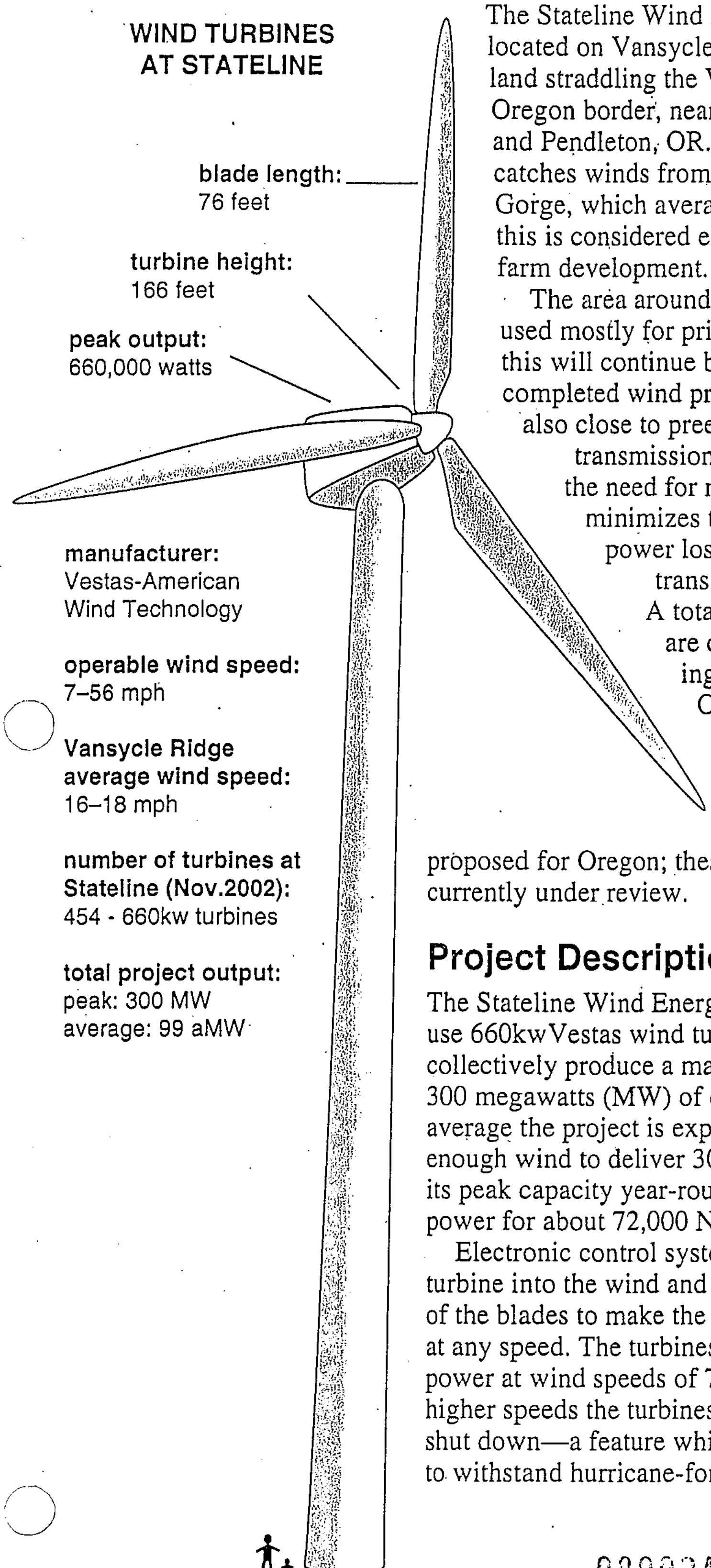
Stateline Wind Energy Center

The Stateline Wind Energy Center is the Northwest's largest commercial facility to generate electricity using wind. It is located near Touchet, WA and began operating in December of 2001.



manufacturer:
Vestas-American Wind Technology

operable wind speed:
7–56 mph

Vansycle Ridge average wind speed:
16–18 mph

number of turbines at Stateline (Nov.2002):
454 - 660kw turbines

total project output:
peak: 300 MW
average: 99 aMW

Project Location

The Stateline Wind Energy Center is located on Vansycle Ridge,a crest of land straddling the Washington/ Oregon border, near Touchet, WA and Pendleton, OR. The ridge catches winds from the Columbia Gorge, which average 16–18 mph; this is considered excellent for wind farm development.

The area around the project is used mostly for private farming,and this will continue beneath the completed wind project. The site is also close to preexisting transmission lines, reducing the need for new cables and minimizes the amount of power lost during transmission.

A total of 454 turbines are currently operating in both states. One expansion is proposed for the Washington side, and several are proposed for Oregon; these expansions are currently under review.

Project Description

The Stateline Wind Energy Center will use 660kwVestas wind turbines, and will collectively produce a maximum output of 300 megawatts (MW) of electricity. On average the project is expected to receive enough wind to deliver 30-35 percent of its peak capacity year-round—enough power for about 72,000 Northwest homes.

Electronic control systems point each turbine into the wind and adjust the pitch of the blades to make the best use of wind at any speed. The turbines can generate power at wind speeds of 7–56 mph. At higher speeds the turbines automatically shut down—a feature which allows them to withstand hurricane-force winds.

Environmental Effects

The Stateline wind project was planned carefully and underwent extensive review to minimize its environmental impact. Early biological studies indicated that the site receives little use by birds or other vulnerable species. The project uses tubular towers and buried cables in order to avoid adding new perching places for birds. Slower-moving blades and an upwind design futher minimize any potential for avian fataility. As a clean power source, the project also eliminates some of the need for fossil fuel electric plants in the region. If natural gas were used to generate the same amount of power, they would emit about 330,000 tons of carbon dioxide per year, as well as air pollutants and acid rain precursors. Wind power produces no air emissions.

Economic Profile

The $300 million wind farm is being built by FPL Energy, Inc., a subsidiary of Florida Power & Light Co. and a major developer of renewable energy sources in the U.S.. Wind power typically costs slightly more than traditional coal and natural gas facilities up front, but less in the long run. With today's volatile fossil fuel prices, wind can be cheaper than natural gas to bring on-line. The wind farm will be operated under a contract with Pacific Power Marketing.

Like other renewable energy projects, the Stateline wind project benefits the local and national economy. It will pay royalties to the farmers who own the underlying land, without disturbing their farming practices, and it will pay taxes to local governments. It will also increase local economic activity by hiring people to build, operate and maintain the wind farm and roads. Construction alone will infuse over $15 million into the local economy, and ongoing maintenance and operations will employ at least 15 permanent staff.. The project's turbines were built by Vestas-American Wind Technology, a company headquartered in Portland, Oregon.

<u>Section 2</u>

SCIENTIFIC REPORTS: Economic Impacts

<u>Document List</u>

- *Oregon Strategic Investment Program Agreement "Echo Windfarms Project."* December, 2008.
- *Oregon Strategic Investment Program Agreement "Combine Hills Turbine Ranch Phase II."* March, 2009.
- *Oregon Strategic Investment Program Agreement "Stateline 3 Wind Project."* April, 2009.
- *ENTRIX, Inc. Economic Impacts of Wind Energy Projects in Southeast Washington.* Prepared for Southeast Washington Economic Development Association. March, 2009

OREGON STRATEGIC INVESTMENT PROGRAM AGREEMENT
"ECHO WINDFARMS PROJECT"

MORROW COUNTY and **UMATILLA COUNTY**, both political subdivisions of the State of Oregon, (hereafter jointly called "Counties") and the following Oregon limited liability companies: Four Corners Windfarm, LLC; Four Mile Canyon Windfarm, LLC; Pacific Canyon Windfarm, LLC; Sand Ranch Windfarm, LLC; Ward Butte Windfarm, LLC; Oregon Trail Windfarm, LLC; Butter Creek Power, LLC; Big Top, LLC; and Wagon Trail, LLC, (individually a "Project Entity" and collectively the "Project Entities") hereby enter into this Strategic Investment Program ("SIP") Agreement (the "Agreement") as of December ~~X~~ 19th 2008 (the "Effective Date"), for a 64.55 megawatt project (the "Project").

WITNESSETH:

WHEREAS, the Oregon Legislature has established the Strategic Investment Program (hereafter "SIP") to promote industrial competitiveness and to improve employment in the area where projects are to be located by encouraging businesses engaged in projects to hire local employees. (See ORS 307.123 and ORS 285C.600 – 285C.620.); and

WHEREAS, SIP encourages local governments to enter into agreements with key industries to attract and retain long-term investment and employment; and

WHEREAS, the Project Entities propose to build and operate a commercial wind energy generation project that crosses over County lines and is situated in both Morrow and Umatilla Counties, with approximately 19 wind towers situated in Morrow County and approximately 18 wind towers situated in Umatilla County. The Project situated in both Counties will have a capital cost of at least $25 million and is expected to include wind turbine generators, machinery and equipment, substation(s), meteorological towers, and an operations and maintenance facility. The project is expected to create approximately four new, permanent full-time jobs; and

WHEREAS, two of the Project Entities are owned 100% by John Deere Renewables, LLC ("Deere"). The remaining seven Project Entities are "flip projects" in which Deere will own 99% of the financial rights and 49% of the voting rights until Deere recovers its investment and receives its required return (the "Flip Date"). After the Flip Date, Deere's financial and voting rights will decrease to 5%. The financial and voting rights for each of the Project Entities before and after the Flip Date are set forth in Exhibit 1; and

WHEREAS, Deere will provide financing, project management, turbine supply, construction management, and operations and maintenance management to each of the Project Entities pursuant to Equity Capital Contribution Agreements, Project Administration Agreements, Construction Management Agreements, and Operations and Maintenance Management Agreements with the Project Entities; and

WHEREAS, the Project Entities each own an undivided interest in certain roads, collection and transmission lines, a substation, interconnection facilities and other facilities and equipment related to wind energy generation and transmission pursuant to an Amended and Restated Shared Facilities Agreement; and

WHEREAS, the Project Entities and Counties have jointly negotiated this Oregon SIP Agreement (the "Agreement"), and the Project Entities have provided to Counties a

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copy of the Oregon Economic and Community Development Department ("OECDD") SIP application filed with the OECDD and will submit updates to the SIP application to the OECDD after the parties have fulfilled their requirements under State law. It is the intent of this SIP Agreement to provide the competitive tax structure in both Counties that is essential for the Project Entities to provide a source of renewable energy in Oregon and to contribute to the State of Oregon's quality of life; and

WHEREAS, each County and Project Entity have provided public information and an opportunity for public input regarding the Strategic Investment Program generally and the Project Entities SIP application specifically, including a formal public hearing on this Agreement held in Morrow County on December 19, 2008, and a formal public hearing on this Agreement held in Umatilla County on December 19, 2008 and;

WHEREAS, this Agreement provides the terms and conditions under which each County agrees to recommend to the State that the SIP application be approved and tax abatement be granted for the Project, as defined below, in exchange for performance by the Project Entities of the obligations herein;

NOW, THEREFORE, in consideration of the mutual covenants of the parties, each to the other giving, the parties do hereby agree as follows:

1. **Project Definition and Scope.** The "Project" shall consist of wind turbine generators which may be installed or placed in service in phases or stages in Morrow and Umatilla Counties during the term of this Agreement, as well as all associated property (the "Associated Property"), including without limitation, roads and civil construction work, underground electrical lines, meteorological monitoring towers, an operations and maintenance facility, grid interconnection facilities, one or more substations, land, and associated supporting infrastructure and facilities, as more fully described in Application for Oregon Strategic Investment Program submitted on behalf of the Project Entities and deemed to have been received by OECDD on June 13, 2008 (the "Application"). Overhead transmission lines are not included in this Agreement and will be taxed separately. Unless otherwise determined by the Project Entities as described below, the Project further includes repairs, replacements, modernization, renovations and remodeling of such property made during the term of this Agreement. For purposes of this Agreement, the Project shall first exist when the real market value of the foregoing property is at least $25 million. Notwithstanding the foregoing, the Project shall include only wind turbine generators and Associated Property that are installed or placed in service within Morrow and Umatilla Counties after receipt by OECDD of the Application on June 13, 2008, and that have, in the aggregate, a nameplate capacity of 64.55 MW or less. Subject to the preceding sentence and subject to Site Permits for the Project Entities and State and local land use laws, the Project Entities may add to or subtract from (but not below $25 million) the property that constitutes the Project in the Counties (including repairs, replacements, modernization, renovations or remodeling). For purposes of this Agreement, "property" has the meaning assigned to that term in ORS 308.505 through 308.665. In the event that it is desired to repower or expand the projects within the SIP period, the Counties shall have the right to re-open negotiation for a new "Per-Megawatt-Amount" as defined in section 4.2.3. Repowering or expansion shall not occur until satisfactory negotiation is concluded.

2. **SIP Exemption Period.** The "SIP Exemption Period" shall begin as defined in ORS 307.123 (1)(b), after the Project commences commercial operation and has a real market

value equal to, or in excess of, $25 million, and shall continue for 15 property tax years as provided by ORS 307.123(1)(b). As used in this Agreement, "commercial operation" shall mean that the Project first produces electrical energy and that electrical energy is transmitted into the regional transmission grid for delivery to a power purchaser, and "property tax year" means a period of 12 months beginning July 1.

3. **Conditions Precedent.** Except for the obligations set forth in Sections 5.1 and 6.1, the obligations set forth herein are conditioned upon a determination by the OECDD or its designee that the Project is eligible for the tax exemption provided in ORS 285C.606, ORS 307.123, and applicable administrative rules.

4. **Exemption, Project Entity Payments and Related Obligations.**

4.1 Each year on or before October 25, after coordination with each other, each County shall submit to Deere on behalf of the Project Entities a statement describing their calculations and an invoice for each County. Deere will separately itemize the amounts due from each of the Project Entities for the year in accordance with Sections 4.2.1, 4.2.2, and 4.2.3, as applicable. The invoiced amounts shall be paid by Deere, on behalf of the Project Entities, to the appropriate County no later than December 1 of each tax year.

4.2 In consideration of participating in the SIP with respect to the Project, each of the Project Entities agrees to pay the Counties such Project Entity's proportionate share (based on the aggregate number of megawatts of nameplate capacity of the wind turbine generators owned by such Project Entity) (the "Proportionate Share") the amounts as set forth below:

4.2.1 Ad Valorem Property Taxes. The first $25 million in real market value of the Project, subject to annual increases at the rate of three percent (3%), shall be taxable at its assessed value as provided by ORS 307.123 and 308.146 and shall be prorated between Morrow and Umatilla Counties based on the aggregate number of megawatts of nameplate capacity of the wind turbine generators owned by the Project Entities installed in each County. Property taxes on such value will be payable at each County's tax rate to each respective County in accordance with ORS 311.505. The remainder of the real market value of the Project shall be exempt from taxation as provided by ORS 307.123.

4.2.2 Community Service Fee ("CSF"). For each year of the SIP Exemption Period, Deere, on behalf of the Project Entities, shall pay a CSF, in an amount equal to twenty-five percent (25%) of the property taxes that would, but for the exemption, be due on the exempt property in each assessment year, but not exceeding an aggregate of $500,000 in any year. The CSF will be calculated pursuant to ORS 285C.609 (4) (b) (B) and shall be prorated between Morrow and Umatilla Counties based on the aggregate number of megawatts of nameplate capacity of the wind turbine generators owned by the Project Entities and installed in each County.

4.2.3 Additional Amount. If in any year of the SIP Exemption Period, the Statutory Amount is less than the Minimum Revenue Amount for the property tax year in either County, then Deere, on behalf of the Project Entities, shall pay to that County an amount equal to the difference between the Minimum Revenue Amount and the Statutory Amount (the "Additional Amount"). The Additional Amount shall be payable in addition to any property taxes and CSF for the year. For purposes of this Agreement, the following definitions apply:

"Statutory Amount" means the sum of (i) the ad valorem property taxes due for the property tax year pursuant to Section 4.2.1, and (ii) the aggregate CSF.

"Per-Megawatt Amount" means, for

Morrow County	$9,192.00
Umatilla County	$10,270.00

"Minimum Revenue Amount" means the sum of the product of (a) the nameplate capacity (in Megawatts) of the Project in each County as of January 1 of that year multiplied by (b) the Per-Megawatt Amount for the property tax year for that County.

4.2.4 Local Improvement Payments. In addition, Deere, on behalf of the Project Entities, agrees to make the following "Local Improvement Payments." These payments may be expended by the Counties on County priorities at the sole and unfettered discretion of the governing body of the County in which said Local Improvement Payments are received, provided, however, that the aggregate amounts payable to each County shall not be subject to change. These payments are further not intended to create any third party beneficiary rights for any entities designated in this agreement. The total Local Improvement Payments are as follows: Morrow County - $400,000 and Umatilla County - $400,000. A Local Improvement Payment shall be paid in five (5) equal annual installments without interest, with the first installment due on December 1 of the first tax year in which the exemption referred to in Sections 2 and 4.2 is effective and on the next four (4) December 1 dates.

4.2.5 County Cost of Preparation of SIP Agreement. In addition to the above, the Project Entities agree to reimburse the Counties for their reasonable costs incurred for SIP Agreement preparation, including staff, legal, administrative, and professional fees, provided however, in no event shall the aggregate of such fees payable to both Counties exceed Thirty Thousand dollars ($30,000). Payment of these costs shall be made within thirty (30) days after receipt of invoice.

4.3 SIP Application. The Project Entities shall file a SIP application with the State and pay all applicable fees as provided in ORS 285C.612 and applicable administrative rules.

4.4 First-Source Hiring Agreement. The Project Entities shall enter into first-source hiring agreements with appropriate third parties acceptable to the Counties in substantially the form required pursuant to OAR 123-070-1000-2400. Each County is to be designated a third-party beneficiary of the agreement for that County and is entitled to enforce its terms. The parties may designate a different provider for this service by letter agreement.

4.5 Property Tax Statements and Information. The Project Entities shall notify each County on an annual basis, at the time of the filing with the Oregon Department of

Revenue ("DOR") of the annual statement for property tax purposes covering the Project, of the nameplate capacity (in Megawatts) of the Project located in each County as of January 1 of that year.

5. **County Obligations.**

5.1 Within 15 days after the Effective Date, the Counties shall request that the Oregon Economic and Community Development Commission determine that the real and personal property constituting the Project situated in that County be granted exemption from ad valorem property taxation for the SIP Exemption Period.

5.2 The Counties shall establish separate tax accounts for each of the Project Entities in accordance with OAR 150-307.123(1).

5.3 The Counties are solely responsible for determining how to allocate the CSF and any Additional Amounts between them and for disposition of the CSF and the Additional Amounts, including paying any portions that are due or payable to any other jurisdictions. In no event shall any Project Entity have any liability in connection with any disagreement, error, or conflict between the Counties related to the division, allocation, or distribution of such amounts. In no event shall any Project Entity have any liability or obligation to any other person with respect to the respective CSFs or the Additional Amounts after such Project Entity has discharged its duty to pay as set forth in Section 4 above, and each County shall hold such Project Entity harmless with respect to any claims to the contrary to the extent allowed under the State Constitution.

6. **Joint Obligations.** In addition to the other obligations set forth in this Agreement, the parties shall:

6.1 Cooperate with the OECDD and the DOR to secure approval of the SIP and take such steps as may, from time to time, be reasonably necessary to maintain the tax exemption.

6.2 Provide such information and resources to each other as may be reasonably necessary to ensure proper calculation of the amounts due under this Agreement.

7. **Ad Valorem Property Taxes.** Nothing herein shall govern the assessment, payment, or collection of ad valorem property taxes on the portion of the Project that is taxable as described in Section 4.2.1 of this Agreement or on property outside the Project.

8. **Miscellaneous Provisions.**

8.1 The laws of the State of Oregon shall govern this Agreement. Venue is in the Circuit Court of the State of Oregon for the County of Morrow involving property in Morrow County and for the County of Umatilla involving property in Umatilla County. Venue for a dispute involving the interpretation or enforcement of this Agreement may be in either County. The parties agree that in case of any disputes that arise under this Agreement they shall first attempt to resolve such disputes through good-faith negotiations between authorized representatives for both parties for a period of thirty (30) days before filing any litigation.

8.2 Unless defined herein, the terms herein shall be given their normal and customary meaning, except that terms relating to the payment of property taxes and fees provided for in this Agreement shall be construed consistently with the tax laws and rules of the State of Oregon. No provision shall be construed against a party simply because that party drafted the provision.

8.3 Failure to make payment in full of the CSFs or the Additional Amounts by the due date shall result in interest being charged on the past due balance in the same amount as is provided by law for late payment of ad valorem property taxes.

8.4 Default by a Project Entity on part of this Agreement by failure to comply with requirements for one County can constitute default of the entire agreement as to that Project Entity for both Counties and the Counties may, jointly or severally, enforce the terms of this agreement at the sole discretion of the Counties. All amounts due by the Project Entities to the County under this SIP shall be considered as taxes due and unpaid and as such shall become a tax lien on the project property covered by the SIP in the event of default and subject to summary collections under ORS 311.405. Said tax lien shall not be voided or impaired. The County or both Counties shall have the right to enforce payment of any and all amounts due to them by a Project Entity and/or any permitted assignee (including interest, as provided in Section 8.3), through an appropriate action to collect such amounts. In case suit or action is instituted to enforce compliance with any of the terms, covenants or conditions of this Agreement, or to collect the CSF or the Additional Amount due hereunder or any portion thereof, a Project Entity found to be in default of this Agreement agrees to pay, in addition to the costs and disbursements provided by statute, such additional sums as the court may adjudge reasonable for attorneys' fees, the County's consulting fees, and other out-of-pocket County expenses to be allowed plaintiff in said suit or action, provided County(s) is the prevailing party. Each Project Entity also agrees to pay and discharge all reasonable costs and expenses actually incurred, including the County's reasonable attorneys' fees, reasonable consulting fees, and other reasonable out-of-pocket County expenses that shall arise from enforcing any provisions of this agreement in the event of any default by such Project Entity even though no suit or action is instituted. Nothing in this Section 8.4 is intended to limit any remedies otherwise available to the County to enforce any of the provisions of this Agreement, including payment of any and all amounts due to the County by the Project Entities and/or any permitted assignee.

8.4.1 The Counties and each Project Entity hereby agree to this Agreement in its entirety. The parties understand and agree that the Counties will only get the full benefit of their bargain if they receive all payments contemplated in this Agreement. The "Default Amount" for each Project Entity shall mean the amount equal to that Project Entity's Proportionate Share of the "Minimum Revenue Amount" for the property tax year in which the Default occurred, multiplied by the number of property tax years remaining in the SIP Exemption Period. "Default" shall mean the material breach of this Agreement by any Project Entity that fails to cure said default within thirty (30) days after that Entity receives notice from the County(s) in which the breach occurred.

8.4.2 In the event that a Project Entity fails to pay the amounts due pursuant to Sections 4.2.2 and 4.2.3 for two (2) consecutive tax years, then in addition to any other remedies allowed at law or in equity, the following shall apply:

8.4.2.1. This Agreement and the SIP exemption for that Project Entity may be terminated at the election of the Counties.

8.4.2.2. That Project Entity shall be obligated to pay to the Counties the Project Entity's Default Amount as "Liquidated Damages."

8.4.2.3 The County(s) in which the Default occurred shall submit to the breaching Project Entity an invoice for the amount of Liquidated Damages due, together with a statement setting forth its calculations.

8.4.2.4. The breaching Project Entity shall pay such invoiced amounts on or before sixty (60) days after its receipt of the invoice; provided, however, in the event the breaching Project Entity does not agree with the calculations, the breaching Project Entity and the County shall attempt to resolve such disputes through good faith negotiations between authorized representatives for both parties during such sixty (60) day period.

8.4.3 In accordance with Oregon law, in the event of an overpayment of the CSF or any Additional Amount, the Counties shall either issue an overpayment refund check or return the incorrect payment and request that the Project Entities reissue payment in the correct amount. In the event of return payment the applicable Assessor shall establish a reasonable schedule for payment.

8.4.4 If a Project Entity fails to pay its Proportionate Share of any CSF or Additional Amount by the end of the property tax year in which it is due, and such failure is not cured within 30 days after the Project Entity receives notice from the County(s) of such failure, the tax exemption for that portion of the Project owned by that Project Entity shall be revoked. The property of the defaulting Project Entity shall be fully taxable for the following year and for each subsequent property tax year for which the Default remains uncured. If an unpaid amounts are paid after the exemption is revoked, the property shall again be eligible for the exemption, beginning with the tax year after the payment is made. Reinstatement of the exemption shall not extend the 15-year exemption period.

8.5 For the convenience of the Counties and the Project Entities, each of the Project Entities hereby designates Deere as the SIP Agreement Administrator and as such, Deere is authorized to receive any and all tax notifications from the Counties. By this designation and appointment of Deere as SIP Agreement Adminsitrator, the Project Entities hereby agree that notice to Deere on their behalf shall constitute actual notice to the Project Entities individually. The SIP Agreement Administrator shall (i) serve as the Project's single point of contact for the Counties and (ii) coordinate the Project Entities' compliance with this Agreement.

8.6 All notices and other communications required or permitted under this Agreement shall be in writing and shall be either hand delivered in person, sent by facsimile, sent by certified or registered first-class mail, postage pre-paid, or sent by nationally recognized express courier service. Such notices and other communications shall be effective upon receipt if hand delivered or sent by facsimile, three days after mailing if sent by mail, and one day after dispatch if sent by express courier, to the following addresses, or such other addresses as any party may notify the other parties in accordance with this Section 8.6:

If to Morrow County, to:
Morrow County Court
PO Box 788
Heppner, OR 97836
Facsimile No.: 541 676 5621
Telephone No.: 541 676 5620
Attention: Morrow County Judge

If to Umatilla County, to:
Umatilla County Board of Commissioners
216 SE 4th Street
Pendleton, Oregon 97801
Facsimile No.: 541-278-5463
Telephone No.: 541-278-6204
Attention: Chair, Board of Commissioners

If to the Project Entities:

Four Corners Windfarm, LLC
Four Mile Canyon Windfarm, LLC
Pacific Canyon Windfarm, LLC
Sand Ranch Windfarm, LLC
Ward Butte Windfarm, LLC
Oregon Trail Windfarm, LLC
Butter Creek Power, LLC
Big Top, LLC
Wagon Trail, LLC
c/o John Deere Renewables, LLC
6400 NW 86th Street
Johnston, IA 50131
Facsimile No: 515-267-4235
Telephone No: 515-267-3871
Attention: Manager, Wind Administration

9. **Merger.** This contract constitutes the complete and exclusive agreement between the parties with respect to the Project, and supersedes all prior agreements and proposals, oral or written and any other communication between the parties on this matter. No waiver, modification, amendment or other change will be binding on either party, except as a written addendum, signed by authorized agents for both parties.

10. **Assignment.**

10.1 Project Entities may not assign this Agreement without the prior written notice to the Counties, provided the assignee satisfies all applicable requirements under ORS 285C.600 to 285C.626 and assumes the obligations, conditions, requirements and other terms of this Agreement provided, however, that no assignment or delegation shall be permitted unless all payments due the Counties under this Agreement as of the time of the assignment or delegation have been paid in full.

10.2 Notwithstanding the above limitations on assignment, the parties recognize that the Project is made up of nine (9) separate LLC's and that the financial and voting rights will change on the Flip Date as set forth in Exhibit A.

IN WITNESS WHEREOF, the parties hereto have executed this agreement in duplicate effective the 9th day of December, 2008.

MORROW COUNTY

County Judge

County Commissioner

ABSENT
County Commissioner

UMATILLA COUNTY

County Commissioner

County Commissioner

County Commissioner

FOUR CORNERS WINDFARM, LLC

By: ____________________
Terry L. Kramer, Manager

FOUR MILE CANYON WINDFARM, LLC

By: ____________________
Terry L. Kramer, Manager

PACIFIC CANYON WINDFARM, LLC

By: Oregon International Holdings, LLC, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ____________________
Terry L. Kramer, Assistant Secretary

SAND RANCH WINDFARM, LLC

By: Columbia Windfarm, LLC, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ____________________
Terry L. Kramer, Assistant Secretary

WARD BUTTE WINDFARM, LLC

By: Pacific Trail Windfarm, LLC, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ______________________
Terry L. Kramer, Assistant Secretary

OREGON TRAIL WINDFARM, LLC

By: Columbia Windfarm, LLC, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ______________________
Terry L. Kramer, Assistant Secretary

BUTTER CREEK POWER, LLC

By: Kent Madison, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ______________________
Terry L. Kramer, Assistant Secretary

BIG TOP, LCC

By: Frank Mader, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ______________________
Terry L. Kramer, Assistant Secretary

WAGON TRAIL, LLC

By: Shannon Rust, its Managing Member
By: John Deere Renewables, LLC, Attorney in Fact

By: ______________________
Terry L. Kramer, Assistant Secretary

Exhibit 1
Financial and Voting Rights in Project Entities

Pre-Flip Date Ownership Interests

Project Entity	Financial Interests	Voting Interests
Four Corners Windfarm, LLC	100% Deere	100% Deere
Four Mile Canyon Windfarm, LLC	100% Deere	100% Deere
Pacific Canyon Windfarm, LLC	99% Deere 1% Oregon International Holdings, LLC	49% Deere 51% Oregon International Holdings, LLC
Sand Ranch Windfarm, LLC	99% Deere 1% Columbia Windfarm, LLC	49% Deere 51% Columbia Windfarm, LLC
Ward Butte Windfarm, LLC	99% Deere 1% Pacific Trail Windfarm, LLC	49% Deere 51% Pacific Trail Windfarm, LLC
Oregon Trail Windfarm, LLC	99% Deere 1% Columbia Windfarm, LLC	49% Deere 51% Columbia Windfarm, LLC
Butter Creek Power, LLC	99% Deere 1% Kent & Shannon Madison	49% Deere 51% Kent & Shannon Madison
Big Top, LLC	99% Deere 1% Frank & LaVonne Mader	49% Deere 51% Frank & LaVonne Mader
Wagon Trail, LLC	99% Deere 1% Tim & Shannon Rust	49% Deere 51% Tim & Shannon Rust

Post-Flip Date Ownership Interests

Project Entity	Financial Interests	Voting Interests
Four Corners Windfarm, LLC	100% Deere	100% Deere
Four Mile Canyon Windfarm, LLC	100% Deere	100% Deere
Pacific Canyon Windfarm, LLC	5% Deere 95% Oregon International Holdings, LLC	5% Deere 95% Oregon International Holdings, LLC
Sand Ranch Windfarm, LLC	5% Deere 95% Columbia Windfarm LLC	5% Deere 95% Columbia Windfarm, LLC
Ward Butte Windfarm, LLC	5% Deere 95% Pacific Trail Windfarm, LLC	5% Deere 95% Pacific Trail Windfarm, LLC
Oregon Trail Windfarm, LLC	5% Deere 95% Columbia Windfarm, LLC	5% Deere 95% Columbia Windfarm, LLC
Butter Creek Power, LLC	5% Deere 95% Kent & Shannon Madison	5% Deere 95% Kent & Shannon Madison
Big Top, LLC	5% Deere 95% Frank & LaVonne Mader	5% Deere 95% Frank & LaVonne Mader
Wagon Trail, LLC	5% Deere 95% Tim & Shannon Rust	5% Deere 95% Tim & Shannon Rust

PROJECT ENTITY	MW	COUNTY
Four Corners Windfarm, LLC	10.00	Umatilla
Four Mile Canyon Windfarm, LLC	10.00	Morrow
Pacific Canyon Windfarm, LLC	8.25	Morrow
Sand Ranch Windfarm, LLC	9.90	Morrow
Ward Butte Windfarm, LLC	6.60	Umatilla
Oregon Trail Windfarm	9.90	Umatilla
Butter Creek Power, LLC	4.95	Umatilla
Big Top, LLC	1.65	Morrow
Wagon Trail, LLC	3.30	Morrow

OREGON STRATEGIC INVESTMENT PROGRAM AGREEMENT
"COMBINE HILLS TURBINE RANCH PHASE II"

UMATILLA COUNTY, a political subdivision of the State of Oregon (hereafter called "County") and Eurus Combine Hills II LLC, a Delaware limited liability company (the "Project Entity") hereby enter into this Strategic Investment Program Agreement (the "Agreement") as of March 4, 2009 (the "Effective Date"), for a 63 megawatt project (the "Project").

WITNESSETH:

WHEREAS, the Oregon Legislature has established the Strategic Investment Program (hereafter "SIP") to promote industrial competitiveness and to improve employment in the area where projects are to be located by encouraging businesses engaged in projects to hire local employees. (See ORS 307.123 and ORS 285C.600 – 285C.620.); and

WHEREAS, SIP encourages local governments to enter into agreements with key industries to attract and retain long-term investment and employment; and

WHEREAS, the Project Entity proposes to build and operate a commercial wind energy generation project in Umatilla County, with 63 wind towers. The Project will have a capital cost of at least $25 million and is expected to include wind turbine generators, machinery and equipment, substation(s), meteorological towers, and an operations and maintenance facility. The Project is expected to create approximately six to eight new, permanent full-time jobs; and

WHEREAS, the Project Entity owns an interest in certain roads, collection and transmission lines, a substation, interconnection facilities and other facilities and equipment related to wind energy generation and transmission pursuant to Wind Energy Lease and Easement Agreements; and

WHEREAS, the Project Entity and County have jointly negotiated this Agreement, and following the mutual execution of this Agreement, the Project Entity will submit its SIP application (the "Application") to the Oregon Economic and Community Development Department ("OECDD"). It is the intent of this Agreement to provide the competitive tax structure in the County that is essential for the Project Entity to provide a source of renewable energy in Oregon and to contribute to the State of Oregon's quality of life; and

WHEREAS, the County and the Project Entity have provided public information and an opportunity for public input regarding the SIP generally and the Project Entity's SIP application specifically, including a formal public hearing on this Agreement held in Umatilla County on February 23, 2009; and

WHEREAS, this Agreement provides the terms and conditions under which the County agrees to recommend to the State of Oregon that the SIP Application be approved and tax abatement be granted for the Project, as defined below, in exchange for performance by the Project Entity of the obligations herein;

NOW, THEREFORE, in consideration of the mutual covenants of the parties, each to the other giving, the parties do hereby agree as follows:

1. **Project Definition and Scope.** The "Project" shall consist of wind turbine generators which may be installed or placed in service in phases or stages in Umatilla County during the term of this Agreement, as well as all associated property (the "Associated Property"), including, without limitation, roads and civil construction work, underground electrical lines, meteorological monitoring towers, an operations and maintenance facility, grid interconnection facilities, one or more substations, land, and associated supporting infrastructure and facilities, to be used in connection with the 63 megawatt Combine Hills Turbine Ranch Phase II project. Overhead transmission lines are not included in this Agreement and will be taxed separately. Unless otherwise determined by the Project Entity as described below, the Project further includes repairs, replacements, modernization, renovations and remodeling of such property made during the term of this Agreement. For purposes of this Agreement, the Project shall first exist when the real market value of the foregoing property is at least $25 million. Notwithstanding the foregoing, the Project shall include only wind turbine generators and Associated Property that are installed or placed in service within Umatilla County after receipt by OECDD of the Application, and that have, in the aggregate, a nameplate capacity of 63 MW or less. Subject to the preceding sentence and subject to Site Permits for the Project and State and local land use laws, the Project Entity may add to or subtract from (but not below $25 million) the property that constitutes the Project (including repairs, replacements, modernization, renovations or remodeling). For purposes of this Agreement, "property" has the meaning assigned to that term in ORS 308.505 through 308.665. In the event that it is desired to repower or expand the Project within the SIP Exemption Period (as defined in Section 2 below), the County shall have the right to re-open negotiation for a new "Per-Megawatt-Amount" as defined in Section 4.2.3. Repowering or expansion shall not occur until satisfactory negotiation is concluded.

2. **SIP Exemption Period.** The "SIP Exemption Period" shall begin as defined in ORS 307.123 (1)(b), after the Project commences commercial operation and has a real market value equal to, or in excess of, $25 million, and shall continue for 15 property tax years as provided by ORS 307.123(1)(b). As used in this Agreement, "commercial operation" shall mean that the Project first produces electrical energy (excluding for testing purposes) and that electrical energy is transmitted into the regional transmission grid for delivery and sale to a power purchaser, and "property tax year" means a period of 12 months beginning July 1.

3. **Conditions Precedent.** Except for the obligations set forth in Sections 5.1 and 6.1, the obligations set forth herein are conditioned upon a determination by the OECDD or its designee that the Project is eligible for the tax exemption provided in ORS 285C.606, ORS 307.123, and applicable administrative rules.

4. **Exemption, Project Entity Payments and Related Obligations.**

4.1 Each year during the SIP Exemption Period on or before October 25, the County shall submit to the Project Entity a statement describing their calculations and an invoice for the County. The Project Entity will itemize the amounts due from the Project for the year in accordance with Sections 4.2.1 4.2.2 and 4.2.3, as applicable. The invoiced amounts shall be paid by the Project Entity to the County no later than December 1 of each tax year.

4.2 In consideration of participating in the SIP with respect to the Project, the Project Entity agrees to pay the County the amounts as set forth below:

4.2.1 Ad Valorem Property Taxes. The first $25 million in real market value of the Project, subject to annual increases at the rate of three percent (3%), shall be taxable at its assessed value as provided by ORS 307.123 and 308.146. Property taxes on such value will be payable at the County's tax rate in accordance with ORS 311.505. The remainder of the real market value of the Project shall be exempt from taxation as provided by ORS 307.123.

4.2.2 Community Service Fee ("CSF"). For each year of the SIP Exemption Period, the Project Entity shall pay a CSF, in an amount equal to twenty-five percent (25%) of the property taxes that would, but for the exemption, be due on the exempt property in each assessment year, but not exceeding an aggregate of $500,000 in any year. The CSF will be calculated pursuant to ORS 285C.609 (4) (b) (B).

4.2.3 Additional Amount. If in any year of the SIP Exemption Period, the Statutory Amount is less than the Minimum Revenue Amount for the property tax year, then the Project Entity shall pay to the County an amount equal to the difference between the Minimum Revenue Amount and the Statutory Amount (the "Additional Amount"). The Additional Amount shall be payable in addition to any property taxes and CSF for the year. For purposes of this Agreement, the following definitions apply:

"Statutory Amount" means the sum of (i) the ad valorem property taxes due for the property tax year pursuant to Section 4.2.1, and (ii) the aggregate CSF.

"Per-Megawatt Amount" means $7,048

"Minimum Revenue Amount" means the sum of the product of (a) the nameplate capacity (in Megawatts) of the Project in the County as of January 1 of that year multiplied by (b) the Per-Megawatt Amount for the property tax year for the County.

4.2.4 Local Improvement Payments. In addition the Project Entity agrees to make the following "Local Improvement Payments." These payments may be expended by the County on County priorities at the sole and unfettered discretion of the Governing Body of the County, provided, however, that the aggregate amounts payable to the County shall not be subject to change. These payments are not intended to create any third party beneficiary rights for any entities except as expressly designated in this Agreement. The total Local Improvement Payments for the County is $2,000,000. The Local Improvement Payment shall be paid over a twenty (20) year period, consisting of an annual installment payment of eighty thousand dollars ($80,000) for each of the first fifteen (15) property tax years following the commencement of the SIP Exemption Period, and an annual installment payment of one hundred sixty thousand dollars ($160,000) for each of the remaining five (5) property tax years (i.e., years sixteen through twenty) for the Project, without interest, with the first installment due on December 1 of the first property tax year in which the exemption referred to in Sections 2 and 4.2 is effective and on December 1 for each of the following nineteen (19) property tax years.

4.2.5 County Cost of Preparation of SIP Agreement. In addition to the above, the Project Entity agrees to reimburse the County for its reasonable costs incurred for the preparation of this Agreement, including staff, legal, administrative, and professional fees, provided however, in no event shall the aggregate of such fees payable to the County exceed Thirty Thousand dollars ($30,000). Payment of these costs shall be made within thirty (30) days after receipt of invoice.

4.3 SIP Application. The Project Entity shall file a SIP application with the State and pay all applicable fees as provided in ORS 285C.612 and applicable administrative rules.

4.4 First-Source Hiring Agreement. The Project Entity shall enter into a first-source hiring agreement with appropriate third parties acceptable to the County in substantially the form required pursuant to OAR 123-070-1000-2400. The County is to be designated a third-party beneficiary of the agreement and is entitled to enforce its terms. The parties may designate a different provider for this service by letter agreement.

4.5 Property Tax Statements and Information. The Project Entity shall notify the County on an annual basis, at the time of the filing with the Oregon Department of Revenue ("DOR") of the annual statement for property tax purposes covering the Project, of the nameplate capacity (in Megawatts) of the Project located in the County as of January 1 of that year.

5. **County Obligations.**

5.1 Within 15 days after the Effective Date, the County shall request that the Oregon Economic and Community Development Commission and the OECDD determine that the real and personal property constituting the Project situated in the County be granted exemption from ad valorem property taxation for the SIP Exemption Period.

5.2 The County shall establish separate tax account for the Project Entity in accordance with OAR 150-307.123(1).

5.3 The County is solely responsible for determining how to allocate the CSF and any Additional Amounts and for disposition of the CSF and the Additional Amounts, including paying any portions that are due or payable to any other jurisdictions. In no event shall the Project Entity have any liability in connection with any disagreement, error, or conflict related to the division, allocation, or distribution of such amounts by the County. In no event shall the Project Entity have any liability or obligation to any other person with respect to the respective CSFs or the Additional Amounts after the Project Entity has discharged its duty to pay as set forth in Section 4 above, and the County shall hold the Project Entity harmless with respect to any claims to the contrary to the extent allowed under the Constitution of the State of Oregon and Oregon law.

6. **Joint Obligations.** In addition to the other obligations set forth in this Agreement, the parties shall:

6.1 Cooperate with the OECDD and the DOR to secure approval of the SIP and take such steps as may, from time to time, be reasonably necessary to maintain the tax exemption.

6.2 Provide such information and resources to each other as may be reasonably necessary to ensure proper calculation of the amounts due under this Agreement.

7. **Ad Valorem Property Taxes.** Nothing herein shall govern the assessment, payment, or collection of ad valorem property taxes on the portion of the Project that is taxable as described in Section 4.2.1 of this Agreement or on property outside the Project.

8. **Miscellaneous Provisions.**

8.1 The laws of the State of Oregon shall govern this Agreement. Venue is in the Circuit Court of the State of Oregon for the County of Umatilla involving property in Umatilla County. The parties agree that in case of any disputes that arise under this Agreement they shall first attempt to resolve such disputes through good-faith negotiations between authorized representatives for both parties for a period of thirty (30) days before filing any litigation.

8.2 Unless defined herein, the terms herein shall be given their normal and customary meaning, except that terms relating to the payment of property taxes and fees provided for in this Agreement shall be construed consistently with the tax laws and rules of the State of Oregon. No provision shall be construed against a party simply because that party drafted the provision.

8.3 Failure to make payment in full of the CSFs or the Additional Amounts by the due date shall result in interest being charged on the past due balance in the same amount as is provided by law for late payment of ad valorem property taxes.

8.4 Default by the Project Entity by its failure to comply with any requirement of this Agreement can constitute default of the entire agreement and the County may enforce the terms of this Agreement at its sole discretion. All amounts due by the Project Entity to the County under this Agreement shall be considered as taxes due and unpaid and as such shall become a tax lien on the project property covered by the SIP in the event of default and subject to summary collections under ORS 311.405. Said tax lien shall not be voided or impaired. The County shall have the right to enforce payment of any and all amounts due to it by the Project Entity and/or any permitted assignee (including interest, as provided in Section 8.3), through an appropriate action to collect such amounts. In case suit or action is instituted to enforce compliance with any of the terms, covenants or conditions of this Agreement, or to collect the CSF or the Additional Amount due hereunder or any portion thereof, the party found to be in default of this Agreement agrees to pay, in addition to the costs and disbursements provided by statute, such additional sums as the court may adjudge reasonable for attorneys' fees, and provided the County is the prevailing party, the County's consulting fees, and other out-of-pocket County expenses to be allowed plaintiff in said suit or action. The Project Entity also agrees to pay and discharge all reasonable costs and expenses actually incurred, including the County's reasonable attorneys' fees, reasonable consulting fees, and other reasonable out-of-pocket County expenses that shall arise from enforcing any provisions of this Agreement in the event of any default by the Project Entity even though no suit or action is instituted. Nothing in this Section 8.4. is intended to limit any remedies otherwise available to the County to enforce any of the provisions of this Agreement, including payment of any and all amounts due to the County by the Project Entity and/or any permitted assignee.

8.4.1 The County and the Project Entity hereby agree to this Agreement in its entirety. The parties understand and agree that the County will only get the full benefit of the bargain if it receives all payments contemplated in this Agreement. The "Default Amount" for the Project Entity shall mean the amount equal to the Project's "Minimum Revenue Amount" for the property tax year in which the Default occurred, multiplied by the number of property tax years remaining in the SIP Exemption Period. "Default" shall mean the material breach of this Agreement by the Project Entity if it fails to cure said default within thirty (30) days after the Project Entity receives notice from the County that the breach has occurred.

8.4.2 In the event that the Project Entity fails to pay the amounts due pursuant to Sections 4.2.2 and 4.2.3 for two (2) consecutive property tax years, then in addition to any other remedies allowed at law or in equity, the following shall apply:

8.4.2.1. This Agreement and the SIP exemption for the Project may be terminated at the County's election.

8.4.2.2. The Project Entity shall be obligated to pay to the County the Project's Default Amount as "liquidated damages." The County shall submit to the Project Entity an invoice for the amount of liquidated damages due, together with a statement setting forth its calculations.

The Project Entity shall pay such invoiced amounts on or before sixty (60) days after its receipt of the invoice; provided, however, in the event the Project Entity does not agree with the calculations, the Project Entity and the County shall attempt to resolve such disputes through good faith negotiations between authorized representatives for both parties during such sixty (60) day period.

8.4.3 In accordance with Oregon law, in the event of an overpayment of the CSF or any Additional Amount, the County shall either issue an overpayment refund check or return the incorrect payment and request that the Project Entity reissue payment in the correct amount. In the event of return payment the County Assessor shall establish a reasonable schedule for payment.

8.4.4 If the Project Entity fails to pay the CSFs or any Additional Amount by the end of the property tax year in which it is due, and such failure is not cured within 30 days after the Project Entity receives notice from the County of such failure, the tax exemption for the Project shall be revoked. The property of the Project in Default shall be fully taxable for the following year and for each subsequent property tax year for which the Default remains uncured. If the unpaid amounts are paid after the exemption is revoked, the Project property shall again be eligible for the exemption, beginning with the tax year after the payment is made. Reinstatement of the exemption shall not extend the 15-year SIP exemption period.

8.5 All notices and other communications required or permitted under this Agreement shall be in writing and shall be either hand delivered in person, sent by facsimile, sent by certified or registered first-class mail, postage pre-paid, or sent by nationally recognized express courier service. Such notices and other communications shall be effective upon receipt if hand delivered or sent by facsimile, three days after mailing if sent by mail, and one business day after dispatch if sent by express courier, to the following addresses, or such other addresses as any party may notify the other parties in accordance with this Section 8.5:

If to Umatilla County, to:

Umatilla County Board of Commissioners
216 SE 4th Street, Pendleton Oregon, 97801
Facsimile No.: 541-278-5463
Telephone No.: 541-278-6204
Attention: Chair, Board of Commissioners

If to the Project Entity:

Eurus Combine Hills II LLC
c/o Eurus Energy America Corporation
4660 La Jolla Village Dr, Suite 400
San Diego, CA 92122
Facsimile No: 858-638-7125
Telephone No: 858-638-7115

9. **Merger.** This Agreement constitutes the complete and exclusive agreement between the parties with respect to the relationship of the SIP to the Project, and supersedes all prior agreements and proposals, oral or written and any other communication between the parties on this matter. For the avoidance of doubt, however, this Agreement in no way supersedes or replaces any obligations in respect of the Eurus community benefit and assistance program described in that certain Umatilla County Board of County Commissioners letter to Eurus Energy America Corp. dated November 1, 2004. No waiver, modification, amendment or other change will be binding on either party, except as a written addendum, signed by authorized agents for both parties.

10. **Assignment.**

10.1 The Project Entity may not assign this Agreement without the prior written notice to the County, and provided the assignee satisfies all applicable requirements under ORS 285C.600 to 285C.626 and assumes the obligations, conditions, requirements and other terms of this Agreement; and provided further, however, that no assignment or delegation shall be permitted unless all payments due the County under this Agreement as of the time of the assignment or delegation have been paid in full. The Project Entity, however, is permitted to assign this Agreement or any of its rights and obligations under this Agreement, without the

County's consent (provided, however, the Project Entity shall provide notice of such assignment to the County and any such assignee pursuant to clause (i) through clause (iv) below shall agree to be bound by the terms and conditions of this Agreement when it acquires title to the Project): (i) to one or more of its affiliates, subsidiaries, or its parent, (ii) to any person or entity succeeding to all or substantially all of the assets of the Project Entity, (iii) to a successor entity in a merger, consolidation or acquisition transaction with the Project Entity, or (iv) to one or more lenders or other third parties in connection with a financing of the Project.

IN WITNESS WHEREOF, the parties hereto have executed this agreement in duplicate effective the 4 day of March, 2009.

UMATILLA COUNTY

W. Lawrence Givens
County Commissioner

Dennis D. Doherty
County Commissioner

William S. Hansell
County Commissioner

BOARD OF COMMISSIONERS UMATILLA COUNTY STATE OF OREGON

EURUS COMBINE HILLS II LLC

By: [signature]
Name: Takashi Shirato
Title: Senior Vice President

OREGON STRATEGIC INVESTMENT PROGRAM AGREEMENT
"STATELINE 3 WIND PROJECT"

UMATILLA COUNTY, a political subdivision of the State of Oregon, ("County") and NEXTERA ENERGY RESOURCES, LLC ("NextEra"), a Delaware corporation authorized to do business in the State of Oregon, hereby enter into this Strategic Investment Program ("SIP") Agreement ("Agreement") as of April 21, 2009 ("Effective Date"), for a wind energy resource with installed capacity up to 100.5 MW to be located in the County. The County and NextEra are sometimes referenced in this Agreement individually as "Party" and collectively as "Parties."

WITNESSETH:

WHEREAS, the Oregon Legislature has established the SIP to promote industrial competitiveness and to improve employment in the area where projects are to be located by encouraging businesses engaged in projects to hire local employees (See ORS 307.123 and ORS 285C.600 – 285C.620.); and

WHEREAS, the SIP encourages local governments to enter into agreements with key industries to attract and retain long-term investment and employment; and

WHEREAS, NextEra proposes to build and operate in the County a commercial wind energy generation project, known as "Stateline 3," pursuant to a certificate issued by the Oregon Energy Facility Siting Council ("EFSC"), as that certificate may be amended from time to time ("Site Certificate"), which project is expected to create 100 – 150 construction jobs and 3 – 6 new, permanent full-time jobs in the County; and

WHEREAS, NextEra and the County have negotiated this Agreement, and NextEra has provided the County with a copy of the SIP application it has filed with Oregon Economic and Community Development Department ("OECDD"), which application is to be updated by NextEra as part of its fulfillment of applicable requirements under State law; and

WHEREAS, it is the intent of this SIP Agreement to provide the competitive tax structure in the County that is essential for NextEra to provide a source of renewable energy in Oregon and to contribute to the State of Oregon's quality of life; and

WHEREAS, the Parties have provided public information and an opportunity for public input regarding SIP generally and the NextEra SIP application specifically, including a formal public hearing on this Agreement held in Umatilla County on April 21, 2009, and;

WHEREAS, this Agreement provides the terms and conditions under which the County agrees to recommend to the State that NextEra's SIP application be approved and tax abatement be granted for the Project, as defined below, in exchange for performance by NextEra of its obligations as specified herein;

NOW, THEREFORE, in consideration of the mutual covenants of the Parties, each to the other giving, the Parties do hereby agree as follows:

1. **Project Definition and Scope.** The "Project" means all tangible and intangible Property (whether held in fee, leasehold or by contract) having the County as its tax situs, consisting of the Stateline 3 wind turbine generators which may be installed or placed in service in phases or stages in the County during the term of this Agreement, as well as all associated property (the "Associated Property"), including without limitation roads and civil construction work, meteorological monitoring towers, operations and maintenance facilities, grid interconnection facilities, electrical towers and poles, underground and overhead electrical conductors, one or more substations, land, and associated supporting infrastructure and facilities, as more fully described in Application for Oregon Strategic Investment Program submitted by NextEra and deemed to have been received by OECDD on January 9, 2009 (the "Application"). Unless otherwise determined by NextEra as described below, the Project further includes repairs, replacements, modernization, renovations and remodeling of such Property made during the term of this Agreement. For purposes of this Agreement, the Project shall first exist when the real market value of the foregoing Property is at least $25 million. The Project's overhead, 230-kV transmission line is not included under this Agreement and that portion of the line located in Oregon will be taxed separately. Subject to the Site Certificate and State and local land use laws, NextEra may add to (up to a maximum nameplate capacity of 100.5 MW) or subtract from (but not below $25 million) the Property that constitutes the Project (including repairs, replacements, modernization, renovations or remodeling). For purposes of this Agreement, "Property" has the meaning assigned to that term in ORS 308.505 through 308.665. In the event NextEra desires to repower or expand Stateline 3 within the SIP Exemption Period, the County shall have the right to re-open negotiation of a new "Per-Megawatt Amount, as defined in Section 4.2.3, regarding the amount of any increase in Project installed electrical capacity and repowering or expansion shall not occur until such renegotiation is concluded, or the parties agree to waive this provision, to the satisfaction of each Party.

2. **SIP Exemption Period.** The "SIP Exemption Period" shall begin, as defined in ORS 307.123 (1)(b), in and for the Property Tax Year during which the Project commences Commercial Operation and has a real market value equal to, or in excess of, $25 million, and shall continue thereafter for 15 Property Tax Years as provided by ORS 307.123(1)(b). As used in this Agreement, "Commercial Operation" shall mean that the Project first produces electrical energy and that electrical energy is transmitted into the regional transmission grid for delivery to a power purchaser, and "Property Tax Year" means each period of 12 months beginning July 1.

3. **Condition Precedent.** Except for the obligations set forth in Sections 5.1 and 6.1., the obligations set forth herein are conditioned upon a determination by the OECDD, or its designee, that the Project is eligible for the tax exemption provided in ORS 285C.606, ORS 307.123, and applicable administrative rules.

4. **Exemption, Payments and Related Obligations.**

4.1 Each Property Tax Year during the SIP Exemption Period, on or before October 25, the County shall submit to NextEra a statement describing its calculations and an invoice for amounts due under this Agreement. The invoiced amounts shall be paid by NextEra no later than the following December 1.

4.2 In consideration for participating in the SIP with respect to the Project, NextEra agrees to pay the amounts as set forth below:

4.2.1 Ad Valorem Property Taxes On Non-Exempt Amounts. The first $25 million in real market value of the Project, subject to annual increase at the rate of three percent (3%), shall be taxable at its assessed value as provided by ORS 307.123 and 308.146. Property taxes on such value will be payable in accordance with ORS 311.505. The remainder of the real market value of the Project shall be exempt from taxation as provided by ORS 307.123.

4.2.2 Community Service Fee ("CSF"). For each year of the SIP Exemption Period, NextEra shall pay to the County a CSF, in an amount equal to twenty-five percent (25%) of the taxes that would, but for the exemption, be due on the exempt Property in each assessment year, but not exceeding $500,000 in any Property Tax Year. The CSF will be calculated pursuant to ORS 285C.609 (4) (b) (B).

4.2.3 Additional Amount. If for any Property Tax Year of the SIP Exemption Period, the Statutory Amount is less than the Minimum Revenue amount for the property tax year in either County, then NextEra shall pay to that County an amount equal to the difference between the Minimum Revenue Amount and the Statutory Amount (the "Additional Amount"). The Additional Amount shall be payable in addition to any property taxes and CSF for the year. For purposes of this Agreement, the following definitions apply:

"Statutory Amount" means the sum of (i) the ad valorem property taxes due for the property tax year pursuant to Section 4.2.1, and (ii) the aggregate CSF.

"Per-Megawatt Amount" means $7,048.00.

"Minimum Revenue Amount" means the sum of the product of (a) the connected nameplate capacity (in Megawatts) of the Project as of January 1 of that year multiplied by (b) the Per-Megawatt Amount for the Property Tax Year.

4.2.4 Local Improvement Payments. In addition to the amounts specified elsewhere in this Agreement, NextEra agrees to make a "Local Improvement Payment" of exactly $2,000,000, payable in the annual installments set forth in Exhibit A to this Agreement, without accrual of interest on unpaid installments, with the first installment due on December 1 of the first Property Tax Year in which the exemption referred to in Sections 2 is effective and on the next nineteen (19) December 1 dates. Exactly $1,000,000 of the Local Improvement Payment specified in this Section 4.2.4 represent full payment and satisfaction of all obligations undertaken by FPL Energy regarding the "Blue Mountain Project" in Schedule A to that certain agreement of August 2001 between the County and FPL Energy. Local Improvement Payments may be expended by the County on County priorities at the sole and unfettered discretion of the governing body of the County. This Agreement shall not be construed to create any third party beneficiary rights for any entities that may be designated by the County for receipt of any portion of Local Improvement Payments.

4.2.5 County Cost of Preparation of SIP Agreement. In addition to the above, NextEra agrees to reimburse the County for the reasonable costs incurred for SIP

Agreement preparation, including staff, legal, administrative, and professional fees, provided however, in no event shall the aggregate of such fees payable to the County exceed Ten Thousand dollars ($10,000). Payment of these costs shall be made within thirty (30) days after receipt of an invoice from the County.

4.3 SIP Application. NextEra shall file a SIP application with the State and pay all applicable fees as provided in ORS 285C.612 and applicable administrative rules.

4.4 First-Source Hiring Agreement. NextEra shall enter into first-source hiring agreements with an appropriate third party acceptable to the County in substantially the form required pursuant to OAR 123-070-1000-2400. The County is to be designated a third-party beneficiary of the agreement and is entitled to enforce its terms. If the third-party provider is unable to perform the first-source hiring agreement to the satisfaction of NextEra or the County, then the Parties shall cooperate in procuring the services of a substitute provider.

4.5 Property Tax Statements and Information. NextEra shall notify the County on an annual basis, at the time of the filing with the Oregon Department of Revenue ("DOR") of the annual statement for property tax purposes covering the Project, of the connected nameplate capacity (in Megawatts) of the Project as of January 1 of that year.

5. **County Obligations.**

5.1 Within 15 days after the Effective Date, the County shall request that the OECDD determine that the Property constituting the Project be granted exemption from ad valorem Property taxation for each Property Tax Year of the SIP Exemption Period.

5.2 The County shall be solely responsible for determining how to dispose of the CSF and the Additional Amount, including paying any portions that are due or payable to any other jurisdictions. In no event shall NextEra have any liability in connection with any disagreement, error, or conflict between the County and any other jurisdiction related to the division, allocation, or distribution of such amounts. In no event shall NextEra have any liability or obligation to any other person with respect to the CSF or the Additional Amount after it has discharged its duty to pay as set forth in Section 4 above, and the County shall hold NextEra harmless with respect to any claims to the contrary, to the extent allowed and permitted by the Oregon Constitution and other Oregon law.

6. **Joint Obligations.** In addition to the other obligations set forth in this Agreement, the Parties shall:

6.1 Cooperate with the OECDD and the DOR to secure approval of the SIP and take such steps as may, from time to time, be reasonably necessary to maintain the Project's tax exemption.

6.2 Provide such information and resources to each other as may be reasonably necessary to ensure proper calculation of the amounts due under this Agreement.

7. **Ad Valorem Property Taxes.** Nothing herein shall govern the assessment, payment, or collection of ad valorem property taxes on the portion of the Project that is taxable as described in Section 4.2.1 of this Agreement or on Property unrelated to the Project.

8. **Miscellaneous Provisions.**

8.1 The laws of the State of Oregon shall govern this Agreement. Venue is in the Circuit Court of the State of Oregon for the County of Umatilla. The Parties agree that in case of any disputes that arise under this Agreement they shall first attempt to resolve such disputes through good-faith negotiations between authorized representatives for both Parties for a period of thirty (30) days before filing any litigation.

8.2 Unless defined herein, the terms herein shall be given their normal and customary meaning, except that terms relating to the payment of Property taxes and fees included in this SIP agreement shall be construed consistently with the tax laws and rules of the State of Oregon. No provision shall be construed against a Party simply because that Party drafted the provision.

8.3 Failure to make payment in full of the CSFs or the Additional Amounts by the due date shall result in interest being charged on the past due balance in the same amount as is provided by law for late payment of ad valorem property taxes.

8.4 All amounts due from NextEra to the County under this Agreement shall be considered as taxes due and any unpaid amounts shall become the basis for a tax lien on the Project Property covered by the SIP in the event of default and subject to summary collections under ORS 311.405. Said tax lien shall not be voided or impaired. The County shall have the right to enforce payment of any and all amounts due from NextEra and/or any permitted assignee (including interest, as provided in Section 8.3), through an appropriate action to collect such amounts. In case suit or action is instituted to enforce compliance with any of the terms, covenants or conditions of this Agreement, or to collect the CSF or the Additional Amount due hereunder or any portion thereof, if NextEra is found to be in default of this Agreement, it agrees to pay, in addition to the costs and disbursements provided by statute, such additional sums as the court may adjudge reasonable for attorneys' fees, the County's consulting fees, and other out-of-pocket County expenses to be allowed plaintiff in said suit or action, provided County is the prevailing party. NextEra also agrees to pay and discharge all reasonable costs and expenses actually incurred, including the County's reasonable attorneys' fees, reasonable consulting fees, and other reasonable out-of-pocket County expenses that shall arise from enforcing any provisions of this agreement in the event of any default by NextEra, if resulting from a valid court order, even though no suit or action is instituted. Nothing in this Section 84 is intended to limit any remedies otherwise available to the County to enforce any of the provisions of this Agreement, including payment of any and all amounts due to the County by NextEra and/or any permitted assignee.

8.4.1 The County and NextEra hereby agree to this Agreement in its entirety. The Parties understand and agree that the County will only get the full benefit of its bargain if it receives all payments covered by this Agreement. The "Default Amount" shall mean the amount equal to Minimum Revenue Amount for the Property Tax Year in which the

Default occurred, multiplied by the number of Property Tax Years remaining in the SIP Exemption Period. "Default" shall mean the material breach of this Agreement by NextEra that is not cured default within thirty (30) days after NextEra receives notice thereof from the County.

8.4.2 In the event that NextEra fails to pay the amounts due pursuant to Sections 4.2.2 and 4.2.3 for two (2) consecutive Property Tax Years, then in addition to any other remedies allowed at law or in equity, the following shall apply:

8.4.2.1. This Agreement and the SIP exemption may thereupon be terminated at the County's election after thirty (30) days written notice to NextEra.

8.4.2.2. NextEra shall thereupon be obligated to pay to the County the Default Amount, which shall represent the County's liquidated damages. The County shall submit to NextEra an invoice for the amount of liquidated damages due, together with a statement setting forth its calculations. If NextEra becomes liable for liquidated damages under this provision, it shall pay such invoiced amounts on or before sixty (60) days after its receipt of the County's invoice; provided, however, in the event NextEra does not agree with the County's calculations, NextEra and the County shall attempt to resolve such disputes through good faith negotiations between authorized representatives of each Party to occur during such sixty (60) day period.

8.4.3 In accordance with Oregon law, in the event of an overpayment of the CSF or any Additional Amount, the County shall either issue an overpayment refund check or return the incorrect payment and request that NextEra reissue payment in the correct amount. In the event of a return of overpayment, the County assessor shall establish a reasonable schedule for payment of the amount actually due under this Agreement.

8.4.4 If NextEra fails to pay the CSF or any Additional Amount by the end of the Property Tax Year in which it is due, and no cure is made within thirty (30) days after NextEra receives written notice from the County of such failure, the tax exemption for the Project shall thereupon be suspended. The Property shall thereupon be fully taxable for the following Property Tax Year and for each subsequent Property Tax Year for which the amounts due under this Agreement remain unpaid. If the unpaid amounts are paid after the exemption is suspended, the Property shall again be eligible for the exemption, beginning with the Property Tax Year after the payment is made. Reinstatement of the exemption shall not extend the 15-year exemption period.

8.5 All notices and other communications required or permitted under this Agreement shall be in writing and shall be either hand delivered in person, sent by facsimile, sent by certified or registered first-class mail, postage pre-paid, or sent by nationally recognized express courier service. Such notices and other communications shall be effective upon receipt if hand delivered or sent by facsimile, three days after mailing if sent by mail, and one day after dispatch if sent by express courier, to the following addresses, or such other addresses as either Party may notify the other Party in accordance with this Section 8.5.

<u>If to NextEra, to:</u>	<u>If to Umatilla County, to:</u>
NextEra Energy Resources, LLC.	Umatilla County Board of Commissioners

700 Universe Blvd Juno Beach, FL 33408 Facsimile No.: (561) 691-7307 Telephone No.: (561) 329-4550 Attention: Business Manager	216 SE 4th Street Pendleton, Oregon 97801 Facsimile No.: 541-278-5463 Telephone No.: 541-278-6204 Attention: Chair, Board of Commissioners

9. **Merger.** This Agreement constitutes the complete and exclusive agreement between the Parties with respect to the SIP, and supersedes all prior agreements and proposals, oral or written and any other communication between the Parties on this matter. No waiver, modification, amendment or other change will be binding on either Party, except as a written addendum, signed by authorized agents for both Parties.

10. **Assignment.** Upon prior written notice to the County, but without prior approval by the County, NextEra may assign its rights and release its obligations under this Agreement to any assignee of its choosing; provided, however, that the assignee must satisfy all applicable requirements under ORS 285C.600 to 285C.626 and must agree to assume the obligations, conditions, requirements and other terms of this Agreement and, further provided, that no assignment shall be permitted unless all payments due the County under this Agreement, as of the date of the assignment, have been paid in full.

11. **Term.** The term of this Agreement shall extend from the effective date, specified below, until the date on which NextEra shall have made the last installment payment it is obligated to make to the County pursuant to Section 4.2.3, provided NextEra is not in default under the terms of this Agreement.

IN WITNESS WHEREOF, the Parties have executed this Agreement in duplicate effective the 21st day of April, 2009.

UMATILLA COUNTY	NEXTERA ENERGY RESOURCES, LLC
County Commissioner	By:
County Commissioner	Name: Dean R. Gosselin
ABSENT	Title: Vice President
County Commissioner	

Exhibit A to the
Strategic Investment Program ("SIP") Agreement
Between Umatilla County and
NextEra Energy Resources, LLC,
Concerning the Stateline 3 Wind Energy Resource

(Annual Installments of the Local Improvement Payment)

Col. 1	Col. 2	Col. 3
Year of SIP Exemption Period	**Local Improvement Payment**	**Portion of Amount Shown in Col. 2 Relating to 2001 Agreement**
1	$58,333	$25,000
2	$58,333	$25,000
3	$58,333	$25,000
4	$58,333	$25,000
5	$58,333	$25,000
6	$133,333	$25,000
7	$133,333	$25,000
8	$133,333	$25,000
9	$133,333	$25,000
10	$133,333	$25,000
11	$133,333	$75,000
12	$133,333	$75,000
13	$133,333	$75,000
14	$133,333	$75,000
15	$133,333	$75,000
16 *	$75,000	$75,000
17 *	$75,000	$75,000
18*	$75,000	$75,000
19*	$75,000	$75,000
20*	$75,000	$75,000
Grand Totals:	$2,000,000	$$375,000.00

*/ Years 16-17 occur after the end of the SIP Exemption Period. They are included in this Exhibit to show Local Improvement Payments for each of those years that relate to the 2001 agreement between the County and FPL Energy concerning the "Blue Mountain" Project.

Economic Impacts of Wind Energy Projects in Southeast Washington

Economic Impacts of Wind Energy Projects in Southeast Washington

Prepared for

Southeast Washington Economic Development Association

By

ENTRIX, Inc.
12009 N.E. 99th Street, Suite 1410
Vancouver, WA 98682-2497

March 6, 2009

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List of Tables and Figures

Executive Summary

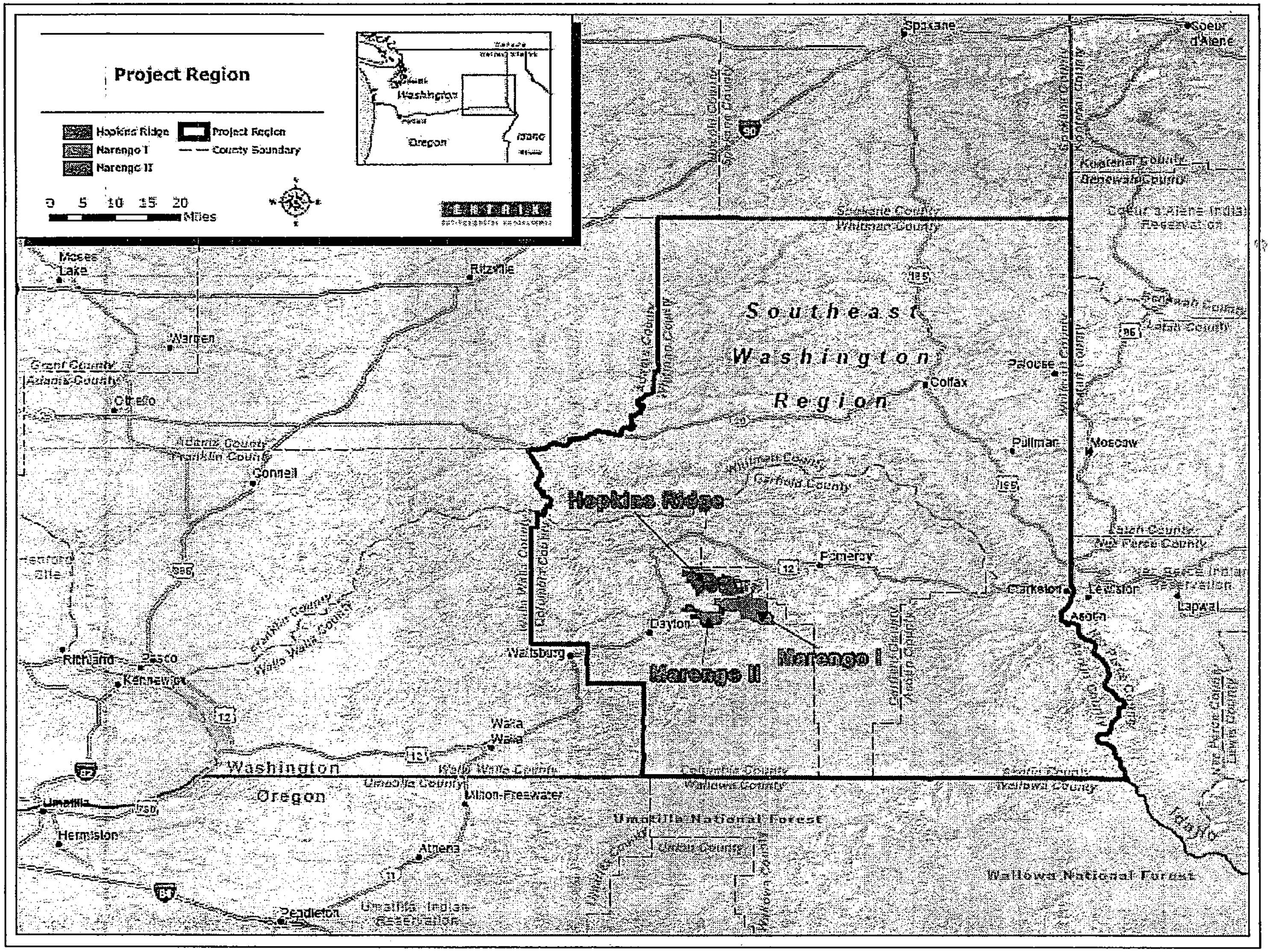
The southeast Washington region consisting of the four Counties of Columbia, Garfield, Asotin, and Whitman (the Region) has long been known for its fertile farmland and its wheat fields. Recently, the Region has also become known for its strong, reliable winds that are suitable for wind energy project development. Three wind energy projects have already been built and are operating near the town of Dayton in Columbia County. Additional projects are being considered elsewhere in the Region.

The three existing wind energy projects, Hopkins Ridge, Marengo I, and Marengo II (Projects), include 204 wind turbines. Hopkins Ridge, the first project constructed, has a capacity of 156.6 MW and became operational in November of 2005. It has 87 1.8 MW wind turbines, with a footprint of approximately 100 acres. It is owned by Puget Sound Energy (PSE), while the other two projects are owned by PacifiCorp. Marengo has a capacity of 140.4 MW and is comprised of 78 1.8 MW wind turbines. It became operational in September 2007. The Marengo II Project, which was completed in late 2008, is located directly southwest of the Marengo Project and generates 70.2 MW. Combined, the three projects have a capacity of 367 MW.

Table ES-1
Summary of Projects

Project Characteristic	Hopkins Ridge	Marengo I	Marengo II
MW Capacity	156.6	140.4	70.2
Number of Turbines	87	78	39
Developer	RES Americas	RES Americas	RES Americas
Utility Owner	Puget Sound Energy	PacifiCorp	PacifiCorp
Year Operational	2005	2007	2008

Figure ES-1
Southeastern Washington Region



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Wind power development in rural areas such as Southeast Washington brings economic development potential in terms of increased employment opportunities, wages, land leases, and business profits. Wind power development also increases local tax revenue, in particular property tax revenues. However, questions are often raised regarding socioeconomic impacts on property values, recreation and tourism, and demand for public services. To gain a greater understanding of the economic impacts of wind energy projects in the Region, the Southeast Washington Economic Development Association (SEWEDA) commissioned ENTRIX to complete a study of the economic and social impacts of the Columbia County wind energy projects and the implications for additional wind energy projects in the Region.

This report analyzes the economic, fiscal, and social effects of the three existing wind energy projects (Projects) near Dayton in Columbia County, Washington. Construction effects are analyzed for the three primary years of construction, 2005 through 2007, while operation effects are estimated for 25 years of operation (2008-2033). The analysis assumes 25 years of project operation as this is the guaranteed life span of the wind turbines; however, the utilities operating the projects expect that the Projects will be operating longer. Based on the analysis of these three wind facilities and a comparison of the economic characteristics of each of the other Southeast Washington counties to Columbia County, the report also provides a brief examination of the potential relative impacts which may result from future wind energy development in Asotin, Garfield, and Whitman Counties.

Economic Effects

Positive economic effects addressed in the analysis include the direct generation of jobs and income by the Projects during both construction and operations phases, as well as the "ripple" effects of project-related spending (known as indirect and induced impacts) on other economic sectors. A potential reduction in agricultural production on the lands used for the Projects was also calculated to account for this "opportunity cost" of the land use.

Study results indicate that the Projects resulted in the net annual employment in Columbia County rising by 189 jobs during construction (of which approximately 20 jobs were to local workers), and by 53 jobs during operations. Net annual income in Columbia County is estimated to have risen by $2.3 million during construction (including only income to local workers), and by $3.5 million during operations. To calculate the total value over time of the Projects, the future annual impacts are summed over the 25-year life of the project after discounting. Discounting takes into account the greater value of money received in the near future compared to money that will be received farther into the future. To do this, a discount rate of three percent is used; so for every year that passes before money is received the value is reduced by three percent. For example, using a three percent discount rate $100 dollars received next year is equivalent to $97 received this year. The discount rate was only applied to discount future income, but was not applied as an interest rate to past income.

Based on this process, in present value terms, the total net income generated by the Projects during construction and over their 25-year operation life is estimated to be $67.2 million.[1] The projects are assumed to have a 25-year project life as this is the period that the manufacturer guarantees the turbine can operate. As the Projects are expected to operate beyond the assumed 25-year life, it is anticipated that the present value of income effects from the Projects may be even greater.

Jobs and income are generated directly by the Projects, as well as in other sectors of the Columbia County economy supplying goods and services to the Projects and to employees of the Projects. Industries providing services to the Projects and its workers include, but are not limited to, lodging, restaurants, grocery stores, gas stations, construction companies, and hardware stores. Table ES-2 summarizes annual and net present value economic benefits of the Projects to Columbia County. Over the development, construction, and assumed 25-year operation phase of the Projects, it is estimated that total income generated will be $67.2 million in present value terms. Approximately 189 jobs were generated annually in the construction and development phase, and approximately 53 jobs are anticipated to be generated annually each year of the 25-year operations phase.

1 Present value represents the current value of the future stream of output and income benefits. In economics (and in finance) the present value of a stream of future revenues or costs is the sum of all future dollars in terms of present year dollars. This is done by discounting future monetary values because society values money in the present more than the same amount of money at a future date. For this project a discount rate of 3 percent was used in the present value calculation.

Table ES-2
Summary of Estimated Net Economic Benefits of Columbia County Projects

Economic Impact	Development and Construction (Annually, 2005 - 2008)	Operations (Annually, 2008 - 2033)	Present Value (Total 2005 – 2033)
Labor Income (Columbia County Residents)			
Direct Effects	$1,771,000	$3,081,000	$58,963,000
Indirect Effects	$100,000	$76,000	$1,623,000
Induced Effects	$411,000	$308,000	$6,596,000
Total Income Effects	**$2,282,000**	**$3,465,000**	**$67,183,000**
Employment (Jobs – All Employees)			
Direct Effects	170	39	N/A
Indirect Effects	6	2	N/A
Induced Effects	12	12	N/A
Total Employment Effects	**189**	**53**	**N/A**

Note: May not add due to rounding

Fiscal Effects

In addition to creating jobs and income in the local community, the Projects have a fiscal effect on local government. Fiscal effects are assessed by examining tax revenues generated by the Projects, as well as potential increased local government expenditures if the Projects cause increased demand for local public services. Little to no demand for public services is anticipated to result from the Projects, so there are no estimated additional fiscal costs of the project.

The Projects increase the property tax base in Columbia County. The Hopkins Ridge Project paid $807,000 in property taxes to the County in 2007, and $907,000 in property taxes in 2008 (see Table ES-3). As the first Project constructed, Hopkins Ridge is the only Project currently paying property taxes, but Marengo I will begin paying taxes in 2009 and Marengo II will begin paying in 2010. Once all three projects are operational and paying property tax in 2010, annual property tax payments from the Projects may total approximately $2.2

million if payments per wind turbine are similar and if property tax rates remain similar.[2] In reality, the average taxable value per wind turbine will likely differ by project, but this approach provides an approximate estimate of the property taxes that may be paid from all three Projects in 2010.

Columbia County receives 82 percent of property tax receipts, with the remainder going to the State of Washington. Property tax revenue from the Projects represents additional revenue to the county, unless tax rates are reduced. A reduction in property tax rates throughout the county would benefit all property owners, but would reduce the increased tax receipts due to the Projects.

Table ES-3
Columbia County Property Tax Changes Due to Projects

Year	Assessed County Property Value	Annual Property Taxes Paid	Annual Project Property Tax Paid	Annual Property Tax Increase Due to Project
2006	$286,148,000	$3,694,000		N/A
2007	$389,870,000	$4,519,000	$807,000	$807,000
2008	$432,520,000	$4,837,000	$907,000	$100,000

Source: Columbia County Tax Levy Sheets provided by Chris Miller at Columbia County Assessor Office.

Sales and use tax revenues are expected to slightly increase due to expenditures by the Projects during the operations phase, but not during the construction phase due to a sales and use tax exemption for equipment and services related to wind power generation. Annual sales tax revenues during the operations phase are estimated to have increased by $14,000 for the state and $3,000 for the County. The present value over 25 years of sales tax receipts generated by the Projects is estimated at $341,000 for the state and $73,000 for Columbia County.

2 The annual property taxes paid by the Projects will fluctuate to some extent in the future, but are expected to be relatively stable due to the manner in which property taxes are assessed on large utilities with assets in multiple counties in Washington State. Future property tax payments will fluctuate based on two factors. First, as the tax base increases in Columbia County due to the Projects and other new construction, the levy rate is expected to decrease, which will reduce the total property tax payments from the Projects and all other property owners in the County. Second, the property tax payment from a utility is based on the total, depreciated value of assets owned by the utility in Washington State as well as the original value of the assets in Columbia County. As the total depreciated value of assets owned by PacifiCorp and PSE will likely change in the future, it is not possible to predict future property tax payments.

Property Values and Recreation

Based on the location of the Projects and a literature review of community effects of wind farms, it appears unlikely that there will be significant impacts of the Projects on property values, recreation, or community services. Overall, there are too many variables in real estate markets to be able to infer property value impacts based on other studies. However, data and analyses from these other locations do indicate that there is little to no correlation between property values and wind energy project development. This lack of correlation is borne out by the experience to date in Columbia County. Although there have been few property sales in the time period since the Projects were built that would aid in assessing the Projects' impact on property values, based on conversations with real estate professionals in Dayton, to date there have been no discernible negative impacts of the Projects on property values.[3]

Likewise, studies on recreation and tourism indicate no negative relationship between wind energy developments and recreational use. Hunting is the primary recreation activity conducted inside Projects boundaries. Due to an existing controlled access hunting program in the Hopkins Ridge Project area and an expected similar program for the Marengo Projects, it is expected that impacts on hunting recreation from the Projects is minimal. Tours of the Hopkins Ridge Project offered by PSE have provided increased tourism opportunities and resulted in approximately 600 to 800 visitors per year. These opportunities may be expanded by tours offered by PacifiCorp in the future.

Impacts of Wind Development in Other Southeast Washington Counties

It is expected that wind projects in other Southeast Washington counties will lead to the same *type* of economic effects as those realized in Columbia County; however the *size* of the economic effects in a county would depend on particular characteristics of the existing economy of each county. Generally, the greater the number and diversity of businesses within a county, the more the area economy can capture from a new business or development. With this in mind, the increase in jobs and income from a new wind development project is expected to be greater for Whitman and Asotin Counties than for Columbia County. This is because Whitman and Asotin Counties have much larger economies with businesses providing goods and services that may not be available in Columbia County. Similarly, the impacts of wind development in Garfield County may be smaller than in Columbia County since Garfield is a smaller county with fewer businesses. However, as a smaller county, the

3 Personal communication with Blaine Bickelhaupt, July 2008, Windermere Real Estate, Dayton Washington.

relative impacts of a project in Garfield County could be greater as a proportion of total county income or employment.

The extent to which a particular wind project would boost economic development throughout the Region, as opposed to the county in which it is located, largely depends on the location of the nearest urban centers with the necessary goods and services for the Project. If the closest urban centers are located in the Region, the greater the economic impact will be in the Region; whereas if the closest urban centers are located outside the Region, the smaller the economic impact in the Region.

Chapter 1 Introduction

The Southeastern Washington Region includes the four counties of Asotin, Garfield, Columbia, and Whitman (see Figure 1). Much of the Region is characterized by rural towns and rolling hills of farmland cultivated in wheat and other crops. In addition to its rich agricultural land, the Region also has tremendous wind energy assets. Wind development in the Region began in March, 2005 in Columbia County. To date, there are three wind energy projects in the Region, all located near the town of Dayton in Columbia County. Additional development is expected elsewhere in the Region in Asotin, Garfield, and/or Whitman Counties.

The three existing wind energy projects, Hopkins Ridge, Marengo I, and Marengo II (Projects), include 204 wind turbines. Hopkins Ridge, the first project constructed, has a capacity of 156.6 MW and became operational in November of 2005. It has 87 1.8 MW wind turbines, with a footprint of approximately 100 acres. It is owned by Puget Sound Energy (PSE), while the other two projects are owned by PacifiCorp. Marengo has a capacity of 140.4 MW and is comprised of 78 1.8 MW wind turbines. It became operational in September 2007. The Marengo II Project, which became operational in late 2008, is located directly southwest of the Marengo Project and generates 70.2 MW. Combined, the three projects will have a capacity of 367 MW.

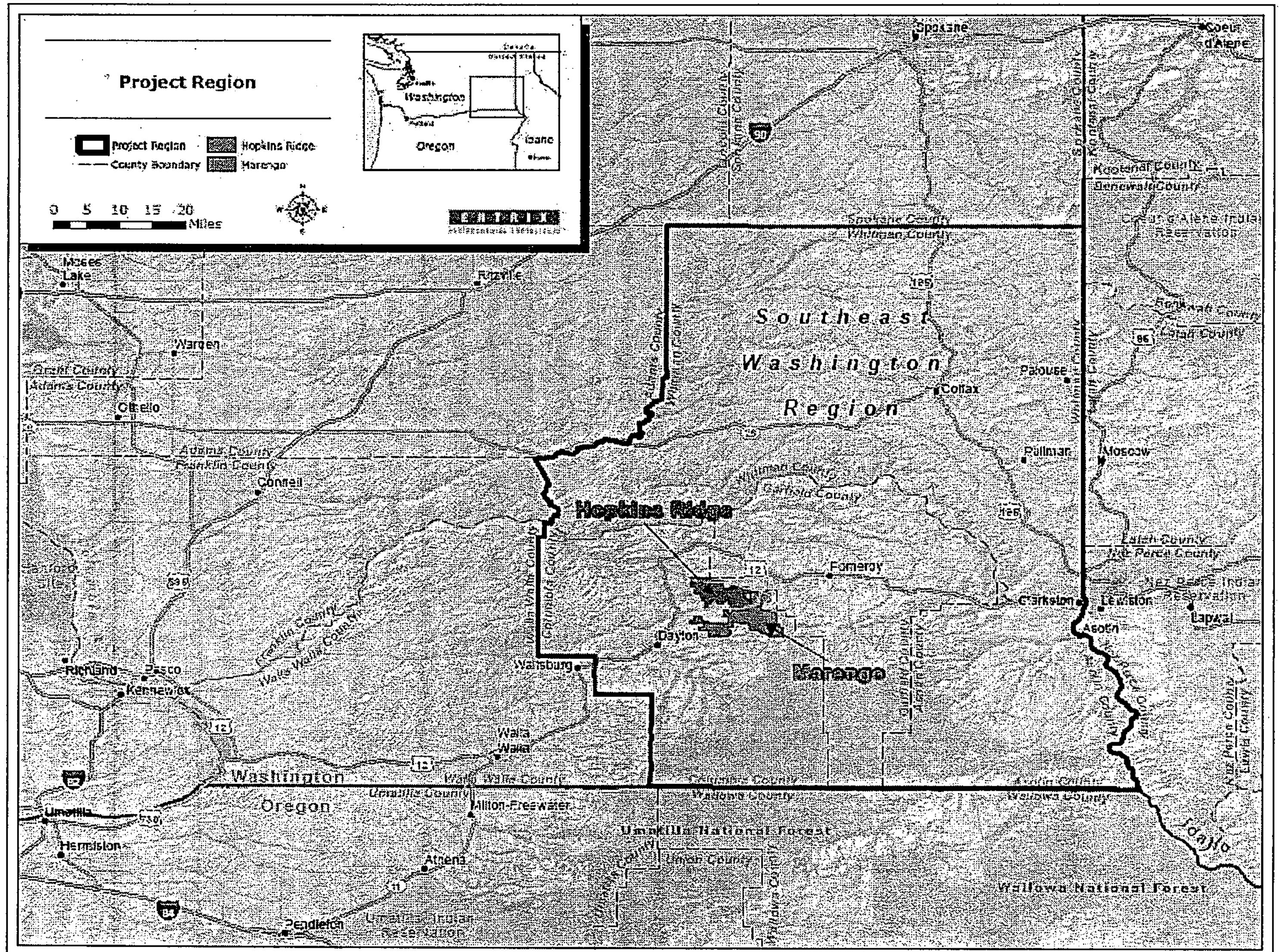
To gain a greater understanding of the economic impacts of wind energy projects in the Region, the Southeast Washington Economic Development Association (SEWEDA) commissioned ENTRIX to complete a study of the economic and social impacts of the Columbia County wind energy projects and the implications for additional wind energy projects in the Region.

Purpose and Scope

The purpose of this study, as commissioned by the Southeast Washington Economic Development Association (SEWEDA), is to assess the economic and fiscal impacts of wind energy project development in the Region. SEWEDA is interested in determining the impacts that have been experienced in Columbia County due to development of wind energy projects, and in understanding how these impacts may differ if wind energy projects are developed in the other three counties in the Region, as anticipated due to local support, good wind speeds, accessible power transmission, and compatible lands for wind energy development. The primary goal of this study is to assess the past and future anticipated economic impacts of the three existing Projects in Columbia County, and secondarily to project how impacts may differ if wind energy projects are developed in Garfield, Asotin, or Whitman Counties.

Economic effects addressed include the direct generation of jobs and income by the wind developments during the construction and operations phases, as well as the "ripple" effects on other economic sectors as expenditures on goods and services throughout the local economy increase to meet project-related demands. Fiscal effects are assessed by examining both tax revenues generated by the project and potential increased local government expenditures if the project causes increased demand for local public services. Finally, socioeconomic effects in terms of potential changes in property values and recreation / tourism in the Region are addressed.

Figure 1
Southeastern Washington Region



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The scope of the project is to provide a detailed assessment of the local impacts of the three wind energy projects currently built in Columbia County. The purpose of this assessment is not only to estimate the magnitude of the socioeconomic impacts of the Projects in Columbia County, but also to understand what the potential impacts would be in the other, similar Southeast Washington Counties. The scope of this report thus also includes a brief summary of how socioeconomic impacts of wind development in other Southeast Washington counties may compare to those experienced in Columbia County.

Organization of Report

There are seven chapters of the report. Chapter 1 is the introduction of the study. Chapter 2 provides an overview of how wind energy project development stimulates economic activity and local economic development. As the size and structure of an economy determines the extent that wind energy projects lead to economic development, Chapter 3 summarizes and compares the socioeconomic conditions in the Region, and details each of the four Southeast Washington county economies. Chapter 4 presents the methodology and results of the economic impact analysis in terms of net change in Columbia County jobs and income. Chapter 5 provides a quantitative estimate of the fiscal impacts (tax revenues and government expenditures) of the Projects, respectively. Chapter 6 discusses the potential socioeconomic impacts to recreation and property values. Finally, based on the findings of the economic impact analysis in Columbia County as well as a review of the structure of the economies in the three other Southeast Washington Counties, Chapter 7 discusses the relative economic impacts that could be expected due to wind project development in Asotin, Garfield, and Whitman Counties.

Chapter 2 Wind Power and Economic Development

There are four primary sources of economic effects of commercial wind energy development. First, wind energy projects often directly bring family wage jobs, during construction and operations, to rural areas. Rural areas, especially with agricultural based economies, often struggle to provide jobs to keep people in the communities. Wind energy development is one way to supplement income and ensure jobs for rural communities. Second, as with any new business, a new wind energy project may lead to additional jobs and income at existing local businesses by expanding their local market and increasing local economic activity. Third, wind energy projects may provide new rents and/or dividends to landowners who provide easements and leases to the developers. Fourth, wind energy projects may also add to the property tax base, which can result in a redistribution of the tax burden, or an increase in total tax revenues. Wind power may also have other economic effects, such as impacts to property values, recreation, and public service expenditures. This section provides an overview of each of these types of economic effects of wind energy projects.

Job and Income Creation

Communities are interested in the creation of new jobs because new jobs increase business and household income, which in turn create more jobs which further increase business and household income, and so on. A problem faced by some rural counties is that this process is in reverse, with jobs leaving and the economy contracting. To stem or reverse this process in counties where it is occurring, ways must be found to bring in new jobs or new income or both.

Natural resources have typically played an important role in the economic life of rural areas in the past and it is not unusual for local governments to continue to recognize the potential value of these resources in terms of building economic stability. For those areas with suitable wind resources and links to electric power transmission facilities, wind energy projects may offer an opportunity to create some long-term jobs and long-term income from wind energy project leases and easements.

Landowner Revenues

Wind developments can be a source of supplemental revenue for landowners in rural areas. Wind developers tend to lease land from landowners rather than purchase the land outright (as is the case with the existing wind projects in Columbia County), although in some instances easements are purchased. Each lease contract with each developer can be different and is usually negotiated individually. However, there are some generalities that can be made about these lease contracts.

Turbines and associated infrastructure (roads, transmission lines, etc) have a footprint that supplants existing land uses. During the development and construction phases, landowners are generally paid on a dollar-per-acre lease agreement. Once the project is operational, payments to landowners are usually a percentage of the gross revenues or are paid based on the production of the wind project in dollars per megawatt generated ($/MW). The landowner is typically still able to farm or allow grazing on all areas surrounding the turbines. Landowners who sell easements for wind energy projects typically receive a one-time, upfront payment.

Tax Effects

Taxes are a redistribution of benefits from wind energy project production to the federal, state, and local government jurisdictions in which the wind energy project production and sales occur. Thus, determining the impact of taxes on a specific community depends entirely on the tax make-up of that jurisdiction. The following paragraphs outline some general concepts regarding state and local taxation of wind energy projects in Washington State.

State taxes related to wind energy projects include sales and income (business and personal) taxes. Washington applies personal and real property taxes to businesses and utilities. Washington also has sales and use taxes.

Counties generally charge real estate and/or personal property taxes. In most cases, taxes collected by the counties are distributed to various levels of local government and district services, such as town governments, water and sanitation districts, emergency response districts, hospitals, and school districts, to pay for these services as well as other infrastructure.

Further, in addition to any taxes collected by counties on behalf of cities and towns, smaller localities often are able to charge sales and income taxes. As the tax make-ups of each of the case study localities are divergent, they will be discussed below on a case-by-case basis.

Real estate taxes are paid by landowners, and since the land that wind energy projects stand on is generally leased, the landowners pay these taxes. Tax impacts depend on any changes in the assessed value of the land or the real estate tax rate.

Personal property tax payments for wind energy projects are based on the installed capital cost of the wind plants. Personal property tax payments tend to be a greater source of tax revenues than other types of generation, per installed megawatt, because they require greater capital investment. Generally speaking, the tax payments on wind energy plants may range between one and three percent of the plant equipment (primarily the wind turbines), depending on the state and jurisdiction. The taxable property value in wind power projects also increases the availability of funding for local levy funds. For example, the wind energy projects contribute significant funding for the voter-approved levy for schools in Columbia County. Although the total funds raised by the levy remains the same, the levy funding provided by the wind energy projects results in lower taxes paid by residents of the County.

The impact on sales tax is a potential indirect effect, stemming from two sources. In most states, the primary source of sales taxes is the construction and operation and maintenance crews' local purchases of equipment and supplies, including hardware and convenience items. However, through June 2009, Washington State law exempts sales and use tax on capital equipment and services used to install energy facilities with a generation capacity of 200 watts or more electricity, which is a very small amount of electricity.[4] The equipment and services utilized in the construction phase of the Projects therefore does not generate sales and use taxes. Sales and use taxes are generated, however, in the operations phase. Another potential source of sales taxes is the potential increase in local disposable income for both landowners and project employees, which could be used for local expenditures.

4 Revenue Code of Washington § 82.08.02567. "The tax levied by RCW 82.08.020 shall not apply to sales of machinery and equipment used directly in generating electricity using fuel cells, wind, sun or landfill gas as the principal source of power, or to sales of or charges made for labor and services rendered in respect to installing such machinery or equipment, but only if the purchaser develops with such machinery, equipment, and labor a facility capable of generating not less than two hundred watts of energy and provides the seller with an exemption certificate in a form and manner prescribed by the Department." For periods prior to July 1, 2001, the exemption applies to facilities capable of generating at least 200 kilowatts of electricity. This was amended so that for periods after July 1, 2001, the exemption applies to facilities capable of generating 200 watts of electricity.

Chapter 3 Southeastern Washington Socioeconomic Overview

This section presents a socioeconomic overview of Columbia County and the surrounding counties (Whitman, Garfield, and Asotin), highlighting the demographic and economic characteristics of the Region. Socioeconomic information for the town of Dayton, which is the nearest town to the Projects, is also presented to the extent that data are available. This socioeconomic overview is intended to provide insight into the local population and economy, as well to provide context to the economic, fiscal and other impacts discussed in more detail later in this report. Additionally, information about the size and structure of Columbia County relative to each of the other Southeast Washington counties aids in assessing how socioeconomic impacts of wind development may differ in the other counties compared to the impacts experienced in Columbia County. This section presents data for the pre-project conditions in 2004 as well data from 2007 which is the most recent available, post-project year data.

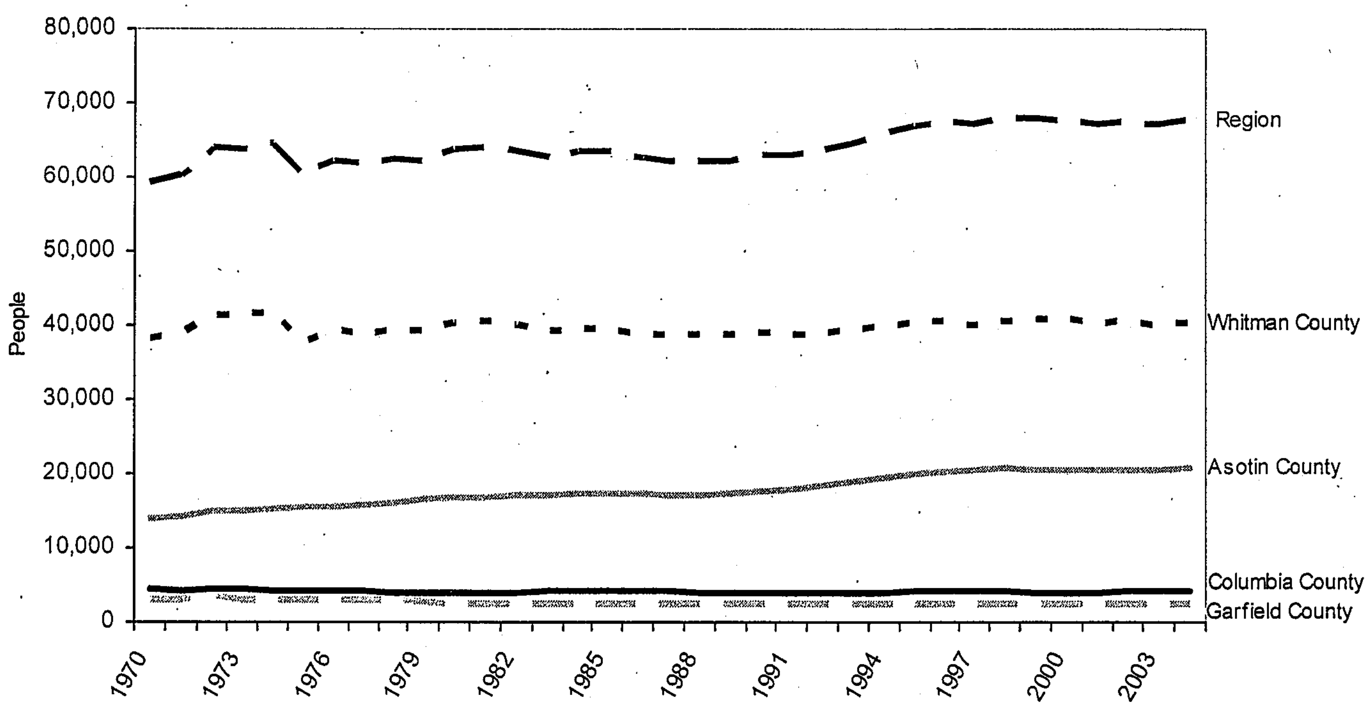
The Region encompasses the four counties of Asotin, Columbia, Garfield, and Whitman, an area of 4,300 square miles. While differing in certain characteristics, the similarities between the four counties allow them to be discussed as a Region. The land in the Region is generally agricultural in purpose, with wheat and barley the primary crops. Peas and lentils are also grown, as well as livestock grazed. The Snake River is an integral part of the transportation system in the Region, with river ports at Clarkston, Columbia, and Garfield, as well as the Port of Whitman sites: Almota, Central Ferry, and Wilma.

Income in the Region has been historically lower than the average across the rest of the state. Per capita income in the Region in 2004 was $23,975, lower than both Washington State ($35,041) and the nation ($33,050). Also, the proportion of people in poverty for all age groups in these four counties recently (between 1989 and 2004) was greater than the proportion for Washington State.

Population

The 2007 population estimate for all four counties is 70,450, with over half of that in Whitman County.[5] The primary population centers in the Region are Pullman (Whitman County, population 26,860) and Clarkston (Asotin County, population 7,280), which comprise nearly 50 percent of the Region's population. Between 1970 and 2004, population in the Region increased at an average annual rate of 0.4 percent per year, while population in Washington and the U.S. has increased annually by 1.8 percent and 1.1 percent, respectively. Figure 2 displays the population growth in the Region since 1970.

Figure 2
Regional and County Population, 1970-2004



Source: Regional Economic Information System, Bureau of Economic Analysis, U.S. Department of Commerce, CA30.

5 Unless otherwise noted all population estimates in the following text are from Washington Office of Financial Management, "April 1 Population of Cities, Towns, and Counties Used for Allocation of Selected State Revenues, State of Washington." Olympia, Washington. June 2008.

Columbia County

The 2007 population of Columbia County was 4,100, of which 64 percent of the population (2,720 people) lives in the incorporated City of Dayton. Starbuck is the only other incorporated town in the county, with 130 people. The rest of the county population lives in rural, unincorporated areas of the county. Between 1970 and 2004, population in the County has declined at an average annual rate of 0.2 percent per year. Population in Columbia County is anticipated to decline slightly to 4,088 by 2030.[6]

Asotin County

Asotin County is significantly larger than Columbia County, with a 2007 population of 21,300. Clarkston is the largest population center within the county, making up over one-third of the county's population (7,280 people). At the community level, recent growth in the county has been primarily in the unincorporated areas, with little to no growth in the cities of Clarkston and Asotin. Between 1970 and 2004, population in the county has increased at an average annual rate of 1.2 percent per year. Projected population in the county indicates significant growth, growing to 26,222 by 2030.

Garfield County

The 2007 population of Garfield County was 2,350. Pomeroy is the only incorporated population center, home to nearly two-thirds of the county's population (1,520 people). Between 1970 and 2004, population in the county decreased at an average annual rate of 0.7 percent per year. In recent years, growth in the county has only occurred in Pomeroy, which has increased only slightly since 2000. Projected population in the county indicates minimal growth, growing to 2,683 by 2030.

Whitman County

The 2007 population of Whitman County was 42,700. As with Columbia County, Whitman County is primarily rural in nature; however, it also houses one of the largest universities in Washington, Washington State University in Pullman. Pullman is the largest population center in the county, with over one-half of the county population (26,860 people). Colfax is the next largest, with a 2007 population of 2,905. Between 1970 and 2004, population in the county has increased at an average annual rate of 0.2 percent per year. Recent growth in the county has been primarily in the incorporated areas, with the cities of Colfax and Pullman

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6 Unless otherwise noted all population projections are from Washington Office of Financial Management, "Final Projections of the Total Resident Population for Growth Management Medium Series: 2000-2030." Olympia, Washington. October 2007.

incurring the greatest growth. Projected population in the county indicates slight annual future growth, with forecasted population of 47,743 by 2030 (0.5 percent annual growth rate).

Outside the Region

Three population centers are located just outside the Region, and are commercial centers that draw Regional residents for shopping and services. These are Moscow, Idaho (population 23,223) which is located less than 10 miles east of Pullman; Walla Walla, Washington (population 30,794) which is located approximately 30 miles southwest of Dayton; and Lewiston, Idaho (population 31,794) which is located just across the Snake River from Clarkston.[7] The presence of these urban areas located very close to the Region is an important factor in determining the magnitude of economic impacts of wind energy development in the Region. The nearby presence of these cities may result in the wind energy projects sourcing materials and services from these areas rather than from within the Region, similarly project employees may reside in these areas rather than living in the Region. Both of these effects can lessen the economic development potential of wind energy projects in the Region by reducing project-related demand for goods and services produced in the Region.

Economic Base, Employment, and Income

The economic base of the Region is not unusual for other rural areas in the United States. Employment has followed along with population increases, and even increased slightly faster than population since 1970 (see Figure 3). The government sector and the service sector are the two largest industries as measured by employment in 2006. The primary employers in the Region include Washington State University (Whitman County), Schweitzer Engineering (Whitman County), Clarkston School District (Asotin County), Tri-State Memorial Hospital (Asotin County), Federal Government (all four counties), Pullman Hospital (Whitman County), McGregor's (Agricultural Services in Whitman County), and Asotin County (Asotin County). Figure 4 shows the relative size of the economic sectors in each County, and illustrates the extent that Whitman and Asotin Counties dominate the Regional economy.

There are several key sectors that provide significant inputs to wind power projects and project workers. These include construction, retail, and service industries. The size of these industries in each county indicates the degree that project-related demands for goods and services can be met locally, and therefore the degree to which commercial wind energy development will spur economic growth in the county. In general, the larger these industries

7 US Census Bureau, 2007 Population Projections, 2000 Census.

are in a county, the more economic growth will be stimulated in the county. As indicated in Figure 4, several key sectors most affected by wind energy projects, including construction, retail, and service industries, are relatively small in Columbia and Garfield Counties. This indicates a smaller potential impact to the economy of these two counties by any new wind energy project.

Figure 3
Regional and County Employment, 1970-2004

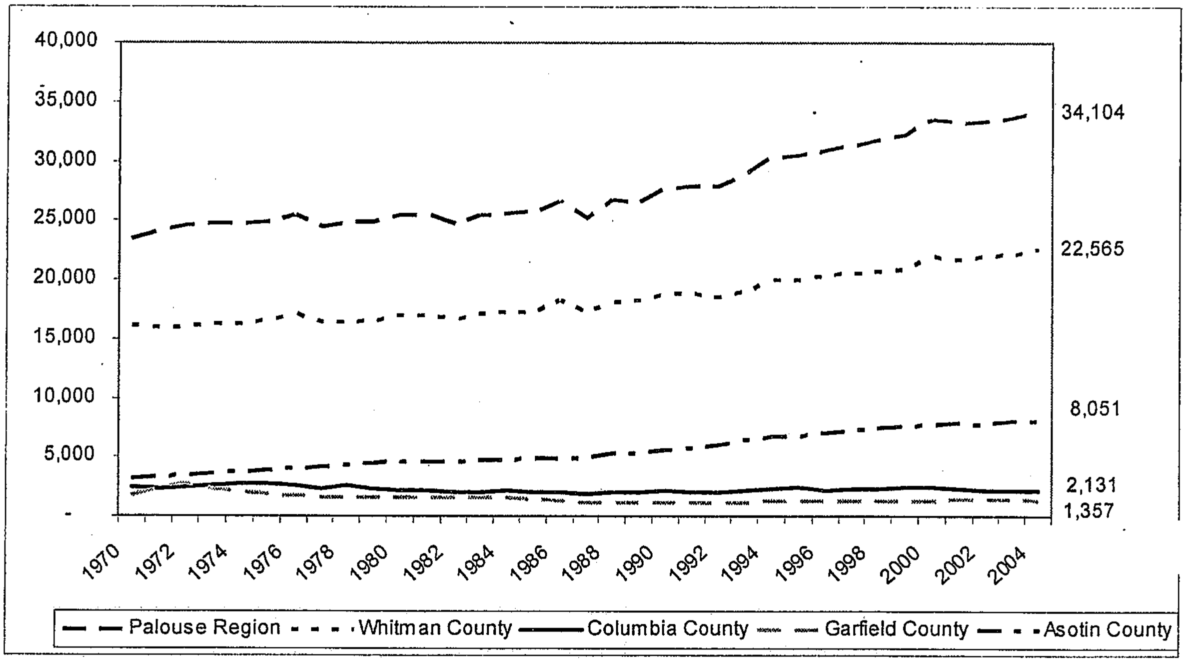

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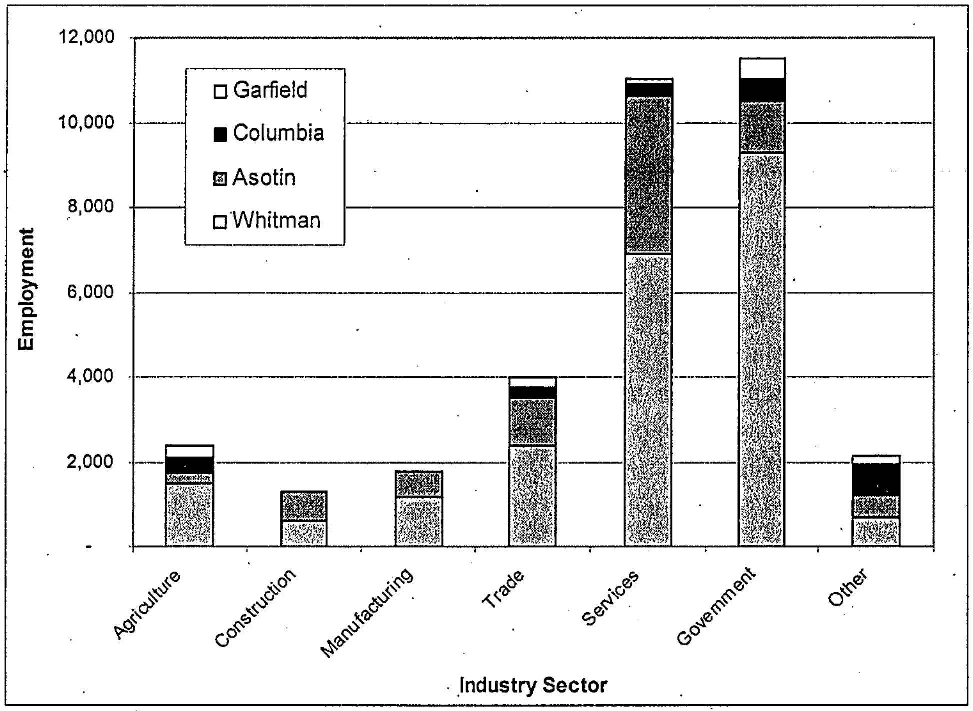
Figure 4
Employment in Primary Sectors by County



Overall unemployment in the Region in 2005 was 5.0 percent, compared to 5.5 percent in Washington State, and 5.1 percent in the nation. Total personal income in the Region in 2004 was over $1.6 billion. Of this total, labor income was $1.0 billion (62 percent). The remaining non-labor personal income was comprised of $291,000 (18 percent) in dividends, interest, and rent, and $327,000 (20 percent) in personal current transfer receipts (which includes retirement and disability insurance benefits, medical payments such as Medicare and Medicaid, income maintenance benefits, and unemployment insurance benefits). The annualized growth rate in personal income between 1970 and 2004 was 1.2 percent per year. However, growth of total personal income has historically been slower in the Region than both Washington State and the nation. Per capita income in the Region in 2004 was $23,975, lower than both Washington State ($35,041) and the nation ($33,050).

With some variation between counties, the Region is generally homogenous in its agricultural commodities. The primary agricultural products in the Region are wheat and barley, with some cattle, peas, lentils, and forage crops as well. In 2002, the total market value of crops and livestock in the Region was $218 million, representing over 13 percent of total economic output in the Region. The value of crop production totaled approximately $200 million and livestock products had a value of $18.6 million.[8]

The four counties forming the Region rank within the top 13 counties in Washington State for the value of sales of grains, oilseeds, dry beans, and dry peas, as well as the number of acres of wheat for grain. These four counties also fall within the top seven counties ranked for acres of barley. The Region includes the top ranked county for all three of these items.[9]

Columbia County

Employment in Columbia County was 2,131 jobs in 2004.[10] Since 1970, 296 jobs have been lost. The primary industries in the county are retail trade and local government, which combined account for about 26 percent of total employment. Further, most of the employment is wage and salary jobs (73 percent) compared to proprietor employment (27 percent), although the proportion of proprietor employment relative to the total employment base has increased over the past three decades. A proprietor is an owner of a business establishment, such as a store or a farm or ranch.

At the industry level, Columbia County has more employees in other services except public administration and government and government enterprises than the U.S. as a whole. In addition, there is a much larger percentage of farm proprietors (12 percent) and farm employment (17 percent), in Columbia County than the U.S. as a whole. Conversely, manufacturing industries in Columbia County are proportionately about half that of the U.S. Over three-quarters of the firms in the county have less than five employees and approximately 90 percent of firms have fewer than 20 employees.

Historically, the unemployment rate in Columbia County has been measurably greater than for the Region, Washington, and the U.S. In 2005, the rate was 7.1 percent, compared to 5.0 to 5.5 for these three areas (as discussed above).

Total personal income in Columbia County was $117 million in 2004, making up about 7.5 percent of the Regional income. Of this total, labor income was $67 million (57 percent). The annualized growth rate in personal income was 0.1 percent between 1970 and 2004. On a per-capita basis, income levels were $28,069 in 2004, lower than Washington State and the nation, but higher than the Region.

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8 United States Department of Agriculture, National Agricultural Statistics Service, "2002 Census of Agriculture County Profile", Columbia, Whitman, Asotin, and Garfield Counties.

9 Ibid.

10 Unless otherwise specified socioeconomic data presented in the remainder of this chapter is all from, Headwater Economics, 2007, "A Socioeconomic Profile, Columbia County," produced by the Economic Profile System, Internet website http://www.headwaterseconomics.org.

Asotin County

Employment in Asotin County was 8,051 jobs in 2004. Since 1970, 4,822 jobs have been created. The primary industries in the county are retail trade, health care and social assistance, and local government, which combined account for about 37 percent of total employment. As with Columbia County, most of the employment in Asotin County is wage and salary jobs (73 percent) compared to proprietor employment (27 percent).

Historically, the unemployment rate in Asotin County has been measurably lower than for Washington and the U.S. However, since 2000, Asotin County unemployment has been greater than the national rate, and since 2002 it has been higher than Washington State. It remains below Columbia County. In 2005, the rate was 6.2 percent.

Total personal income in Asotin County was $567 million in 2004, accounting for 35 percent of the Regional total. Of this total, labor income was $333 million (59 percent). The annualized growth rate in personal income was 2.6 percent between 1970 and 2004. On a per-capita basis, income levels were $27,128 in 2004, lower than Columbia County, Washington State, and the nation, but higher than the Region.

Garfield County

Employment in Garfield County was 1,357 jobs in 2004. Since 1970, 347 jobs have been lost. The primary industries in the county are agriculture, wholesale trade, retail trade, and state and local government, which combined account for about 82 percent of total employment. Agriculture alone (both proprietors and private employment) account for over 36 percent of total employment. As with Columbia County, most of the employment in Garfield County is wage and salary jobs (67 percent) compared to proprietor employment (33 percent).

Historically, the unemployment rate in Garfield County has been measurably lower than for Washington State, as well as for the nation until 2000. Since 2000 Garfield County's unemployment rate has been greater than the national rate. It remains below Columbia County. In 2005, the rate was 5.5 percent relative to the 2005 unemployment rates for these areas (previously discussed above).

Total personal income in Garfield County was $57 million in 2004, which totals about 2.5 percent of the Region. Of this total, labor income was $28 million (49 percent). The annualized growth rate in personal income was negative 1.0 percent between 1970 and 2004. On a per-capita basis, income levels were $24,541 in 2004, lower than Columbia County, Washington State, and the nation, but higher than the Region.

Whitman County

Employment in Whitman County was 22,565 jobs in 2004. Since 1970, 6,479 jobs have been created. The primary industries in the county are agriculture, retail trade, health care and social assistance, accommodations and food services, and state and local government, which combined account for about 71 percent of total employment. Agriculture alone (both proprietors and private employment) account for over 11 percent of total employment. As with Columbia County, most of the employment in Garfield County is wage and salary jobs (81 percent) compared to proprietor employment (19 percent).

Historically, the unemployment rate in Whitman County has been measurably lower than for the Region, Washington State, and the nation. It remains below Columbia County. In 2005, the rate was 4.2 percent relative to the 2005 unemployment rates for these areas (previously discussed above).

Total personal income in Whitman County was $879 million or 55 percent of the Region in 2004. Of this total, labor income was $572 million (65 percent). The annualized growth rate in personal income was 0.8 percent between 1970 and 2004. On a per-capita basis, income levels were $21,878 in 2004, lower than Columbia County, the Region, Washington State, and the nation.

Chapter 4 Regional Economic Impacts of Columbia County Wind Projects

This section presents the methods and results of the Regional economic impact analysis of the impact of the Projects on Columbia County jobs and income. The economic effects of wind energy projects are akin to other developments that have a construction phase as well as on-going operations. These types of projects typically provide an initial, short-term boost to the local economy during project construction as goods and services are purchased locally and local labor is used. However, a wind project is unique in the sense that the type of capital equipment used (wind turbines) is very specialized, and often is imported from outside the local economy. Once construction is completed, project operations provide extended local economic benefits over the long-term through spending on goods, services, lease payments, and labor that support operations.

Following an overview of the methodology, this section presents the estimated economic impacts of the project, focusing on the increased income and employment impacts that are expected to have accrued within Columbia County during Project construction as well as expected ongoing impacts occurring annually during operations. Employment and income generated by the Projects are first discussed, followed by a section presenting net employment and income effects after taking into account the small costs to employment and income associated with displacing land from agricultural production.

The time period of the analysis includes the development, construction, and operations phases of the Projects. Development started in approximately 2000 and continued through 2007. Construction began in 2005 and continued through 2008. As the bulk of the development and construction impacts were felt during the period 2005 to 2007, total development and construction impacts are summed from the period 2000 to 2007 and then averaged across these three years to provide an indication of the annual impacts for this time period. Although the three Projects began operating in different years, all three are assumed to have an operating life of 25 years as this is the period that the manufacturer guarantees the turbine can operate. Operations impacts are therefore projected for the years 2008 through 2033. As the Projects are expected to be maintained and operated beyond the assumed 25-year life, it is anticipated that Projects' effects may extend beyond 25 years, increasing the total value of the Projects over time.

This analysis provides an estimate of the total number of jobs and the income supported by the Projects. Due to other, concurrent changes occurring in the Columbia County economy, the estimate of jobs supported does not necessarily represent new employment. In 2004, just prior to construction beginning on the Projects, a food processing plant closed in Dayton. It is expected that some of the employment and income that was previously supported by this plant is now supported by the Projects. In other words, the economic activity generated by the Projects creates new jobs and supports jobs that previously existed that otherwise may have been lost.

In addition to the net economic benefits that are realized in Columbia County and concentrated in the community of Dayton, the Projects serve as a reliable source of clean and renewable power serving households and industries in Washington. These and other economic impacts outside the Region are addressed qualitatively. The section concludes with a discussion of economic benefits that are expected to be generated outside Columbia County. Increased local tax revenue impacts are discussed separately in Chapter 5.

Methodology

To understand how an economy is affected by a new business or industry, such as wind energy projects, we develop a snapshot of the economy at a particular point in time. This snapshot shows us how some parts or "sectors" in the economy are linked to each other. Using forest industries as an example, the sawmill industry buys logs from the logging industry, which buys trees from the forest owners, who in turn then buy seedlings from the nursery industry and the forest services sector to reforest their lands. These are referred to as backward linkages. If there were further processing beyond the sawmill industry, such as making lumber into doors and windows, it would be called a forward linkage.

Typically, most economic sectors also need to make purchases of goods and materials from outside of the local economy. Purchases made from outside the local economy are called "imports." Money spent on imports is said to be a "leakage" from the local economy. Likewise, businesses typically do not sell all of their production to businesses in the local area, but sell some or all of their production to businesses outside the local area. Products sold outside the local area are "exports," and money received for exports brings "new" money into the area and increases the size of the local economy through a multiplier effect.

The extent to which "new" money, generated by exports or by a new project are able to expand the local economy is greatly dependent on how much of the money received *remains* in the local economy. As money is received as part of project-related expenditures, the local suppliers then spend that money. To the extent that there are plenty of other local businesses on which the local suppliers can depend, less of this money leaves the local economy to buy imports. If there are few local businesses from which needed purchases can be made, much of the money will leave, or "leak" from, the local economy.

As other local businesses receive a portion of the money from the first supplier, they too can spend the money either within or outside the local economy. The more money spent within the local economy, the larger the local impact from the initial money received for the project related expense. This round by round pattern of spending associated with a new project is called the multiplier effect. The size of this multiplier effect depends on how local businesses are linked together and how much leakage there is to outside areas for imports. If the economy has numerous sectors that are linked, multipliers will be higher than if there are few linkages between sectors.

The household sector is linked to all sectors as it provides the labor and management needed by all sectors. In turn, changes that affect the incomes of the household sector typically have more significant impacts on a local economy compared to a change in the sales of other sectors. This does not mean that the effect on an individual sector, such as retail trade, will be insignificant as it will also indirectly affect the household sector.

We use an economic model, called IMPLAN to develop this picture of a local economy. This picture shows us the sectors that exist in a local area at a particular point in time, the links between them, and the level of economic activity that occurred at that time. This section describes the approach used to measure the total impacts of Project related spending as it ripples through the economy.

Economic Model

The Regional economic impacts of the Projects were estimated using IMPLAN (Impact Analysis for Planning), an economic input-output (I-O) model.[11] I-O models are constructed based on the concept that all industries within an economy are linked together; the output of one industry becomes the input of another industry until all final goods and services are produced. I-O models can be used both to analyze the structure of a regional economy and to estimate the total economic impact of projects or policies. For this analysis, a 2007 economic model for Columbia County was constructed by ENTRIX using IMPLAN software and data, and used to estimate economic impacts of the Project.

[11] The IMPLAN model consists of commercial software and region-specific economic data, which is maintained and distributed by the Minnesota IMPLAN Group, Inc.

IMPLAN I-O models provide three economic measures that describe the economy: output, labor income, and employment. Output is the total value of the goods and services produced by businesses in the county. Labor income is the sum of employee compensation (including all payroll costs and benefits) and proprietor income (profits). Employment represents the annual average number of employees, whether full or part-time, of the businesses producing output. Income and employment represent the net economic benefits that accrue to the Region as a result of increased economic output.

Total economic effects include direct effects attributed to the activity being analyzed, as well as the additional indirect and induced effects resulting from money circulating throughout the economy. Because the businesses within a local economy are linked together through the purchase and sales patterns of goods and services produced in the local area, an action which has a direct impact on one or more local industries is likely to have an indirect impact on many other businesses in the Region. For example, an increase in construction will lead to increased spending in the local area. Firms providing production inputs and support services to the construction industry would see a rise in their industry outputs as the demand for their products increases. These additional effects are known as the indirect economic impacts. As household income is affected by the changes in regional economic activity, additional impacts occur. The additional effects generated by changes in household spending are known as induced economic impacts.

Data Collection

This section describes the data collection effort used to assess the economic impacts of the existing three Columbia County Projects. This section also describes the data collected to consider how economic impacts of potential wind energy projects in the three other Southeastern Washington counties of Asotin, Garfield, and Whitman might compare with impacts realized in Columbia County.

To measure the effect of the wind energy projects on a local economy, it is necessary to identify the mix of goods and services purchased locally to construct and operate the projects. This mix of goods and services is like a recipe, with the ingredients measured in dollars; so many dollars for turbines, so many dollars for towers, so many dollars for wiring, so many dollars for various labor and management skills. Ideally, this list of inputs is composed of the items that will actually be used in constructing and operating the project. However, even with projects that have already been constructed, as in Columbia County, the dollar expenditures on local goods and materials for the Projects are often not known with certainty.

Although the Projects have been constructed, the total dollar expenditures (by the project developer, project employees, and the operating utilities) on local goods and materials related to the Projects are not known with certainty. The project developer for all three projects, RES Americas Inc (RES), provided estimates for the development and construction phases, while the utilities owning the three projects, PacifiCorp and Puget Sound Energy (PSE), provided estimates regarding the operations phase. Additional information was compiled from extensive interviews with local organizations and businesses.

Project data was provided by RES and PSE. For the development phase prior to construction, RES provided the payments to landowners for testing on their property for wind energy potential, as well as estimates of local expenditures for goods and services during the planning phase. For the construction phase, RES estimated the number of construction employees and the number of employees that were local hires.[12] RES also provided total equipment costs and labor cost estimates, as well as an estimated proportion that was sourced locally. The estimates of materials purchased locally were utilized in the analysis to the extent that local businesses verified that their business provided goods and services to the Projects. An estimate of total annual lease payments to landowners in the area was also provided by RES. PSE, the utility that owns the Hopkins Ridge Project, provided estimates of the number of employees that were hired during the construction phase of the project, as well as their total compensation.

In addition to these figures, it is necessary to estimate the expenditures by non-local construction workers. The money that non-local construction workers spent while in Columbia County represents 'new' money to the local economy and contributes significantly to impacts due to the Projects. These non-local worker expenditures were based on the number of employees and the length of the construction period, combined with interviews with local RV parks, motels, restaurants, grocery stores, and assorted businesses and the chamber of commerce.

For the operations phase, PSE and Vestas (which maintains the turbines for the utilities) provided the number of staff employed locally, as well as employee wages. PSE, which has an office in Dayton, also estimated their annual expenditures on local goods and services. It is expected that there are additional economic benefits of the operations phase of the wind energy projects that are not captured in this analysis, including spending by project visitors/service providers and non-local Vestas and utility employees. Additionally, little data were provided on local expenditures by PacifiCorp, so with the exception of the one operations employee currently in Dayton, any expenditure by PacifiCorp in the local area during operations is not captured in this analysis.

12 Personal communication with Jacob Davis, RES, August 4, 2008; Personal communication with Nicole Hughes, RES, October 9, 2008.

Results

This section presents the estimated past and future income and employment generated in Columbia County due to the Projects. Benefits due to the project are first presented for employment, then for income. Opportunity costs, which result from displacement of agriculture on the land that is now being used for wind energy production, are also estimated in terms of the small amount of income and jobs that were previously supported by agricultural production in the Projects' footprints. Finally, the last section presents the *net* income and employment benefits of the project (found by subtracting the opportunity costs from the benefits) on an annual and project lifetime basis.

Employment Benefits

Employment impacts are described below for the development/construction and operations phases of the Projects. Employment estimates include the jobs that are directly created by the Project, as well as the estimated additional jobs created in other sectors due to the overall economic stimulus caused by the Project. Estimates below report total job numbers, counting both full and part-time jobs.

Development and Construction Phase

The primary employment effects during the development phase (which occurs prior to construction) are due to services hired by the developer for permitting, real estate work, and community relations. During construction, the estimated employment effect on Columbia County of the three wind energy projects primarily stem from labor hired to construct the Projects. The projects' developer, RES Americas, estimates that during the main construction period between 2005 and 2007 there were typically 150 to 200 construction employees working on the Projects, with an average of approximately 165 workers employed throughout each year.[13] Of these workers, approximately 20 employees were local residents of Columbia County. The remaining construction workers were temporary residents that relocated for the duration of the construction phase in either Columbia County or in nearby Walla Walla County. There were another four employees hired during the construction phase by the utility operating the Hopkins Ridge Project.[14] Total direct employment impact during construction was therefore approximately 170 jobs (both part-time and full-time).

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13 Personal communication with Jacob Davis, RES, August 4, 2008, and Personal communication with Nicole Hughes, RES, October 9, 2008.

14 Personal communication with Anne Walsh, PSE, October, 2008.

In addition to these jobs directly generated by the Projects, employment was generated in other sectors through the induced effects created by construction employees spending their wages in the local community. Non-resident construction workers spent money in Columbia County on such goods and services as lodging (hotels, RV parks, and private rentals), food (restaurants and grocery stores), and gas, which resulted in small employment increases in these sectors. Increased spending by local construction worker households also generated some additional employment in Columbia County. Based on 2006 economic data regarding the relationships between output and employment in Columbia County, the IMPLAN analysis indicates that the increased spending by construction workers supported 22 jobs, of which 10 jobs were in the hotel industry. However, interviews with local hotel owners indicated that they did not hire additional staff due to the increased demand for their services, so it is estimated that the total induced employment generated by construction worker spending was likely closer to 12 jobs.

Data from the local community also indicates that some local jobs were supported through the indirect effect of Project-related expenditures on goods and materials used as inputs for the Projects. Local businesses in Dayton as well as the project developer reported expenditures on local goods and services that were used as inputs to the construction process, including professional services, vehicle fuel and maintenance purchases, hardware store purchases, and miscellaneous construction and maintenance materials and labor. Based on interviews with local businesses as well as economic data regarding the relationship between Columbia County output and employment, it is estimated that this spending on Project inputs supported seven jobs, primarily in the construction industry. Considering the size and cost of the Projects, expenditures for Project inputs resulted in relatively few additional jobs. Although expenditures on capital equipment for the Projects were over several hundred million, much of the equipment was specialized and was purchased from sources outside Columbia County and the Region, and therefore had little to no local or Regional impact.

In summary, Project-related economic activity during the construction phase had three impacts on employment. First of all, there was a direct impact of the labor working for the Projects, estimated at approximately 170 workers annually. The induced economic activity generated by construction employees spending their wages in the local economy supported an additional 12 jobs. Finally, Project-related spending on local materials and services resulted in indirect employment impacts of six jobs. Therefore, the total construction employment impact is estimated at 189 jobs in Columbia County during the construction phase of the Projects.

The ratio of total jobs created (189 jobs) to direct jobs created (170 jobs) gives us an employment multiplier of 1.1. The multiplier indicates that for every direct job created in the construction of the wind energy projects, an additional 0.1 job was created elsewhere in Columbia County. The size of the multiplier provides an indication of the strength of economic linkages in the local area; the greater the multiplier, the greater total economic effect resulting from the direct impact.

Operations Phase

During the operations phase of the Projects, jobs are primarily being generated to meet the need for maintenance and operation of the wind turbines. In the case of the Columbia County Projects, the utilities that own the Projects have a contract with the turbine manufacturer, Vestas, to maintain and operate the turbines. Vestas has hired 31 employees, many of whom were local Columbia County residents that were trained by Vestas in Portland, Oregon.[15] Puget Sound Energy, which owns and operates the Hopkins Ridge Project, is employing seven full-time staff in the Dayton area.[16] PacifiCorp, which owns and operates the Marengo I and II Projects, currently employs one full-time person in Dayton.[17] Thus, Project employment in Columbia County is approximately 39 jobs during operations.

In addition to jobs directly generated by Project operations, the purchase of Project-related materials and services is also indirectly generating some local employment. Although limited, some employment is being supported by demand for such ongoing services as vehicle maintenance and repair, miscellaneous repair and maintenance activities, office rent and cleaning services, office supplies, and hotel accommodations and restaurant services for temporary workers hired by the Projects. Known expenditure on such items is estimated at approximately $211,000 per year, which is likely a conservative estimate. This expenditure is estimated to support two jobs in Columbia County.

Finally, ongoing expenditures during operations by Project employees of their wages in the local economy also support local employment. Most Project employees live in Columbia County, and by retaining this population in the local area and providing these individuals with family wage jobs, it is expected that through their expenditures they support an additional 12 jobs, primarily in the trade and service sectors. Thus, total employment supported by the project, including direct, indirect and induced employment, is estimated at 53 jobs: 39 employed directly, two indirectly, and 12 due to the induced effect. The ratio of total jobs created (53 jobs) to direct jobs created (39 jobs) gives us an employment multiplier of 1.4.

Employment Benefits Summary

The total employment effects for both construction and operations phases are shown in Table 1. A total of 189 jobs were created in Columbia County during construction, of which approximately 40 to 45 were filled by local residents. During the ongoing operations phase,

15 Personal communication with Dan Ortega, Vestas, August 2008.

16 Personal communication with Anne Walsh, PSE, October, 2008.

17 Personal communication with Doug Mollet, PacifiCorp, August, 2008.

it is estimated that approximately 53 jobs are being created or supported by the economic activity generated by the Projects.

Table 1
Employment Impacts in Columbia County

Economic Impact	Development / Construction (Annually 2005-2007)[1]	Operations (Annually 2008-2033)
Employment (Jobs)		
Direct Effects	170	39
Indirect Effects	6	2
Induced Effects	12	12
Total Employment Effects	**189**	**53**
Employment Multiplier	**1.1**	**1.4**

[1] Note that there were slight employment effects during 2004 during development due to demand for community relations and project permitting. These impacts are included in the average impacts from 2005 to 2007.

Income Benefits

Income impacts are described below for the development/construction and operations phases of the Projects. Income figures represent total labor income, which includes both profits to business owners and wages to employees.

Development and Construction Phase

During construction, approximately 90 percent of Project workers temporarily located in the region during construction; this analysis does not include the income received by these relocated construction workers.

Just like employment, income generated during development and construction is a temporary benefit for the local economy that comes in the form of additional wages and profits. Local income increased from the development phase through payments for permitting and planning services as well as payments to landowners for testing of wind energy potential. Prior to constructing the Projects, approximately $25,000 was paid by the developer to landowners for anemometer leases to test the wind on their lands.

In the construction phase, income is increased not only through the direct spending by the Projects on wages to local individuals, but also by the profits and wages to the local owners and workers employed at businesses supplying the project with goods and services. This indirect income effect is felt in the businesses noted above that supply goods and services to the Projects, notably businesses providing construction and maintenance services, hardware stores, and vehicle maintenance and fuel operations. Income is also generated in sectors that supply goods and services to the workers employed by the Projects, which primarily includes such businesses as hotels and RV parks, grocery stores, restaurants, and gas stations.

During construction, direct income benefits in terms of project wages and profits to local workers are estimated to have been at $1,771,000 annually. The indirect wages and profits generated in other sectors was an additional $100,000. Finally, wages and profits induced by Project employee spending during the construction phase was approximately $411,000. Total estimated annual income generated during the three-year construction phase was $2,282,000.

Operations Phase

The operations phase of the Project increases income not only for the employees maintaining and operating the Project, but also for the landowners who are leasing their lands to the Projects. This income is estimated at approximately $3,110,000 annually.[18] Additional profits and wages are generated in the economy as this income is re-spent in the local area; it is estimated that this induced effect adds approximately $311,000 annually to local household income. Finally, expenditures at local businesses supplying goods and services to the Projects (indirect effect) are anticipated to result in $76,000 in additional profits and wages to local households. Total household income is expected to rise annually by $3,497,000 in Columbia County during the 25 years of Project operations due to increased profits and wages generated by the Projects.

Income Benefits Summary

Table 2 summarizes total household income impacts (profits and wages) in Columbia County during the construction and operations phases.

18 For some but not all of the direct project employment, this figure includes benefits, which are a form of compensation. Personal communication with Dan Ortega, Vestas, August 2008; Nicole Hughes, RES Americas, October 2008; and Anne Walsh, PSE, October, 2008.

Table 2
Household Income Impacts in Columbia County

Economic Impact	Construction (Annually 2005-2007)	Operations (Annually 2008-2033)
Household Income (Profits and Wages)		
Direct Effects	$1,771,000	$3,110,000
Indirect Effects	$100,000	$76,000
Induced Effects	$411,000	$311,000
Total Income Effects	**$2,282,000**	**$3,497,000**
Total Income Multiplier	**1.3**	**1.1**

[1] Note that there were some income effects during 2004 during development due to demand for community relations and project permitting. These impacts are included in the average annual impacts form 2005 to 2007.

[2] Note: May not add due to rounding.

Net Income and Employment Benefits

In addition to generating employment and income, the Projects also displace some agricultural production, resulting in small income and employment losses. These losses must be taken into account to estimate the net economic benefits of the Projects.

The three Columbia County Projects have a footprint of approximately 235 acres, and would displace this acreage of agricultural land. The value of using this land in its next best use (agriculture) is called the opportunity costs of using the land for wind energy projects. The opportunity cost is a real economic cost and must be subtracted from the Projects' benefits presented above to estimate net economic impacts. This section summarizes the opportunity costs and estimates the associated net economic benefits.

Crops grown in the Region typically include wheat (winter, soft white spring, and hard red spring), spring barley, peas, lentils, garbanzos, spring canola, and pushed spring canola, grown in various rotations. Current crop enterprise budgets for these crops, various crop rotations, and current pricing information results in an average gross return per acre of $504,[19] which over 235 acres results in a gross opportunity cost of $118,187. Net returns after total and variable costs average $123 per acre,[20] resulting in a net opportunity cost of

19 Painter, Kathleen, PhD, 2008 Crop Rotation Budgets, Over 18" Precipitation Zone Under Conventional Tillage, Whitman County, Washington.

20 Ibid.

$28,840. However it should be noted that these figures are for Whitman County, which generally realizes greater productivity than the other three counties, so the results may be a high estimate for Columbia County and the other two Southeast Washington counties of Garfield and Asotin.

As the reduction in farmed cropland is divided among several operations, it is unlikely that any of the operations with wind turbines would decrease the number of farm employees. Additionally, the direct foregone income of $29,000 leads to approximately $3,000 in induced income effects. Therefore, the total opportunity cost of changing the use of land away from farming grain and toward producing wind energy is approximately $32,000 income annually for all Columbia County projects. Landowners are compensated for lost agricultural production during the construction phase, so this $32,000 in reduced grain farming income is only experienced during the operations phase when it is more than offset by the gain in wind energy payments, as indicated in Table 3.

By subtracting the opportunity cost of $32,000 from the beneficial income impact estimate during operations, the net effect on income of the Projects during operations is a positive impact of $3,465,000 (see Table 3). As there are no anticipated opportunity costs of the Project on employment or on construction income, these estimates are the same as presented in Tables 1 and 2.

Table 3
Summary of Net Economic Impacts of Project Construction and Operations

Economic Impact	Construction (Annual, 2005-2007)	Operations (Annual, 2008-2033)
Labor Income (Columbia County Residents)		
Direct Effects	$1,771,000	$3,081,000
Indirect Effects	$100,000	$76,000
Induced Effects	$411,000	$308,000
Total Income Effects*	**$2,282,000**	**$3,465,000**
Employment (Jobs – All Employees)		
Direct Effects	170	39
Indirect Effects	6	2
Induced Effects	12	12
Total Employment Effects*	**189**	**53**

Net Present Value of Income Effects

Over the assumed 25-year life of the Projects, the total net economic income benefit may be calculated by considering the net present value (NPV) of income impacts from the Projects. The NPV of any project is the net gain or loss estimated in each year in the future added up in 2008 dollars. The value is net, because it is based on the total benefits less the opportunity costs discussed above. To calculate the NPV of any project, the time value of money is considered, which takes into account the greater value of money received in the near future compared to money that will be received farther into the future. To do this, a discount rate of three percent is used; so for every year that passes before money is received the value is reduced by three percent. For example, using a three percent discount rate $100 dollars received next year is equivalent to $97 received this year. The discount rate was only applied to discount future income, but was not applied as an interest rate to past income.

This NPV estimate assumes that the Projects continue operating through 2033; to the extent that the Projects continue operating past 2035 this estimate understates the long-term net income benefits of the Projects. Based on these assumptions and the annual net income estimates provided in the previous section, the total NPV of income in Columbia County due to the Projects is estimated at $67.2 million (Table 4).

Table 4
Net Present Value of Income Impacts of Project Construction and Operations

Economic Impact	Total Present Value Income
Labor Income (millions $)	
Direct Effects	$58,963,000
Indirect Effects	$1,623,000
Induced Effects	$6,596,000
Total Income Effects	$67,183,000

Economic Impacts Outside Columbia County

Economic benefits of the Projects have, and will continue to extend outside Columbia County. During construction, these out-of-county benefits were driven primarily by expenditures for large equipment and other goods and services that are not produced locally. Items that were imported from outside the county include major equipment such as wind turbines, blades and towers and other specialized electrical equipment, as well as standard construction materials that might have been sold locally, but manufactured elsewhere. Additionally, during construction numerous services were provided to the Projects by businesses located outside of the county and the Region. These services include permitting, truck transportation of capital equipment, engineering costs, and site investigations. Based on information provided by RES Americas (Projects' developer) and Puget Sound Energy (utility owning Hopkins Ridge Project), few of these goods and services procured outside Columbia County were provided by businesses located elsewhere in the Region.

These out-of-county construction expenditures resulted in direct and indirect economic benefits (income and employment) in the economies where these items were produced. In addition, the extent to which that local labor was not available in Columbia County and/or specialized labor was needed, workers were drawn in from surrounding counties and/or states with larger and more diverse construction work forces. It is estimated that 90 percent of the construction workforce, or approximately 145 workers on average, were drawn into the Region from other areas. This resulted in employment benefits and wage earnings that were leaked outside the county, thereby benefiting other regional economies.

Operation of these wind energy projects also generates positive economic effects outside of Columbia County. These effects include: (1) economic benefits (jobs and income) in areas where operations-related goods/services are purchased and manufactured, including replacement parts; (2) benefits associated with renewable energy development; and (3) power reliability- and cost-related benefits in areas where the wind energy projects are used to facilitate economic growth and production.

Chapter 5 Fiscal Impacts of Existing Columbia County Projects

The fiscal impacts from wind energy projects can include changes to both government costs and revenues. The cost impacts are attributable to any Project-related requirements for public services. The most commonly required public services during construction and operations are road maintenance, water, fire, and police protection. None of these are typically large for wind projects.[21] Typical revenue impacts are sales/use taxes during construction and property and sales taxes during Project operations. Taxes are a redistribution of benefits from wind energy production to the federal, state, and local government jurisdictions in which the wind energy production and sales occur. Thus, determining the impact of taxes on a specific community depends entirely on the tax structure of that jurisdiction.

The fiscal impacts from the Project evident thus far are beneficial to Columbia County. The impacts differ significantly during the construction and operational phases of the Project. During construction, tax revenue impacts directly generated by the Projects are expected to be very small due to a state sales and use tax exemption on capital equipment and services used to install energy facilities with a generation capacity of 200 watts or more electricity. During the operations phase, however, both property taxes and sales taxes are being generated from the Projects.

Fiscal Revenues (Taxes)

Project impacts on property tax and local sales/use tax revenues are analyzed in this section. Property tax benefits represent a long-term source of tax revenues for Columbia County,

21 Bureau of Land Management, North Palm Springs Field Office, September 24, 2006, "Economic and Fiscal Report, Alternative A, Mountain View IV Wind Project, Palm Springs, CA," prepared by AES Sea West, San Diego.

which would accrue over the approximate 25-year life of the Project. There will also be a small increase in sales and use taxes due to spending during the operations phase. The sales tax analysis presented here is based on the direct effects of project spending.

Property Tax

Property taxes have been paid on the Hopkins Ridge project for the past two years (2007 and 2008). The amount and distribution of these past payments are first described. Approximate projections of future property tax payments once all projects are operational are then discussed.

Past Property Taxes

Property taxes have been generated from the Hopkins Ridge project since 2007. The Marengo I and Marengo II projects will begin paying property taxes in 2009 and 2010, respectively, once the projects are fully operational. In 2008, the Washington Department of Revenue assessed the total taxable value of the Hopkins Ridge project at $81.2 million. The applicable property tax levy rate in Columbia County (Levy Code 2-3) is $11.17 per $1,000 of the property value, which is a 1.12 percent tax rate. Based on this rate, property taxes from the Hopkins Ridge Project in 2007 were $807,000 and will be $907,000 in 2008, which represents 18.8 percent of the total 2008 county property tax collections.[22]

22 The property taxes from Hopkins Ridge in 2007 and 2008 were assessed based on 84 wind turbines. An additional three wind turbines were installed in 2008 and will be included in property tax assessments in future years.

Table 5
Columbia County Assessed Value and Property Tax Changes 2006 - 2008

Year	Assessed County Property Value	Annual Property Taxes Paid	Annual Project Property Tax Paid
2006	$286,148,000	$3,694,000	
2007	$389,870,000	$4,519,000	$807,000
2008	$432,520,000	$4,837,000	$907,000

Source: Columbia County Tax Levy Sheets provided by Chris Miller at Columbia County Assessor Office.

The primary recipients of Hopkins Ridge property tax payments were schools with $174,537 (#2 School M&O), the state with $164,714, and the county road fund with $158,011 (see Table 6). The school levy, indicated in Table 5 as #2 School M&O, is structured to raise a set amount of funds for the Columbia County schools. Due to the significant taxable value of the wind power projects, a large proportion of the M&O fund is being paid for by the wind power projects. As the total amount raised by the levy remains the same, the significant payments by the Projects ($174,500 in 2008 by the Hopkins Ridge project) result in an equivalent reduction in the amount paid by the residents of Columbia County. According to the Columbia County tax assessor, it is projected that in 2009 the Projects will pay 35 percent of the hospital levy and 39 percent of the school levy.[23]

Table 6
Recipients of 2008 Hopkins Ridge Property Tax Payments[24]

Recipient	Levy	Rate	Amount
#2 School M&O	$2.1488	0.21%	$174,537
State Tax	$2.0278	0.20%	$164,714
County Road Fund	$1.9453	0.19%	$158,011
County Current Expense	$1.6155	0.16%	$131,223
Fire District #3	$0.8807	0.09%	$71,539
Hospital Bond 2003	$0.8409	0.08%	$68,300
Hospital District	$0.6263	0.06%	$50,872
Col. Co. Rural Library	$0.4561	0.05%	$37,051
Port of Columbia	$0.4110	0.04%	$33,384
Road – Diverted	$0.1927	0.02%	$15,655

23 Personal communication with Chris Miller, March 5, 2009.

24 Personal Property Tax Statement, 2008, Columbia County Treasurer, Parcel Number 4-000-00-570-0060.

Recipient	Levy	Rate	Amount
Mental Health	$0.0250	0.00%	$2,031
Soldier Relief	$0.0035	0.00%	$282
Total	**$11.1737**	**1.12%**	**$907,598**
Total Columbia County Receipts (Less State Tax Receipts)			**$742,884**

Future Property Taxes

All three Projects will pay property taxes starting in 2010. If the taxable value per wind turbine is similar in the Marengo I and II projects to the taxable value per turbine in the Hopkins Ridge Project[25], and if county property tax rates remain the same, the annual total property tax payments in 2010 will be approximately $2.2 million. In reality, the average taxable value per wind turbine will likely differ by project, but this approach provides an approximate estimate of the property taxes that may be paid from all three Projects in 2010.

The annual property taxes paid by the Projects will fluctuate to some extent in the future, but are expected to be relatively stable due to the manner in which property taxes are assessed on large utilities with assets in multiple counties in Washington State. Future property tax payments will fluctuate based on two factors. First, as the tax base increases in Columbia County due to the Projects and other new construction, the levy rate is expected to decrease, which will reduce the total property tax payments from the Projects and all other property owners in the County. Second, the property tax payment from a utility is based on the total, depreciated value of assets owned by the utility in Washington State as well as the original value of the assets in Columbia County. As the total depreciated value of assets owned by PacifiCorp and PSE will likely change in the future, it is not possible to predict future property tax payments.

Sales and Use Tax

Sales and use tax receipts also increase during the construction period. Increased sales tax receipts at the local level arise from project spending in Columbia County on construction materials for the Projects. Similarly, use tax revenues are generated on goods and equipment purchased outside Washington, but used on the project. The applicable sales and use tax rate

[25] The per turbine property tax value in 2008 from the Hopkins Ridge Project was approximately $10,900 per wind turbine. Property tax payments in 2008 are based on thee 83 turbines that were installed in the Hopkins Ridge Project by early January 2008. Four additional turbines were installed in the Hopkins Ridge Project later in 2008.

in Columbia County is 7.9 percent.[26] Of that amount, the State of Washington receives 6.5 percent and the remaining 1.4 percent is distributed locally.[27] However, in 2006 Washington State exempted equipment used to generate electricity from wind (and other renewable sources) from sales and use tax.[28] The tax exemption also applies to labor and services related to installation of the equipment. Therefore, no sales and use tax are calculated for the development or construction phases of the Project. However, as it is likely that some purchases of goods and services during the development and construction phases were not tax-exempt, this analysis likely results in an underestimate of total sales and use taxes generated by the Projects.

Annual operations spending is not exempt and will generate sales tax revenues. Reported operations-related spending on local goods and services (apart from wages for Project employees) is estimated at approximately $211,000 annually.[29] This is expected to result in annual sales and use tax receipts from operations of approximately $14,000 for the State and $3,000 locally. Over the life of the project, these sources of sales tax revenue will total $341,000 in state and $73,000 in local sales tax revenue. Discounting these annual payments to 2008 dollars, the net present value over 25 years of sales tax receipts from operations totals $238,000 for the state and $51,000 for the county.

Table 7 summarizes total sales and use tax receipts from the operations phase. The total present value of construction and operations sales and use tax receipts to the state is $238,000 while the total present value to the county is $51,000.

Table 7
Sales and Use Tax Receipts from Operation Materials Purchases

Type and Time Period of Receipt	State Revenue	County Revenue
Operation Receipts		

[26] The sales and use tax rate are the same in the State of Washington. Generally, the same types of items that are subject to sales tax are subject to use tax. Sales and use tax applies to the sale or use of tangible personal property in Washington.

[27] Washington State Department of Revenue, "Sales and Use Tax Rates," Web page: http://dor.wa.gov/content/findtaxesandrates/salesandusetaxrates/lookupataxrate, accessed: August 26, 2008.

[28] Revenue Code of Washington § 82.08.02567. "The tax levied by RCW 82.08.020 shall not apply to sales of machinery and equipment used directly in generating electricity using fuel cells, wind, sun or landfill gas as the principal source of power, or to sales of or charges made for labor and services rendered in respect to installing such machinery or equipment, but only if the purchaser develops with such machinery, equipment, and labor a facility capable of generating not less than two hundred watts of energy and provides the seller with an exemption certificate in a form and manner prescribed by the Department."

[29] This value is based on reported expenditures from PSE and Vestas and does not include potential expenditures by PacifiCorp, which were not available at the time of analysis.

Annual Receipts	$14,000	$3,000
Total Present Value over 25 Years	**$238,000**	**$51,000**

This estimate of local and state sales tax receipts is expected to underestimate the total increased tax revenue due to the Projects as it does not include any sales tax revenues generated from construction or operation employee spending. During the construction phase, many non-local workers spent a portion of their wages at local hotels and restaurants, which would have generated sales tax receipts in Columbia County. Additionally, the increased income of local residents may have increased their spending on consumer goods and services in the local area, thereby also increasing sales tax receipts.

Tax Summary

Property tax receipts from the Projects constitute the primary fiscal effect of the Projects. In 2008, the Hopkins Ridge Project generated $907,000 in property tax payments. Marengo I and II will begin paying property taxes in 2009 and 2010, respectively. Annual property tax payments from the Projects in 2010 may total approximately $2.2 million if payments per wind turbine are similar across Projects and if property tax rates remain similar.[30] The annual property tax rates are expected to fluctuate in future years due to changes in county property tax rates and due to changes in the assessed value of the Projects.

Columbia County receives 82 percent of property tax receipts, with the remainder going to the State of Washington. Property tax payments from the Projects benefit Columbia County by increasing tax revenues for the County and by decreasing property tax rates for all property owners in the County.

Sales and use taxes during the construction phase of the Project are estimated to be minimal as the Projects are exempt from most use and sales taxes. During the operations phase, sales tax receipts are estimated to increase by $17,000 annually, of which $3,000 accrues to local jurisdictions.

30 The annual property taxes paid by the Projects will fluctuate to some extent in the future, but are expected to be relatively stable due to the manner in which property taxes are assessed on large utilities with assets in multiple counties in Washington State. Future property tax payments will fluctuate based on two factors. First, as the tax base increases in Columbia County due to the Projects and other new construction, the levy rate is expected to decrease, which will reduce the total property tax payments from the Projects and all other property owners in the County. Second, the property tax payment from a utility is based on the total, depreciated value of assets owned by the utility in Washington State as well as the original value of the assets in Columbia County. As the total depreciated value of assets owned by PacifiCorp and PSE will likely change in the future, it is not possible to predict future property tax payments.

Public Services Expenditures

The previous section outlined the total expected fiscal gains from the Projects. In order to estimate the true fiscal impacts, however, potential costs to local governments arising from the Projects must also be considered. This section provides a brief evaluation of public service impacts and associated changes in government expenditures. A final section subtracts any losses from the gains to provide an estimate of the net fiscal impacts.

A range of community services could potentially be affected by the construction and operation of the proposed project. Potential impacts during construction arise primarily from the presence of the construction workforce in the Region; and transport and use of heavy machinery and equipment. During operations, community service effects are based on the size of the operations workforce and indirect employment in the Region, as well as the operating requirements of the wind farm. The analysis of community service effects is organized by service type.

- **Road Maintenance.** The primary access route to the site is through county roads that provide regional access to the area. During project construction, some damage to county roads did occur as the result of traffic from heavy commercial vehicles. However, all road reconstruction was paid for by project developers as per stipulations in the project permits and therefore did not place any additional demands on the county. The rural county roads providing access to the project areas, under normal circumstances, are not plowed for snow removal during the winter months. During the construction phase of the project, developers requested the county provide snow removal services to provide uninterrupted access to the project areas. [31] Any such additional services, such as snow removal, provided by the county were paid for by the developer.

- **Water and Wastewater Service.** The Projects did require water supplies for dust abatement and wastewater disposal during construction and for continued operations. Water sources were negotiated between the project developer and private land owners. During construction the wastewater disposal needs of the project were provided by developers via portable toilets. None of these services were provided via public or community systems.[32]

- **Law Enforcement and Security.** No additional law enforcement demands were generated by the Projects during construction. All security measures were paid for by project developers. Security for ongoing operations is accomplished through fences,

31 Personal communication with Drew Woods, Columbia County Public Works Engineer, July 28, 2008.

32 Ibid.

electronic security systems, and contracted security guards. Projects require additional on-site security during the hunting season to protect against vandalism. The service demands on law enforcement services are expected to be minimal.

- **Fire Protection.** The net effects of the Projects on fire protection are immaterial. To date, there have been approximately three dispatches to project areas since construction began; one was a construction accident and the other two were false alarms triggered by a faulty alarm system. There may be a slight increase in the risk of fire events and accidents, and therefore need for emergency services and medical aid provided by the Columbia Fire District #3. To negate the increased demands on fire protection personnel and equipments, PSE donated a Technical Rescue vehicle and paid for Rope Rescue/Rappel training for eight Columbia County emergency responders. Current emergency services are minor and are generally expected to be minor for operations of modern wind generation projects.

- **Schools and Education.** The impact of the Projects on education and school services has been negligible. For the last decade enrollment numbers have been declining annually. On average, 20 students exit the Dayton school district each year (see Table 8). The non-local construction workforce for the project did not re-locate with their families, so the number of school-aged children in the area did not increase. However, the operations workforce of local employees has allowed more families to stay in the county, thus slowing the number of students exiting the school district.[33] For example, in 2008, there were 21 students enrolled in the Dayton School District that are children of employees working at the Projects.[34]

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33 Personal communication with Mona Himmelberger, Business Manager, Dayton School District #2 July 30, 2008.

34 Personal communication with Anne Walsh, Puget Sound Energy, February 13, 2009.

Table 8
School Year Enrollment by Head Count and Full Time Enrollment[1 2]

School Year	Average Head Count	Average Full Time Enrollment
2004-05	556	525
2005-06	550	511
2006-07	538	497
2007-08	497	467

Source: Personal communication with Mona Himmelberger, Business Manager, Dayton School District #2 July 30, 2008

1/ Average of monthly counts on grades Kindergarten through 12

2/ Numbers in table do not include the 15 students in Starbuck, WA enrolled in grades K through 7.

- **Waste Disposal.** Trash and waste generated during construction and operations were hauled off the site directly to a landfill/transfer station or disposed by a licensed waste disposal company outside of the county.

- **Parks and Public Recreation.** The effects of project construction and operations on parks and other recreation venues have been minimal. The effects are discussed in depth in the previous section.

- **Utilities.**[35] Electric and telephone utility services have been extended to the project areas for operations. All of the utility services and installations have been paid for by project developers.

Overall, the effect of the projects on community services is negligible to minor depending on the type of service considered. In general, the increase in service demands has either been funded directly by project developers or is being met locally by public service providers paid by the Projects.

Summary of Net Fiscal Impacts

As noted in the previous section, additional fiscal expenditures for public services related to the Project are anticipated to be negligible. Therefore the net fiscal impacts of the Projects are expected to equal the additional tax revenues generated by the Projects.

35 Data from PSE only.

Chapter 6 Other Impacts of Columbia County Projects

This chapter addresses the potential impacts of the Project on property values, recreation, energy prices, and charitable contributions. For both property values and recreation, the visual or audio impact of the Project may affect scenic vistas or the rural undeveloped nature of the area. This section describes these potential impacts, as well as the potential impact on energy prices. The chapter ends with an overview of the charitable contributions of the Projects to local organizations.

Property Values

This section provides an overview of the potential impacts on property values in Columbia County due to the Projects. The discussion is based on the key issues and theory related to wind developments and property values, in addition to a detailed literature review of studies and reports that have analyzed the issue in other parts of the country and internationally.

Generally, changes in land use have the potential to affect the value of property experiencing the changing land use, as well as nearby properties through externality effects.[36] The property on which the Projects are sited is private property, currently used for grain production. The change in the value of these lands was reduced based on the potential reduction in cultivated land but increased by the long-term lease revenues. The net effect of these offsetting factors is overwhelmingly positive as very little land is taken out of grain production, and the wind leases provide significant income.

To assess potential property value impacts on nearby properties, it is important to understand the spatial context within which the Projects have been developed. The Projects are located

36 In economics, an externality is a cost or benefit resulting from an economic transaction that is borne or received by parties not directly involved in the transaction.

in a rural portion of southern Columbia County, near Dayton. In general, the Projects are visible from locations which have a direct and unobstructed "line-of-sight" to the Projects. For the general population this primarily includes highways and roads in the southern part of the county, but does not include the town of Dayton.

The potential impact of wind energy projects on land values is related to the land use of the surrounding area. In Columbia County, a little less than half of the land area is publicly owned (federal, state, and county). Of that, the federal government (U.S. National Forest) owns the most, with about one-third of the county land. The Washington State Departments of Natural Resources and Fish and Wildlife, Washington State Parks and Recreation Commission, and the Umatilla Tribe also manage lands within Columbia County. The remainder of county land is in private ownership and mainly consists of agricultural lands. Agricultural land values in Columbia County have experienced significant increases over the past 5 years, according to the Columbia County Assessors Office.[37] No changes have been specifically attributed to the wind energy projects.

Turning to private land, property values are based on many factors, one of which is demand. Demand for property is associated with local population and employment. Other factors relevant to these Projects on which property values are based include aesthetic effects, and the potential speculation for additional wind turbines.

For private properties located in proximity to the wind energy developments, the two key issues are visual and noise impacts. Noise impacts have been cited as a concern with wind projects, but noise effects are generally limited to properties with turbines, whose property values typically increase because of long-term revenue streams from leases. In the context of visual impacts, assuming scenic values are incorporated or "internalized" into the existing value of properties in the Project area, there is the potential for downward pressure on property values if wind facilities are perceived to adversely affect the quality of viewshed, although it is also recognized that some find the view of wind turbines to be appealing. There is likely greater internalization of scenic values on residential properties compared to undeveloped land in agricultural uses, such as grazing. Therefore, the key questions that would need to be answered in order to understand the effect of wind energy projects on property values are:

- To what degree have scenic values been internalized in local residential property values?
- How would the Project affect the scenic quality of the area?

37 Personal communication with Chris Miller, Columbia County Assessor, January 12, 2009.

Conversely, there are also sources of potential upward pressures on nearby property values emanating from wind energy developments. First, these projects offer both short- and long-term economic benefits in the Region, including job and income creation, as well as future economic development opportunities associated with expanded infrastructure and a new power source. Second, wind developments may boost tourism to the area, thereby promoting Regional economic development. Finally, the Projects would provide long-term revenue streams as lease payments to property owners on whose land the Project facilities would be located. In summary, there appear to be conflicting pressures on property values from wind energy developments.

The manner in which these pressures interact for the Columbia County Projects is unknown, and data are not sufficient to quantify the property value effects of the Projects. Additional insight on the potential effects of the Projects can be gained from empirical studies that have attempted to measure the effect that wind energy developments have on property values. Literature reviews concerning the effect of wind energy projects on the value of surrounding properties have generally indicated a lack of negative linkage between the two; in fact some indicate the possibility of a positive value effect.

Literature Review – Property Values

The environmental and economic effects of wind energy projects have been well documented. Several studies that have evaluated potential property value impacts are highlighted below (organized chronologically). No clear inference can be drawn from these studies and available research as the analyses vary in terms of rigor; methodology (e.g., survey sampling, statistical analysis, and expert opinion); size, location and site character of projects analyzed; and results and conclusions. However, the preponderance of research on this issue suggests that there is no negative relationship between wind energy developments and property values.

- **Economic Impacts of Wind Power in Kittitas County – Final Report. Prepared by ECONorthwest for the Phoenix Economic Development Group. November 2002.**

This comprehensive economic study analyzes three types of economic impacts, including project effects on property values. The property valuation section includes two separate analyses: (1) interviews of tax assessors in jurisdictions where wind farms had been constructed within the ten previous years, and (2) literature review. The study sample for the tax assessor interviews included 22 wind farms located in 13 counties. Six of the counties had residential properties with views of turbines while in the seven other counties there were no residential properties with views of the wind farm. Assessors in all six of the counties with residential views stated that they had not determined that wind projects had any negative impact on property values.

- **The Effect of Wind Development of Local Property Values. Prepared by the Renewable Energy Policy Project (REPP). Contributing Authors: G. Sterzinger, Beck F., and Kostiuk, D. May 2003**

This study represents the most comprehensive study on wind energy impacts on property values. The study is based on a review of market data on property sales within the viewshed and comparable areas associated with 10 wind projects located in California, New York, Texas, Vermont, Wisconsin, Pennsylvania, and Iowa. The viewshed was generally defined as a five-mile radius from the outermost turbine. Comparable areas (used as control communities) were defined as reasonably close communities with similar demographic, economic, and geographic characteristics and trends compared to properties within the viewshed, but located outside of the wind turbine viewshed area. The study used statistical analysis to determine whether and to what extent the visual presence of turbines influenced selling prices of nearby properties. The study evaluated the rate of change in property values inside and outside the viewshed of the turbines relative to comparable areas. Three different case examinations (or approaches) were utilized: (1) an analysis of how prices changed over the entire period of the study for the viewshed and comparable region; (2) an analysis of how prices changed within the viewshed before and after the projects came on-line; and (3) an analysis of how prices changed for both the viewshed and the comparable region, but only for the period after the projects came on-line. The study used simple regression analysis to estimate how rate of property value change was affected in each of the cases.

The study found no significant empirical support that property values were diminished in any of 10 case studies from around the country. Conversely, the study found that for most projects property values rose more quickly in the viewshed than they did in the comparable community. Further, values increased faster in the viewshed after the projects came on line than they did before, and after projects came on line, values increased faster in the viewshed than they did in the comparable community. In sum, in 26 of the 30 individual scenarios analyzed, property values in the affected viewshed rose more than in comparable communities.

- **A Real Estate Study of the Proposed Forward Wind Energy Center, Dodge and Fond Du Lac Counties, Wisconsin. Prepared for Invenergy Wind LLC. Prepared by Poletti and Associates. May 2005**

The purpose of this report is to determine if the proposed Forward Wind Energy Center is located so as to minimize any adverse effect on the character of the surrounding area and on surrounding property values. The analysis was based on expert opinion and relied on a detailed review of the subject property and plans for the proposed wind energy center; on-site inspection of the subject property and surrounding area; inspection of other wind development sites; a review of uses and property values of surrounding tracts of land, including data on real estate transactions; and discussion with various assessors. Specifically, the project was reviewed in the context of its compatibility with the established and historic land uses in the project area and its impact on those uses, as well as marketability and value of other property in the vicinity. The study concludes that the proposed wind energy project is located such that it would have minimal effects on the value of the surrounding property.

- **Impact of Wind Farms on the Value of Residential Property and Agricultural Land. Prepared by the Royal Institution of Chartered Surveyors (RICS). 2005**

This survey study was implemented by the Royal Institution of Chartered Surveyors in the United Kingdom in an effort to gauge professional opinion about the role wind energy development has on both residential and agricultural property values. The study found that:

  - 60 percent of the sample suggested that wind farms decrease the value of residential properties where the development is within view.
  - 67 percent of the sample indicated that the negative impact on property prices starts when a planning application to erect a wind farm is made.
  - The main factors cited for the negative impact on property values are: visual impact of wind farm after completion; fear of blight; and the proximity of a property to a wind farm.
  - Once a wind farm is completed, the negative impact on property values continues but becomes less severe after about two years.
  - A significant minority of surveyors with experience in residential sales affected by wind farm developments (40 percent) indicated that there is no negative price impact.
  - Only 28 percent suggested wind farm development negatively influences the value of agricultural land, while 63 percent suggested there is no impact at all (either positive or negative). The remaining 9% suggest a positive impact.
  - The survey suggests that wind farms do not impact residential property values in a uniform way. The circumstances of each development can be different.

- **Impacts of Windmill Visibility on Property Values in Madison County, New York. Project report prepared by Ben Hoen. Submitted to: Faculty of the Bard Center for Environmental Policy. Prepared in partial fulfillment of the requirements for the degree of Master of Science in Environmental Policy, Bard College. April 30, 2006**

This study represents the most current and statistically-rigorous analysis of property value effects from wind energy projects. In fact, most of the weaknesses in the REPP study (2003) were addressed and corrected in this study that focused on the property value impacts of the Fenner wind energy project in Madison County, New York. This study analyzed 280 arms-length single-family residential sales in the vicinity of the proposed wind development using a hedonic regression model. The sales occurred between 1996 and 2005 (140 transactions occurred after facility construction began in 2001) and were within 5 miles of the 20 turbines/30 megawatt (MW) wind development. None of the home sales were on properties that contained turbines, and none of the properties were compensated for the operation of the turbines. This study is unique in that all properties in the database were visited to "ground-truth" the actual level of turbine visibility.

The hedonic model focuses on two key characteristics, view of and distance from turbines, and combines them with a number of house and neighborhood characteristics, to estimate the specific effect on home sales prices of the view of and distance from turbines. Although the model provides a strong statistical explanation of home values, the analysis concludes that there are no statistically-measurable effects of wind farm visibility on property values, even for those properties located within one mile of the facility and those that sold immediately following the announcement and construction of the wind farm

- **<u>Evaluating Impacts of Wind Power Projects on Local Property Values</u>. Prepared by: P. Barton DeLacy, (Cushman & Wakefield, Inc.). Prepared for: UPC Wind Management, LLC. Technical memorandum submitted to the Cohocton Planning Board for the Cohocton Wind Power Project. November 15, 2006.**

The purpose of this technical memorandum is to summarize the findings of an analysis that evaluated whether the proposed Cohocton and Dutch Hill Wind Power Projects might affect property values in the vicinity of the wind turbine generators. The analysis was conducted by a Certified General Real Estate Appraiser who has experience in evaluating property value impacts from wind energy projects. The methodology consisted of site inspections of comparable projects, a comprehensive literature review, examining demographic profiles in affected jurisdictions, and reliance on professional experience. The researcher concluded that the project should have negligible impacts upon property values for undeveloped properties or existing farms, while premium-priced homes located in the project area or viewshed, which would derive a premium from scenic values, may be adversely affected. However, in these cases, isolated impacts from wind projects would not necessarily diminish property values because of the more important influences of local economic conditions and the national housing market. Further, to the extent that the wind project creates jobs, reduces local property taxes, and generates tax revenues that benefit local schools and infrastructure, then property values should be supported in affected jurisdictions.

Discussion

As described above, the studies generally support the notion that wind energy developments do not adversely affect property values. However, the applicability of the studies referenced above to the Projects is difficult to ascertain. As such, it is worthwhile to review these studies in the context of the Projects.

The Projects can be seen from highways and roads in the county, but not from Dayton. In the Washington counties reviewed by ECONorthwest, 2002, the Projects could be seen from nearby towns. However, even in that study, none of the county assessors interviewed believed that the wind projects adversely affected property values, which was supported by an increasing tax and employment base (in Walla Walla County, Washington) and empirical research conducted by the assessor (in Lincoln, Wisconsin). Sterzinger, et al (2003) is based on a case-study approach that covers the entire country. The similarities between the Projects and these case studies are unknown. However, in some cases, the data indicate that property values had increased after the projects were constructed and were higher relative to comparable communities. In other studies, the results suggested that property value appreciation was slower in areas near wind projects.

The applicant-sponsored studies conducted by Poletti and Associates (2005) and Cushman and Wakefied (2006) concludes that wind projects would have minimal, if any, effects on property values in Wisconsin and New York, respectively. Again, due to differences in site characteristics and the surrounding region, it would be difficult to infer potential property value impacts in the vicinity of the Columbia County Projects. Finally, the study prepared by Hoen (2006) appears to be the most statistically rigorous and empirically defensible piece of research on this topic. Although the results are for Madison County, New York, and a smaller wind project (20 turbines), data on actual home sales do not support the notion that wind projects have a negative impact on property values.

Overall, there are simply too many variables to infer property value impacts from other studies; however, data and analyses from these other locations do indicate that there is a weak relationship between property values and wind energy development. Furthermore, interviews with a local real estate agent indicate that changes in land values in Columbia County have mirrored national trends. Although there have been few property sales in the time period since the Projects were built that would aid in assessing the Projects' impact on property values, to date there have been no discernible negative impacts of the Projects on property values.[38]

Recreation and Tourism

This section provides an overview of the potential impacts of Columbia County wind development on tourism and recreation. The analysis is based on interviews, data collection, and analysis of post-construction trends in recreation and tourism in the county. Additionally, results from other studies of the impacts of wind development on recreation are presented and discussed in the context of Columbia County.

38 Personal communication with Blaine Bickelhaupt, July 2008, Windermere Real Estate, Dayton Washington.

Many people are drawn to the Region for its scenic beauty, cultural, and historical sites, and recreational opportunities. Both locals and visitors to Columbia County enjoy outdoor recreation such as hunting, fishing, skiing, boating, camping, picnicking, and golfing. Columbia County contains part of the 1.4 million acre Umatilla National Forest, located in the Blue Mountains. This area offers commercial skiing at the Bluewood Ski Resort, located 21 miles from Dayton. In addition to skiing, Bluewood manages the Jubilee Campgrounds, the largest and most popular campground on the Umatilla National Forest. Many people go to the Jubilee Campgrounds to fish, boat, swim, hike, and mountain bike.[39] Other activities in the Umatilla National Forest include camping and cabin rentals; many miles of trail accessible by foot, horseback, or bicycle; off-highway vehicle (OHV) trails; and ample hunting and fishing opportunities.[40] The wind farms are not visible from the Bluewood Ski Resort area and the number of annual visitors has been consistent over the last five years.[41]

There are two state parks in Columbia County; the Camp Wooten Environmental Learning Center (ELC) and the Lewis and Clark Trail State Park. Camp Wooten ELC is located on the Tucannon River in the Blue Mountains and offers hiking, canoeing, swimming, and fishing from a stocked pond. The Lewis and Clark Trail State Park is a 37-acre camping park with 1,333 feet of freshwater shoreline on the Touchet River. The park is open year-round for camping and day use. Summer activities include hiking, swimming, wildlife viewing, and fishing for rainbow and brown trout. Winter activities include cross-county skiing and snowshoeing.[42] The wind farms are not visible from the either park and no adverse effects from the projects have been observed.[43]

The Lyons Ferry Park and Marina (Lyons Ferry) is located on the northern edge of Columbia County on the banks of the Snake River near Starbuck. Lyons Ferry is located half in Columbia County and half in Franklin County. Activities at Lyons Ferry include boating, camping, RV's, fishing, swimming, canoeing, kayaking and day use. An estimated 60,000 to 80,000 vehicles visit annually and demand is increasing. The wind farms are not visible from Lyons Ferry; however, during construction of the projects many Lyons Ferry RV spaces were

39 Bluewood Ski Resort, Recreation Management Campgrounds, Jubilee Lake http://www.bluewood.com/camp.htm, accessed July 30, 2008.

40 U.S. Forest Service, Umatilla National Forest, Walla Walla Ranger District, http://www.fs.fed.us/r6/uma/walla2/index.shtml, accessed July 30, 2008.

41 Personal Communication with Bruce Goodell, Bluewood General Manager, July 23, 2008.

42 Washington State Parks, Lewis and Clark Trail, http://www.parks.wa.gov/parkpage.asp?selectedpark=Lewis%20%26%20Clark%20Trail, (accessed July 30, 2008.

43 Washington State Parks, Camp Wooten ELC, http://www.parks.wa.gov/elcs.asp, accessed July 30, 2008.

rented for extended periods by wind farm employees. Additionally, during construction many project employees and their families recreated there on the weekends.[44]

In the winter months locals and visitors to Columbia County enjoy snowmobiling at Eckler Mountain and Hatley Gulch, located east of Dayton, and Touchet Corral, located southeast of Dayton.[45] Winter recreation does not occur on project areas or within site of turbines, and so it is not expected to be affected.

A large number of tourists travel State Highway 12 and stop in Dayton. Wind farms are visible to tourists / scenic drivers on Hwy 12 just east and west of town. There is no evidence to suggest that the Projects have discouraged tourists from traveling that route, though there is some evidence that the wind turbines have attracted new tourists as many people are interested in viewing wind turbines. Wind energy has shown to be a tourist attraction at other locations. For example, the PSE Wild Horse Renewable Energy Center near Ellensburg, Washington had over 17,000 visitors in 2008.[46] The center is not comparable to the PSE tours offered in Dayton, as it offers formal exhibits providing information on wind and solar power generation. Visitation at Wild Horse Renewable Energy Center, however, does indicate the level of interest from the public in learning about renewable energy.

The Dayton Chamber of Commerce has begun marketing the area using themes of wind energy projects and alternative energy. Furthermore, PSE operates free tours of the Hopkins Ridge Project. People interested in viewing the project can schedule tours through the Dayton office of PSE. Tours have been given to visitors passing through Dayton, as well as numerous organized groups including classes from local schools and colleges, class reunions, church groups, and senior citizen groups. Visitors are from Dayton, as well as Pullman, Walla Walla, and Lewiston. PSE is promoting that people visit for a tour and then stay for lunch at a local restaurant. The Weinhard Hotel in Dayton has partnered with PSE to market a wine and wind tour as a tourist attraction for its guests.

PacifiCorp anticipates starting a similar program at their Marengo I and II facilities. Data provided by PSE indicates that the annual number of people visiting the Hopkins Ridge Project is approximately 600 to 800 (see Table 9).

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44 Port of Columbia, Lyons Ferry Park and Marina, http://portofcolumbia.org/index.php?option=com_content&task=view&id=19&Itemid=40, accessed July 30, 2008, and Personal communication with Ed Merritt, Lyons Ferry Concessionaire, July 22, 2008.

45 Washington State Parks, State Snowmobile Sno-Parks, http://www.parks.wa.gov/winter/parks/motorparks.asp?Region=6, accessed July 30, 2008.

46 Puget Sound Energy, 2008, "PSE Renewable Energy Center at Wild Horse Marks Successful First Season of Operation, Press Release from Bellevue Washington, November 19.

Table 9
Annual Number of Visitors to Hopkins Ridge Wind Farm

Year	Tour Numbers
2005	224 (In construction this year)
2006	701
2007	650
2008 – January to June, 2008	440

Source: Personal communication with Joanie Hudson, July 15, 2008

Hunting is the only recreational activity conducted within wind project boundaries and the primary recreational activity conducted within sight of the Projects. As such, it is expected that it is the recreational activity most affected by the wind farms. The section below describes hunting in the project area, and potential impacts of the wind development on hunting recreation and tourism.

Potential Impacts on Hunting

Columbia County has three operating wind farms, Hopkins Ridge and Marengo (I and II). Both project areas are considered prime hunting areas.[47] Some of the public and private lands that are now leased by PSE and PacifiCorp were formerly available for hunting through a state managed "Feel-Free-to-Hunt" Program (Program) whereby private land owners allowed hunting access in return for state assistance in planning or implementing practices for enhancing wildlife habitat. The Program posts signs on properties that define the boundaries and establish safety zones in which no shooting is allowed. The state also provides extra enforcement against violations.[48]

Often, once wind farm construction begins, the entire leased project area is closed to the public due to theft and liability concerns. However, closing access to large tracts of hunting areas can cause unanticipated problems for lease-holding farmers. Without regulated hunting in these areas, wildlife populations can increase, causing potential damage to crops.[49]

47 Personal communication with Scott Rasley, Wildlife Biologist with the Washington Department of Fish and Game, July 31, 2008.

48 Personal communication with Kurt Merg, Private Lands Biologist, Washington Department of Fish and Wildlife, August 1, 2008.

49 Personal communication with Kurt Merg, Private Lands Biologist, Washington Department of Fish and Wildlife, August 1, 2008.

Additionally, if area access is prohibited, poachers and other violators can find refuge from law abiding hunters and enforcement agencies.[50]

Both PacifiCorp and PSE have hunting programs to allow access to the wind project lands. The PacifiCorp program was implemented just before the 2008 hunting season, and therefore little information was available on the program at the time of analysis. More information is available on the PSE program at Hopkins Ridge, which has been implemented since 2006.

Prior to wind project construction at Hopkins Ridge, approximately 7,000 acres of the 11,500 acre project area were available for hunting through the state-managed Program. During the construction phase the entire project area was closed to the public. In 2006, PSE began the "Access-With-Written-Permission" program (AWWP) for the Hopkins project area. Under the AWWP program the number of acres available for hunting increased to approximately 8,000 acres, a net gain of 1,000 acres.[51] In the first year, PSE granted 838 permits to hunters and fishermen from five different states. In 2007 that number increased to 876 permits. Over 600 permits had already been granted for 2008 by late July and many more were expected.[52] The permitting process is free and involves providing photo identification, a vehicle description including license plate number, and a fishing and/or hunting license number. Once the appropriate paperwork has been filed and the applicant has watched a three minute video provided by PSE outlining safety in the wind farm area, access is granted.[53] Permit holders are provided a map of the available hunting areas and the permit is valid until March 31st the following year.[54] Hunters are primarily seeking elk, deer, and upland game birds[55] in

50 Personal communication with Scott Rasley, Wildlife Biologist with the Washington Department of Fish and Game, July 31, 2008.

51 Ibid.

52 Personal communication with Scott Rasley, Wildlife Biologist with the Washington Department of Fish and Game, whom presided over the hunting access program, July 31, 2008, and PSE has not placed any restrictions on the maximum number of permits granted.

53 Granted access to Hopkins leased land comes with several access rules. Violation of the rules results in the violator's total loss of access privileges.. The rules include no hunting during turbine maintenance or construction; no access of any kind within 300 feet of the turbines or substations; no pointing or shooting of any weapon at the turbines, people, overhead power lines, maintenance vehicles, etc.; no vehicle traffic on wind farm property except on normally traveled county roads; no blocking access to gates or entrances; no violating of Washington State game rules; no overnight camping, parking, or fires unless previously authorized; and a copy of the access permission agreement must be carried at all times while within the Hopkins boundaries. As of July 2008 there have been no reported violations of the access rules.

54 The Last Resort Camp Store & Blue Mountains KOA Campgrounds, July 2008, "Fishing and Hunting Report" http://www.thelastresortrv.com/fishing_hunting_report.htm, accessed July 29, 2008.

55 Upland birds are non-water fowl game birds such as Quail, Pheasant, Grouse, and Turkey.

the project areas and fishermen are primarily seeking steelhead. There have been no reported violations of the AWWP program.[56]

The Marengo I and II projects, operated by PacifiCorp, also contains prime hunting land, and has been working on allowing a similar hunting access program but has not yet finalized the permitting details. Currently, access for hunters is not allowed.[57]

In summary, the data from the "Feel-Free-to-Hunt" program and the Hopkins Ridge "Access with Written Permission" program suggest that individuals are continuing to access the hunting lands in the controlled access Hopkins Ridge Project areas. Due to this program and the expected implementation of similar programs in the Marengo Projects, as well as the availability of alternative hunting lands elsewhere in the vicinity, it is expected that the Projects' impacts on hunting recreation in the area is limited.

Other recreation or tourism effects are difficult to quantify due to insufficient data. However, insight on the direction (positive or negative) and magnitude of potential effects can be gained from empirical studies that have attempted to measure the effect that wind energy developments have on recreational use and tourism. Some of these studies are reviewed below. The studies seem to suggest a weak leak between recreation and wind farm developments, and some even indicate that wind developments increase tourism.

Previous Studies Related to Recreation and Tourism Impacts

This section provides a summary of potentially relevant studies addressing how wind development has affected tourism and recreation.

- **Tourist Attitudes towards Wind Farms. Research Study Conducted for Scottish Renewables Forum & the British Wind Energy Association. Summary Report. September 2002.**

This study depicts the results of a survey of tourists visiting Argyll & Bute, an area of Scotland with the greatest concentration of wind projects (three large commercial wind farms in operation). The area also has an economy with a high dependence on the tourism industry, which is based on the landscape value of its scenery and natural environment. The purpose of the survey was to assess the awareness and perception of wind farms of 307 tourists in order to answer questions about how wind farm development might affect tourism within

56 Personal communication with Jim MacArthur, host of the Last Resort Camp Store, July 28, 2008 and with Scott Rasley, Wildlife Biologist with the Washington Department of Fish and Wildlife, July 31, 2008.

57 The Last Resort Camp Store & Blue Mountains KOA Campgrounds, July 2008, "Fishing and Hunting Report" http://www.thelastresortrv.com/fishing_hunting_report.htm, accessed July 29, 2008.

Scotland. The results indicate that tourists are able to appreciate the natural beauty of an area, while also reacting positively to the presence of wind farms. The study found that the presence of wind farms actually encouraged more people to return than to stay away. It also determined that there are opportunities for wind developers to develop wind site visitor centers to encourage more tourists to the area.

- **<u>Kittitas Valley Wind Power Project, Washington, Tourism and Benefits to the Local Economy</u>. Horizon Wind Energy. Available at: www.horizonwind.com, accessed September 18, 2007.**

This report discusses and quantifies many benefits of the proposed Kittitas Valley Wind Power Project, including impacts to tourism. The report states that a wind farm in the nearby community of Walla Walla, Washington had over 1,600 recorded visitors and more unrecorded visitors in less than three months. It also sites European sources indicating that some wind projects are tourist attractions and continue to attract attention, and other tourist destinations that are near wind energy projects continue to attract a large number of visitors.

- **<u>The Case Against Wind 'Farms'</u>. Country Guardian. May 2000. Available at: www.countryguardian.net/case.htm, accessed September 20, 2007.**

This study makes the case for the negative aspects of wind energy projects. As related to tourism and recreation, the report sites older studies with anecdotal evidence (letters from local residents to the press) that tourism slows with the development of wind energy project sites. It also cites a survey stating people like to go to the countryside for its own sake and seek nothing further (but does not mention anything about wind energy projects), and a survey from 1980, when the wind technology was much different than it is today.

- **<u>Proposed Arecleoch Windfarm – Assessment of Recreation, Sports, and Tourism Opportunities, Executive Summary</u>. Peter Scott Planning Services Ltd. November 2005.**

This study assesses potential opportunities for, and impacts to recreation and tourism related to the proposed wind farm development at Arecleoch Forest, in Scotland. It states that although there may be decreased use by walkers and horseback riders, "the potential to enhance recreational and tourism opportunities in the vicinity of the proposed windfarm and to increase visitors to nearby settlements is likely to exceed the scale of potential impacts of the development on such activities." It also suggests some tourism promotion and development at the project, including providing parking spaces, a viewpoint, information (board and leaflets), and self-guided walking tours, as a way to increase visitor numbers.

Energy Price and Externalities

Several utilities provide electricity to customers in the Region. These include PacifiCorp and Avista for most of the urban areas. Inland Power & Light provides service to portions of Whitman County, and Columbia Rural Electric Association serves areas of Columbia County.

The power produced at the Columbia County Wind Projects is available to the owner utilities (PacifiCorp and PSE) for inclusion in their energy portfolios, and enters their transmission and distribution systems from the Projects. The costs of the power from the Columbia County Projects are blended into their total electricity costs. This blending of costs indicates the likelihood that these Projects neither increase nor decrease the cost of power to consumers within Columbia County or the Region.

Charitable Donations

The addition of new local businesses can increase funds for local organizations and events. This has been the case for Dayton and surrounding areas with the added presence of PSE and PacifiCorp. Both utilities have provided charitable contributions to communities in Columbia County and adjacent areas. PSE, which has an office in Dayton, provided estimates of its local charitable giving through 2008 (see Table 10); similar estimates were not available from PacifiCorp at the time of analysis. Since 2006, PSE has donated nearly $37,000 to local Columbia County organizations, and has also donated approximately $6,000 to Garfield County and slightly over $2000 to Walla Walla County.[58] PacifiCorp and other businesses associated with the Projects may also have contributed charitable donations, but this information was not available.

Table 10
PSE Charitable Donations 2006- November 2008

	County of Recipient		
Year	**Walla Walla**	**Columbia**	**Garfield**
2006	$325	$17,101	$5,000
2007	$1605	$7,375	
2008	$250	$12,500	$1,041
Total	$2180.00	$36,976.00	$6,041

[58] Personal communication with Anne Walsh, PSE, November 12, 2008.

Chapter 7 Economic Implications for Future Wind Development in Other Southeastern Washington Counties

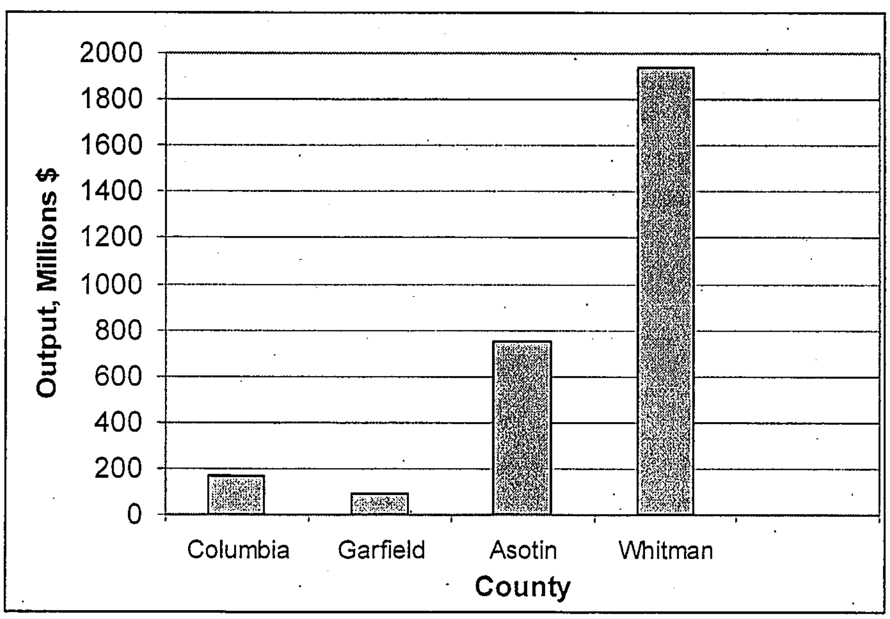
This section compares and contrasts the potential effects of wind energy projects in each of the other three Southeastern Washington Counties (Garfield, Asotin, and Whitman) to the effects experienced in Columbia County. The expected size of economic effects for each of the counties is discussed. The property and sales/use tax rates are similar in each of the Southeastern Washington counties, so tax impacts are expected to be comparable across counties for similarly sized projects. However, if the Washington State sales and use tax exemption on equipment and services used for installing wind energy projects is allowed to expire in 2009, the sales and use taxes generated by projects in other counties would be greater. Potential recreational and property value impacts that might be experienced in the other counties are not addressed as these largely depend on the specific location of a project.

To qualitatively assess how impacts of wind development in other Southeastern Washington counties would compare with the impacts experienced in Columbia County, three types of information were considered. First, data were analyzed on the structure of the local economy and in particular, the size of potential linkages between sectors that would supply inputs and services for wind energy projects. Second, data were collected regarding the Regional retail commerce patterns in terms of where people go to purchase goods and services. Finally, in each of the counties interviews were conducted with local chamber of commerce and business owners to verify data from published sources, and to get a feel for the size and type of businesses that could benefit from wind energy projects.

As seen in previous sections, wind energy projects can boost an economy through several mechanisms; direct effects come through lease payments to landowners and increased employment and wages during construction and operations, while indirect and induced effects increase economic activity through increased purchases of local goods and services by the project and by project workers. The magnitude of this indirect and induced effect depends on the capacity of local businesses and residents to provide the goods and services required by the project and its workers, as well as the presence of nearby larger urban areas that can provide goods and services that aren't available locally. Based on the analysis of economic impacts in Columbia County and a comparative review of the structure of the economies in the other three Southeastern Washington counties, this section summarizes how the potential economic impacts of future wind energy projects in Asotin, Garfield, and Whitman Counties may compare with the economic impacts experienced in Columbia County.

Wind projects in other Southeastern Washington counties will lead to the same *type* of economic effects; the *size* of the economic effects, however, will depend on particular characteristics of the economy in each of the other counties. Generally, the greater the number and diversity of businesses within an economy, the more the area economy can capture from a new business or development. With this in mind, the increase in jobs and income from a new wind development will likely be greater for Whitman County than for Columbia County since Whitman is a much larger county with businesses that provide goods and services that may not be available in Columbia County. Likewise, the impacts of wind development in Garfield County may be smaller than in Columbia County since Garfield is a smaller county with fewer businesses. However, as a smaller county, the relative impacts of a project in Garfield County may be greater as a proportion of total county income or employment. Figure 5 summarizes the total output levels in each of the Southeastern Washington counties in millions of dollars; the figure highlights the much larger size of the economies in Whitman and Asotin Counties compared to the economies of Garfield or Columbia Counties.

Figure 5
2006 Economic Output in Southeastern Washington Counties (Millions $)



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Insight on the relative impacts of wind energy projects in the different Southeastern Washington counties may be gained through an examination of economic multipliers for each of the economic sectors most affected by these types of projects. As indicated in Chapter 4, not all businesses will be directly affected by a new development. The businesses that would first experience a noticeable change in revenue are typically businesses serving construction workers and providing inputs to the wind projects. Such businesses include hotels and other accommodations, food and drink establishments, gas stations, grocery stores, and construction firms. The size of total economic impacts resulting from a particular wind project is determined by the presence of these key industries as well as their industry-specific multipliers for a particular county.

Industry-specific multipliers for each of the Southeastern Washington counties indicate the strength of the linkages of that industry to other industries in a county, and the potential for increased demand in that industry to generate increased demand in other industries. Specifically, an industry income multiplier indicates the total increase in income throughout the county that results from a dollar increase in income in that industry. Similarly, an employment multiplier indicates the total increase in employment resulting from an increase in one job in an industry.

Table 11 provides multipliers for income and employment for some of the industries typically affected by wind energy projects. These multipliers are from the IMPLAN model constructed for each of the counties. If multipliers for the affected economic sectors are similar in neighboring counties to the multipliers for Columbia County, then the magnitude of expected effect is likely to also be similar. If the multipliers are smaller or greater than those in Columbia County, the total economic effects are expected to be smaller or greater, respectively. The industry multipliers for income and employment across the Columbia, Whitman, and Asotin counties are similar, which suggests that the economic impacts may be similar across the Southeastern Washington counties. The exception is Garfield County, which has smaller multipliers in all industries and which actually lacks businesses in key industries. The 2006 data for Garfield County indicates that the gasoline and service station sector does not exist, although there is one gas station located in Pomeroy. The next section describes potential economic effects in more detail for each county.

Table 11
Multipliers for Selected Sectors
Across the Southeastern Washington Counties

County	Food and Beverage Stores	Gasoline Stations	Hotels and Motels	Restaurants	Construction	Retail
Income Multiplier						
Columbia	1.2	1.1	1.2	1.1	1.1	1.1
Asotin	1.3	1.3	1.3	1.2	1.2	1.2
Garfield	1.2	N/A[2]	1.1[1]	1.0	1.0	1.0
Whitman	1.4	1.1	1.3	1.2	1.2	1.2
Employment Multiplier						
Columbia	1.1	1.1	1.1	1.1	1.2	1.1
Asotin	1.2	1.3	1.2	1.2	1.4	1.3
Garfield	1.0	N/A[2]	1.0[1]	1.0	1.0	1.0
Whitman	1.2	1.2	1.1	1.1	1.3	1.2

[1] This multiplier is for the "other accommodations" sector, rather than for the "hotels and motels" sector.

[2] There is no IMPLAN data for this sector as the data indicated that in 2006 there were no gasoline stations in Garfield County. However that are currently two fueling stations in Pomeroy.

Asotin

As indicated in Table 12, Asotin generally has higher multipliers than Columbia County, indicating that economic impacts of wind energy projects may be larger. The Asotin County economy is larger, with more businesses and more diversity in goods and services provided than in Columbia County. Asotin County, and in particular the City of Clarkston, has more lodging options, retail outlets (including department stores), restaurants, construction, and other businesses that would be able to supply services to a wind energy project and its workers. However, Clarkston is located just over the state border from Lewiston, Idaho, and has strong economic ties with Lewiston. Economic impacts in Asotin County from wind energy projects may be lessened due to the nearby presence of the larger urban area of Lewiston. For example, Clarkson has approximately six hotels and motels while Lewiston has 20 motels and hotels. Additionally, Pullman, in Whitman County, is located just 30 miles north of Clarkston, and also has businesses that may provide goods and services to the Project, thereby potentially reducing the impact in Asotin County. In general, however, it is expected that the economic impact of comparable wind energy projects in Asotin County would be at least as great as the economic impact experienced in Columbia County.

Garfield

All of the multipliers in Table 12 are smaller for Garfield County than for Columbia County, indicating that economic impacts may be smaller (although fiscal, or tax impacts, will likely be similar). Garfield County is a small county with fewer and less diverse businesses than Columbia County. Businesses in Garfield County can be classified in 56 sectors, considerably fewer than the 87 sectors present in Columbia County. Given the absence of some industries, wind energy projects in Garfield County may rely heavily on surrounding counties for goods and services. In particular, there is some construction occurring in the county but the relatively low amount of construction output (including the lack of concrete manufacturing or rock quarries) and the relatively few options for housing, eating, and shopping may decrease economic impacts. There are two RV parks in Garfield County, and another located approximately 12 miles from downtown Pomeroy in Columbia County. Similarly, there is only one motel and grocery store in Pomeroy. There are multiple hotel and grocery options in Asotin County (Clarkston), which is located approximately 30 miles away from downtown Pomeroy.

Due to the close proximity of larger urban areas with more services, construction workers, and potentially even operations workers, may choose to reside in these other urban areas and not spend their wages in Garfield County, thereby decreasing the economic development potential of wind energy projects specifically to Garfield County. The proximity of Clarkston and Lewiston indicates that these cities may likely gain from wind development in Garfield County if wind project workers live in these cities or if Project inputs are procured from businesses in these cities.

A key factor for increasing the economic impact of wind energy projects in Garfield County is ensuring that construction workers and others visiting a wind energy project have adequate lodging and services within Garfield County. Lodging options could include a motel, RV park, or short-term apartment rentals. Important services to offer include drinking and eating establishments, laundromats, grocery stores, and general retail.

Whitman

Whitman County is by far the largest of the Southeastern Washington counties in terms of population and economic output, which indicates that economic impacts of comparable wind development may be larger than those experienced in Columbia County. It also has the most diverse economy in terms of types of businesses present. Much like Clarkston and Lewiston, the proximity of the town of Pullman in Whitman County to the town of Moscow, Idaho results in a fair amount of inter-regional and inter-state trade. Whitman County has many if not all of the industries typically providing locally services for the development of turbines.

For example, there are approximately ten hotels or motels in Pullman and two in Colfax as well as a number of RV parks within the county. There are also many retail and restaurant options in Whitman County. Additionally, the size of the population will likely result in more construction workers being from the local area, thereby increasing retention of Project wages. Despite this, the inter-regional ties with Moscow, Idaho may reduce some of the economic benefit to Whitman County.

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Section 3

SCIENTIFIC REPORTS: Property Values

Document List

- **Springfield-Sangamon County Regional Planning Commission.** ***2009. Effect of Wind Farms on Property Values.*** **2009, updated 2010.**

- **Sterzinger, G., F. Beck, and D. Kostiuk. 2003.** ***The Effect of Wind Development on Local Property Values.*** **Renewable Energy Policy Project.**

- **Hoen, B., R. Wiser, et al. 2009.** ***The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi- Site Hedonic Analysis.*** **Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division.**

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Information Brief

SSC RPC Springfield-Sangamon County Regional Planning Commission

Original: March 23, 2009
Updated: Jan. 11, 2010; March 1, 2010; Oct. 21, 2010

Key Findings:

After reviewing some of the most often cited literature concerning the effect of wind farms on property values, the SSCRPC found:

-- No compelling research indicating that proximity to a wind farm results in a measurable decline in property values over time. Research was found indicating that people might *believe* it would lead to such a decline, which may result in a short-term decline prior to property owners gaining experience with a wind farm.

-- A trend in the quantitative research indicating that wind farms have no significant effect on surrounding property values, and may in some limited cases increase property values. The belief that wind farms depress property values may have such an effect on the most proximate properties over the near term.

-- A great deal of econometric analysis indicating the overall economic benefits of wind farms to the areas in which they are located, which may affect surrounding property values and disguise any minimal losses for individual properties.

The Springfield-Sangamon County Regional Planning Commission

Room 212
200 South 9th Street
Springfield, Illinois 62701

Phone: 217.535.3110
Fax: 217.535.3110
Email:
sscrpc@co.sangamon.il.us

www.sscrpc.com

Effect of Wind Farms on Property Values

A Brief Review of the Literature

The potential development of large-scale wind farms in Sangamon County has raised questions concerning their potential effect on local property values. This is not unimportant in that property often represents a family's largest investment.

Opponents of wind farms have pointed to such factors as changes in the income-earning potential of the property, aesthetic appearance of the turbines, and noise, as potentially reducing the value of surrounding properties. Proponents have argued that these factors are mitigated or eliminated by regulations that establish setback, aesthetic and noise requirements for wind farms, and that there is no objective empirical research that shows that wind farms negatively affect the value of surrounding property. They contend that under certain circumstances wind farms may even increase land value.

This report provides a brief review of some of the most often cited literature concerning the effect of wind farms on local property values as well as more recent studies. In conducting the research for this paper the SSCRPC focused on empirical research that had been subjected to scholarly review or provided enough information that scholarly review would be possible. We found that while there was a good deal of material prepared by both opponents and proponents of wind farms (and many of the studies noted below are cited by both to advance their arguments), there was not much independent analysis and a tendency toward qualitative (e.g., anecdotal, case-based) and opinion survey-based studies, rather than quantitative (e.g., land transaction-based) research. We believe that this is largely because the subject is a rather new one and the scholarly community simply has not caught up with it.

We also found that while some research had been done, it was often conducted on properties in Europe. This should not be surprising in that wind energy systems appear to have more quickly grown in use in some parts of Europe than in the U.S. We also found that a portion of the research is drawn from studies of high voltage transmission lines (see Hoen, 2006, pp. 11-16, for examples) not upon wind farms, which may lead to different results.

The research would indicate that this is a difficult question to answer because property values are affected by many variables outside of the presence or absence of a wind farm. Additionally wind farms are typically located in sparse rural communities with few property sales transactions for comparison. This leaves any study open to methodological challenge, even if that challenge is specious. However, we conclude that there is no compelling research indicating that proximity to wind farms results in a decline in property values that is of significant magnitude or lasting.

The Studies Reviewed

As Hoen points out in his review of the literature surrounding the effect of wind farms on property values (pp. iii-iv, and 6-18), the literature is rather limited, often contradictory, and sometimes poorly constructed. Hinman (2010, pp. 15-19), for example, provides a list of 98 localized analyses of wind farms in relationship to property values, finding that 61 (62.3%) found no relationship between proximity to a wind farm and property values, 27 (27.6%) found a positive relationship, and 10 (10.2%) found a negative relationship. These 98 studies are of mixed empirical value, but include cases from one turbine to over 3,500, done from 1994 to 2009, and involving as little as one property to as many as 9,000.

One of the oldest and most quoted studies of the effect of wind farms on land values was conducted by the Renewable Energy Policy Project (REPP) under federal agency sponsorship (Sterzinger, et al., 2003). Noting that no systematic review of the impact on property values had been done at the time the study was undertaken, the authors looked at 10 existing wind farm projects under three different cases. The study found no support for the contention that wind farm development would harm property values:

> If property values had been harmed by being within the view-shed of major wind developments, then we expected that to be shown in a majority of the projects analyzed. Instead, to the contrary, we found that for the great majority of projects the property values actually rose more quickly in the view shed than they did in the comparable community. Moreover, values increased faster in the view shed after the projects came on-line than they did before. Finally, after projects came on-line, values increased faster in the view shed than they did in the comparable community. In all, we analyzed ten projects in three cases; we looked at thirty individual analyses and found that in twenty-six of those, property values in the affected view shed performed better than the alternative. (Sterzinger, et al, p.2).

While objections to the REPP report have been raised on methodological grounds (see Energy Center of Wisconsin, 2004, Part 3, pp. 119-137; Hoen, 2006, pp. 16-18), other studies have come to the same conclusion regarding the effect of the view shed on property values.

Since the areas in which wind farms are typically located are rural ones, our attention was drawn to a study (Pedden, 2006) by the National Renewable Energy Laboratory (NREL). NREL is a laboratory of the US Department of Energy operated by Battelle's Midwest Research Institute. This study compiled completed studies on the economic impact of wind farms in rural communities and then compared them. While the majority of the studies considered dealt with the larger economic effects of wind farms, one study specifically addressed property values by considering whether or not views of wind turbines negatively affected property values. This study (ECONorthwest, 2002) focused on the Kittitas County, WA, wind farms and estimated the effects of the increase in jobs and local spending on property values, the local economy, and tax revenues. The study found that views of wind turbines would not negatively impact property values. This conclusion was repeated in a 2006 update of that study funded by the State of Washington's Office of Trade and Economic Development and the Energy Foundation. It noted:

> Based on a nation-wide survey conducted of tax assessors in other areas with wind power projects, we find no evidence supporting the claim that views of wind farms decrease property values. (ECONorthwest, 2006, p. 1).

Other studies of individual wind farm locations have shown similar results. A study of a site in Franklin County, New York, was conducted to determine if various factors associated with wind farms would affect local property values (Lloyd, 2007). The primary conditions specific to wind farms that might affect surrounding property values were seen as the view shed, noise and shadow flicker from the turbine blades. Three wind farms in New York State, each of which had been in operation for over five years, were considered in the analysis, and the effect of each was considered separately. The study found:

> ...no influence on property values since the construction and operation of the wind farm. Average sales prices on a whole have increased indicating that the existence of the wind farm has not diminished real property values in this sub market. Additionally, the subject target area has appreciated at a similar rate as the remaining county ... [and] [i]n conclusion it appears that the existence of the wind farm does not appear to have any impact on surrounding property values as a whole. (Lloyd, pp. 19, 23, 30, 32).

An additional study of an existing site was conducted in Madison County, NY, in 2006 (Hoen). This study considered the adverse effects of wind farm visibility on surrounding property values. It analyzed 280 arms-length single-family residential sales that took place from 1996-2005 within five miles of a wind farm in Madison County. The analysis found no measurable effect of wind farm visibility on property transaction values, even for properties concentrated within one mile of the wind farm and those that sold immediately following the announcement and construction of the wind farm (Hoen, 2006, pp. 34-37).

This result is consistent with other recent studies. Sims and Dent (2007) studied 919 home transactions within five miles of two wind farms in the United Kingdom, finding that the limited evidence of a relationship between proximity to a wind farm and sales prices was due to other causes. A subsequent study (Sims et al., 2008) of 199 residential transactions within a quarter mile of a wind facility in Cornwall, UK, found no relationship between the number of wind turbines and sales prices.

Although conducted for a wind energy company, two studies by Poletti (2005; 2007) are instructive because they attempted to provide a comparison between target groups of homes and control groups using a *t*-Test. These studies compared the mean sales prices of 187 and 256 homes in Illinois and Wisconsin located near wind facilities with those further away, finding no statistical evidence that homes near wind farms sold for different prices than those further away.

The 2006 study by Hoen was ultimately expanded upon by Hoen and others under the auspices of the U.S. Department of Energy's Office or Energy Efficiency and Renewable Energy (Hoen et al., 2009). This study may be the most comprehensive and data-rich study of this subject to date[1], as it collected data on nearly 7,500 sales of single family homes situated within 10 miles of 24 existing wind farms in nine different states. It used eight different hedonic pricing models (used by economists and real estate professionals to assess the impacts of house and community characteristics on property values by investigating the sales

[1] Following dissemination of the Jan. 2010 update to this paper, it was brought to our attention that the Hoen et al. study was negatively critiqued in an unpublished paper by Wilson (2010) available on Mr. Wilson's website. Many of the issues noted by Wilson appear identical to those posed earlier by the Industrial Wind Action Group (IWAG), of which the SSCRPC was already aware. These IWAG criticisms were addressed by Wiser et al. in a 2009 paper. We would refer the reader to these papers for a complete consideration of the methodological issues discussed, and provide this footnote for informational purposes.

prices of homes; see Hoen et al., pp. 4-6) as well as repeat and sales volume models in assessing possible wind farm impacts on property values. The study considered what the researchers termed "Area Stigma" (the concern that the general area surrounding a wind energy facility would appear more developed, which might adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines), "Scenic Stigma" (the concern that a home may be devalued because of the view of a wind energy facility, and the potential impact of that view on an otherwise scenic vista), and "Nuisance Stigma" (the concern that factors that may occur in close proximity to wind turbines, such as sound and shadow flicker, will have a unique adverse influence on home values) (Hoen et al., p. 2).

The study concluded that:

> ...none of the models uncovers conclusive evidence of the existence of any widespread property value impacts that might be present in communities surrounding wind energy facilities. Specifically, neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices. Although the analysis cannot dismiss the possibility that individual homes or small numbers of homes have been or could be negatively impacted, it finds that if these impacts do exist, they are either too small and/or too infrequent to result in any widespread, statistically observable impact. (Hoen et al., p. iii).

More recently, Hinman (2010) conducted a study specific to Central Illinois. This study examined whether or not proximity to Phases I and II of the 240-turbine Twin Groves wind farm in eastern McLean County, IL, had an impact on neighboring property values and whether property values changed over different stages of wind farm development. This analysis is considered particularly instructive due to: the similarities between McLean and Sangamon counties; it considered property values prior to project announcement through to operation; addressed property transactions in much closer proximity to the wind farm than did the study by Hoen et al.; and used a pooled hedonic regression analysis that improved upon the method used by Hoen et al. in the study discussed above.

The Hinman study considered 3,851 residential property transactions in McLean and Ford counties that occurred from Jan. 1, 2001, through Dec. 1, 2009, comparing property transactions within one mile of the wind farm to those outside of this area. The results did indicate a "location effect", but a transient one. Hinman provides this summary of her results:

> The results demonstrate that before Twin Groves I and II were even approved by the McLean County Board, properties near the eventual wind farm site were valued less on average than properties located further away from the eventual wind farm site, and these results are statistically significant across all estimations. Thus, a *location effect* exists such that the wind farm happened to locate in an area that already exhibited depressed property values in comparison to other areas within parts of McLean and Ford Counties...
>
> Some of the estimation results support the existence of *wind farm anticipation stigma theory*, meaning that property values may have diminished due to the uncertainty surrounding a wind farm project regarding the aesthetic impacts on the landscape, the actual noise impacts from the wind turbines, and just how disruptive the wind farm will actually be.
>
> However, the results demonstrate that in comparison to properties in many of the surrounding areas in McLean and Ford Counties, properties in close proximity to Twin Groves I and II (*Near Wind Farm*) experienced higher appreciation rates, in addition to,

> higher property value levels (in percentage terms) after the wind farm achieved commercial operations (*Wind Farm Operation*), Thus, during the operational stage of the wind farm project, as surrounding property owners living close to the wind turbines acquired additional information on the aesthetic impacts on the landscape and actual noise impacts of the wind turbines to see if any of their concerns materialized, property values rebounded and soared higher in real terms than they were prior to wind farm approval. (Hinman, p. 83; italics in the original.)

In other words, to the extent that Hinman found a reduction in property values near the wind farm, this reduction appeared to be the result of property owners *anticipating* negative impacts, not the *result* of any negative impacts. Once the anticipated negative impacts were unrealized, values rebounded and property values increased in real terms. We interpret this as the nearby property owners perceiving an increased risk to their property, leading to early on – prior to wind farm completion – disposal of the property at less than its real longer-term value, depressing value on the near term.

Hinman appears to agree with this interpretation, as she sees her results as providing evidence of a "transfer of welfare" between early sellers and buyers, similar to that found by Kiel and McClain in their study of incinerator siting. They write, "if a house was sold during a phase when fears of the facility depressed prices, the seller would suffer a capital loss. If those fears are later unrealized and prices rebound, that loss becomes the buyer's gain" (1995, p. 242). This appears to be the case found in the McLean County study, and will be mentioned again below.

While the studies cited above primarily deal with the effect on the value of properties in the vicinity of a wind farm, a study conducted by Northwest Economic Associates (2003) addressed land values for farmland involved in the project. This project was based upon the study of wind farms in three areas: Lincoln County, MN; Morrow and Umatilla counties, OR; and Culberson County, TX. Two findings from this study are pertinent. First, in looking at the overall impact of the projects to the areas, the study found that:

> While there were differences between the study areas in the mix of annual leases and permanent easements and the size and type of payment, ***the annual revenue received by households in the areas was a significant source of household income and had a significant total effect on the economies.*** In all cases, the cost of foregone opportunities from farming and livestock grazing was small compared to the revenues obtained. (Northwest Economic Associates, 2003, p. 43: Emphasis in the original.)

Second, the study found that the form of the payment had an influence on land values:

> Payments from easements and leases on farmland for the wind power site are an important source of income. How this affects farmland values depends to a large extent on the terms of the contract entered into. If the contracted payment were a one-time lump sum payment, all of the benefit would accrue directly to the landowner at the time of the payment, and there would be no long term income stream associated with the contract. Under these conditions, it would not be expected that land values would be affected. If the contractual arrangement resulted in a potential future income stream, such as a lease payment based on a share of power revenues, and this income stream went to the owner at the time each payment was made, rather than the owner at the time the contract was made, then it would be expected that this future income stream would be capitalized into the value of the farmland. (Northwest Economic Associates, p. 46.)

This would indicate that the revenue generated by the wind farm would offset any value loss should it occur. It might also provide a reason as to why property values do not decline in areas around wind farms regardless of visual and other impacts. To the extent that wind farms generate additional economic benefits in an area (see Pedden, 2006, for examples of studies that came to this conclusion), this new income would accrue to residents of the area in various ways, "rolling over" in the local economy and potentially leading to property improvements or new construction as incomes increased, ultimately increasing surrounding property values. Additionally this new revenue would accrue to the various taxing bodies, potentially reducing future tax demands and diversifying the tax base. This also could lead to increased property values. The end result may be to "disguise" any small or infrequent losses of the type the Hoen team considered possible.

Hinman (2010, p. 84) comes to a supportive conclusion in her study of the McLean wind farm, pointing out that two of the reasons why she believed property values rose post wind farm development were: a decline in property tax rate because of the new revenue steam that the wind farm generated in local property taxes; and the increase in tax revenue to the school districts generated by the wind farm increasing the attractiveness of the areas for families. This second reason may however be unique to the area studied since she reports it was experiencing a decline in residents in the surrounding area prior to wind farm development.

We also wish to note that there have been studies conducted outside of the United States that would appear to reach the same conclusions as those above: little or no impact on property values. Since these are not based upon the US property market, Americans may have less familiarity with wind farms than some Europeans, and many are based on surveys rather than land transactions, they may not be as valid to the local situation as those mentioned above that studied wind farms in the United States. Examples of these studies include:

- Research by the Danish Institute of Local Government Studies found that the economic expenses in connection with noise and visual effects from the turbines are minimal. It did find a small effect on house prices, but not at a level of statistical significance (Jordal-Jørgensen, 1996).
- A study of the Novar wind farm in Scotland in which a survey found 72% of property owners saying it did not decrease house prices and 26% saying they did not know. One percent noted an increase in property value (Robert Bell Associates, 1988).
- A study of the Nympsfield, Gloucestershire (UK), project that found house prices gained after plans for the turbine were announced and continued to increase after operations began. (British Wind Energy Association, 1998).

Some researchers have found that proximity to wind farms did affect property values, and as mentioned previously, Hinman identified 10 such studies in the 98 she reviewed. However only three of these 10 studies involved before and after wind farm land transaction analysis (Kielisch, 2009; Sterzinger et al., 2003), and two of those considered vacant residential land sales (Kielisch, 2009). Other studies identified and reviewed by the SSCRPC tend to be based upon small sample sizes, provide no statistical test, and most often do not report statistical significance.

For example, McCann (2008) found that two homes near a wind facility in Lee County, IL, had lengthy selling times that he contends adversely affected selling prices. Kielisch (2009) compared 12 transactions involving undeveloped land near two wind facilities in Wisconsin and found that they sold for lower prices per acre than undeveloped property further away, but unfortunately did not report statistical significance. Both of these studies were prepared for wind farm opponents.

While the studies provided above (and 61 of the 98 studies reviewed by Hinman) indicate little or no impact on surrounding land values, the study most often cited to provide a contradictory finding comes from an analysis of a wind farm proposed for Nantucket Sound (Haughton, et al., 2004). This study provided a cost-benefit analysis of the proposed project and came to the conclusion that the wind farm would have a significant effect on property values in the area. However that conclusion was not based on actual property transactions but upon a survey of 501 home owners on Cape Cod and Martha's Vineyard, as well as a survey of 45 Cape Code realtors (Haughton, et al., p. 8). Based upon the belief that the wind farm would worsen the view of Nantucket Sound:

> On average, homeowners believe that the wind farm would reduce property values by 4.0% (and among these, households with waterfront property believe that the loss would be 10.9%). When these numbers are grossed up to represent the six towns likely to be impacted by the wind farm, the total loss in property value would be over $1.3 billion. As a result, the six towns stand to lose $8.0 million in property tax revenue (Haughton, et al, p. 8).

Hoen provides a critical analysis of this and similar survey studies (Hoen, 2006, pp. 6-11; see also Hoen et al., 2009, pp. 7-8), questioning their validity. Ultimately their usefulness in answering the question of wind farm effect on land values is dependent upon how accurate one thinks a group of homeowners and realtors might be in predicting future land values with and without the presence of wind farms. Overall it appears to us that studies based upon actual land transactions pre- and post-wind farm are more valid.

Of the 98 studies listed by Hinman (pp. 15-19), only 44 (44.9%) involved analyses of property values "before and after" wind farm construction. Of these 44 studies, 21 (47.7%) found no effect on property values, 3 (6.8%) found a negative effect, and 20 (45.5%) found a positive effect. These results should not be taken as indicative of a complete answer to the question of wind farm effect on property values for too many reasons to adequately list here. For example, Hinman notes (p. 19) that a "positive" or "negative" result does not necessarily imply that an increase or decrease in property values was due to the wind farm as property values could have changed for other reasons. It may also indicate that the period under study could affect the findings. For example, of the 10 studies showing a negative effect on property values, half did not compare post-wind farm land values to pre-wind farm values.

While a meta-analysis of these studies might help to resolve this question, and it appears to us that enough studies may have been conducted for such an analysis to be possible, at the present time we can only conclude that the results indicate a trend in the research findings.

Proximity and Property Values

Critics of studies such as the Lawrence Berkley National Laboratory one (Hoen et al, 2009), contend that these studies under-estimate the true impact of wind farms on property values either because they include properties too far from the turbines (which we will call *lack of sample proximity*) or are tainted by properties included in the project that may be reaping some financial benefit from it (*effect of project economic 'spillover'*)[2]. In the first case the contention is that if only the properties closest to the wind farm were considered, a larger, negative impact would be found. In the second case the contention is that if properties receiving benefits from a project were excluded from the results, a larger, negative impact would be found. Addressing these issues is not inappropriate and is important, but may also be methodologically problematic.

Related to the first issue (lack of proximity), as several studies point out, wind farms are often sited in rural or undeveloped areas where there are simply not enough arms length residential property transactions to generate a sample size large enough for sound statistical analysis. Should an analysis be done with a small sample, it is likely that no results would be statistically significant even if some effect would be found if the sample were larger. Only by enlarging the area or including multiple different areas could the number of transactions be enlarged to allow valid analysis.

Moreover, while there may be a sufficient number of transactions in a larger area to allow for some valid area-wide results, this would not mean that subsections of that area would have sufficient transactions to allow for proper statistical analysis. For example, simply because there are sufficient property transactions within a three-mile radius of a wind farm to provide an adequate number, does not mean that there would be a sufficient number within a quarter mile, between a quarter mile and a half mile, and so forth. Each "cell" or subset subject to the analysis would have to have a sufficient number.

In terms of economic spillover, we believe that this criticism asks the researcher to address the quandary of studying property transactions close enough to the wind farm to deal with proximity effect, but not too close, so as to avoid spillover. Extracting these properties from the analysis seems incongruent with the ultimate question the research is meant to address: what is the effect of wind farms on property values? It seems to us important to come to terms with this question both for properties that may be harmed (if any) as well as those that might benefit (if any). If the presence of a wind farm *does* result in some direct economic reward or spillover to surrounding properties because the property owners are receiving project benefits, these should be consider in assessing any property value effects.

In any event, recent work presented by Hoen (2010) using data from the 2009 Lawrence Berkley National Laboratory study might be somewhat instructive as to the effect that distance to wind farms has on property values. Readers should be aware that the following information is drawn from the 2009 study as presented at the Feb. 27, 2010, Illinois Wind Working Group Conference and, as far as the SSCRPC is aware, does not represent new research.

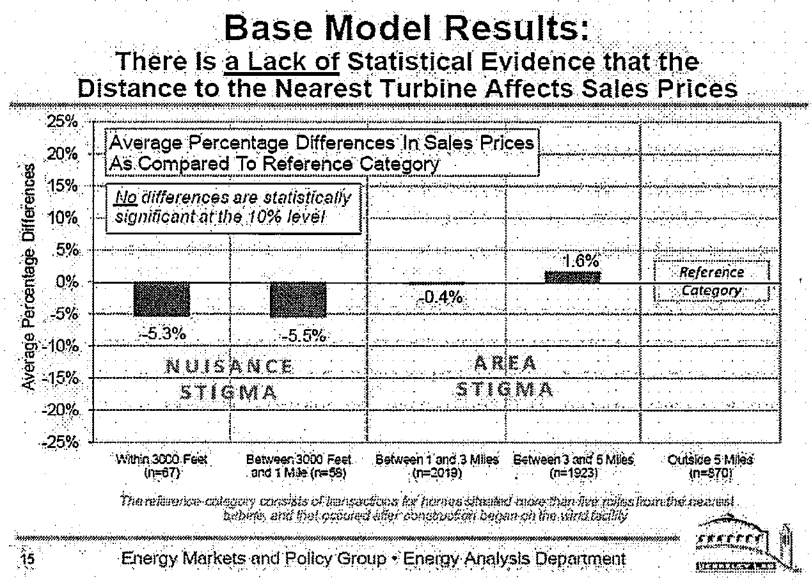
As previously mentioned, the Hoen et al. 2009 study considered three "stigmas" related to wind farms that could affect surrounding property values: *scenic vista*, *nuisance*, and *area* stigmas. Nuisance stigma may be the most relevant to the consideration of proximity because nuisance stigma is intended to address the concern that factors that may occur in close proximity to wind turbines (such as sound and shadow flicker) will have a unique adverse influence on home values, and because a sufficient number of cases was presented for nuisance stigma to get some feel for the influence of closer proximity

[2] This is reflected, for example, in the response to a study of property values conducted by the zoning administrator in Lincoln Township, WI, for the Lincoln Wind Turbine Moratorium Study Committee (Sagrillo, et al., 2000). For a complete review of this case see Energy Center of Wisconsin, 2004.

Chart 1, below, shows the results, as presented by Hoen, related to both nuisance and area stigmas. Since nuisance stigma was considered as having a more proximate effect, analysis was done for properties within 3000 feet of the nearest turbine and between 3000 feet and one mile of the nearest turbine. Please note that the number of cases for both distances is roughly comparable. While 3000 feet is more than twice the requirement currently in the Sangamon County zoning ordinance for setback from properties not participating in the project, we believe that it is still informative.

The data indicates that to the extent that nuisance stigma might exert an effect, the effect is similar (-5.3% and -5.5%) for both distances. This might lead one to conclude that there is a slight negative effect, but that it does not appear to vary much by distance (or at least for the distances assessed). However, these results were not even statistically significant at the 10% level, meaning that we cannot reach such a conclusion. Most often results are considered significant at 3% to 5% depending upon the research question. Because of this level of significance, we cannot say that proximity has an effect on property values as the results indicated may simply be due to chance.

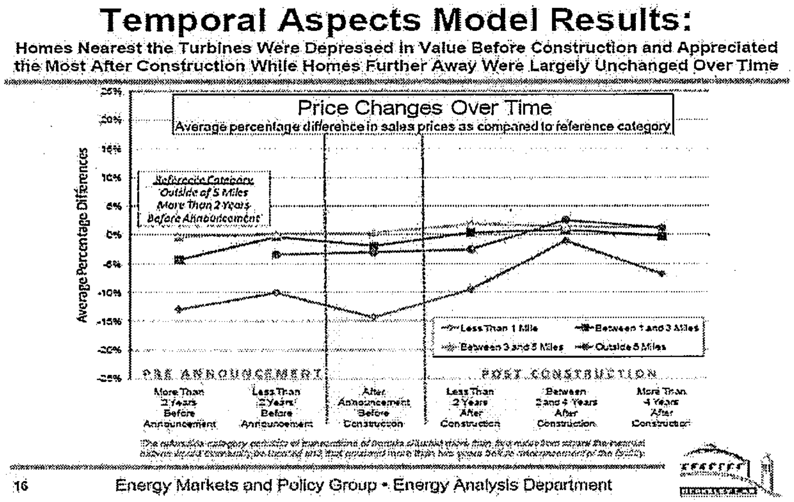
Chart 1



Also informative is Chart 2, below. This chart displays the price change over time of homes based on distance. While the data does not present us with distances nearer than a mile, it indicates several things of note.

The first is that homes closest to a turbine (within less than a mile) tended to be of less value than properties further away at the outset, prior to wind farm project announcement (more than 2 years before). This finding by Hoen is consistent with the results found by Hinman in her study of the effect of wind farming on property values in McLean County, IL, discussed above. She found that prior to governmental actions to approve the wind farm, properties already exhibited depressed values when compared to other areas, a result further supported by evidence of a declining population and number of housing units, which the area had been experiencing for a number of years (p. 83).

Chart 2



We suspect that this is because wind farms are most often sited in the most rural and undeveloped areas where residential property values are less than in more urban, developed areas. This might be supported by Hoen's finding that more than 2 years prior to the announcement, properties between 1 and 3 miles were valued higher than those within less than 1 mile, and properties between 3 and 5 miles were valued higher than those between 1 and 3 miles. Only those outside of 5 miles had a slightly lower initial value prior to announcement, and these properties still were valued at higher levels than those less than 1 mile from the nearest turbine.[3]

The change in value over time of the homes nearest the turbines is noticeable. Pre-announcement the value of these homes appears to track with the other homes if the initial, lower value is taken into account and adjusted to be more comparable with homes further away. It falls after the project announcement and before construction, but begins to rebound following construction. Again, this is consistent with the results of the Hinman study noted perviously.

It seems intuitive that if the construction of a wind farm has a significant effect on property values, one would expect a continuing decline of property value for the homes closest to the turbines, but this is not the case. Even the decline in value 4 years after construction appears to track with small declines in at least two of the other three categories, although the magnitude appears greater. What then might be happening?

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[3] We suspect that overlapping setback and other regulatory requirements may also lead to this finding as they may push the location of turbines toward more marginal properties that do not include residential structures. Further research would be needed to determine if this speculation is correct.

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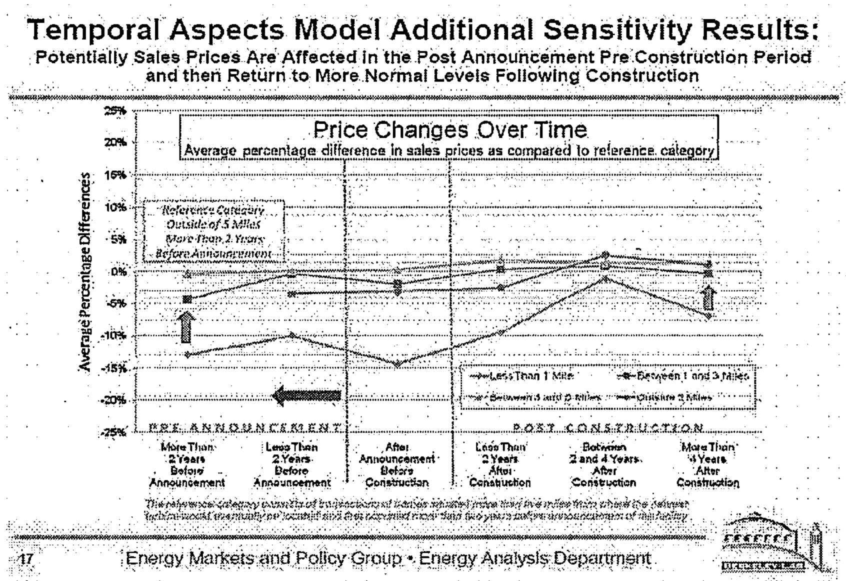
We believe that this result is consistent with the findings from the opinion survey-based research that even if proximity to wind farms does not generate a statistically significant change in residential property values, people believe it will, leading to a self-fulfilling outcome. Public concerns about wind farm proximity may depress property values for properties closest to the turbines for a period of time, with these values rebounding following construction as referenced in Hoen's Chart 3, below. The extent to which they rebound is still open to conjecture, though the Hinman study provides more information in this regard than we had previously. [4]

Chart 3



This leads to the Berkeley Lab team's conclusion pertaining to nuisance stigma that "homes in the sample that are within a mile of the nearest wind facility, where various nuisance effects have been posited, were not found to have been significantly affected by the presence of those wind facilities" (Hoen, 2010), but:

> This is not to say that effects do not exist though; there is not reason to assume that they do not. But rather, if they do exist in our sample, they are either too small and/or too infrequent to result in any statistically observable effect. Further, where they do exist they are likely to do so immediately following the announcement and in close proximity. (Hoen, 2010).

Based upon the results found by both Hoen and Hinman, we believe that Hinman's conjecture of a "wind farm anticipation stigma" is correct. Upon anticipation of a wind farm project, those concerned about the effect of the project on surrounding properties perceive a risk to their property and respond by disposing of them – when and if they can – resulting in a reduction in

[4] It may also be due to the fewer arms length residential transactions closer to a wind farm. If there are fewer transactions, a large decline in only a few properties could affect the average and overstate the trend.

property value in what is already a rather limited market due to the mostly rural nature of the areas in which wind farms locate. Similarly, those considering the purchase of property in areas adjacent to the wind farm are hesitant to do so because of the concerns voiced, further depressing property values. However, following experience with the project once it becomes operational, fears are reduced as the realities associated with it are then better known and the perception of risk is reduced if not eliminated. This results in a rebounding of property values as the area is no longer stigmatized.

This may also explain why studies of impact in Europe may result in different outcomes than in the US: since Europeans have more experience with the proximate effects of wind farms than do Americans, they perceive less initial risk.

The wind farm anticipation stigma relates to the perception of risk, and Hinman quotes Slovic et al. (1987, p. 281) in this regard:

> Research further indicates that disagreements about risk should not be expected to evaporate in the presence of evidence. Strong initial views are resistant to change because they influence the way that subsequent information is interpreted. New evidence appears reliable and informative if it is consistent with one's initial beliefs; contrary evidence tends to be dismissed as unreliable, erroneous, or unrepresentative.

Summary

Based upon the research mentioned above, we continue to agree with the National Association of Realtors who report in their *Field Guide to Wind Farms and their Effect on Property Values*, "Although the research remains scant, wind farms appear to have a minimal or at most transitory impact on property values" (National Association of Realtors, 2009).

In our brief review we were unable to find compelling research, particularly research based upon actual arms-length, pre- and post-wind farm property transactions, that proximity to a wind farm results in a decline in property values. The trend in the research using pre- and post-transaction data appears to indicate minimal if any effect, and the recent work by Hinman is representative of this trend.

As Hoen et al. report in their 2009 study, after reviewing the literature:

> When this literature is looked at as a whole, it appears as if wind projects have been predicted to negatively impact residential property values when pre-construction surveys are conducted, but that sizable, widespread and statistically significant negative impacts have largely failed to materialize post construction when actual transaction data become available for analysis. The studies that have investigated Area Stigma with market data have failed to uncover any pervasive effect. Of the studies focused on Scenic Vista and Nuisance Stigmas, only one is known to have found statistically significant adverse effects, yet the authors contend that those effects are likely driven by variables omitted from their analysis (Sims and Dent, 2007). Other studies that have relied on market data have sometimes found the possibility of negative effects, but the statistical significance of those results have rarely been reported. (p. 8).

Clearly there is evidence that people believe that a wind farm will affect their property's value, as the Haughton study, referenced above, indicates, and this has come up during the siting of wind farms in other central Illinois jurisdictions (see, for example, Niziolkiewics, 2008). This belief may even lead to a self-fulfilling result, and Hinman's work appears to at least partially confirm this.

But the trend we found in the literature studied seems to indicate otherwise. While there does appear to be evidence from both Hoen and Hinman indicating that a wind farm anticipation stigma may negatively affect property values during the early stages of a wind farm project, the evidence also indicates that this stigma is relatively short-lived, being mitigated over time as property owners become more aware of the real effect of the project on the surrounding area.

There is also some indication that wind farm projects may slightly increase the value of properties, especially those that become part of the project, depending upon the extent of its larger economic impact and the form of the payment provided to property owners. Indeed these larger economic impacts may positively affect property values indirectly through their stimulative effect and the diversification of the local tax base, potentially disguising any localized value loss due to roll-over of financial gains in the local economy.

This report and update prepared by E. Norman Sims, SSCRPC, Executive Director

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The Springfield-Sangamon County Regional Planning Commission (SCRPC) serves as the joint planning body for Sangamon County and the City of Springfield, as well as the Metropolitan Planning Organization for transportation planning in the region.

The Commission has 17 members including representatives from the Sangamon County Board, Springfield City Council, special units of government, and six appointed citizens from the city and county. The Executive Director is appointed by the Executive Board of the Commission and confirmed by the Sangamon County Board.

The Commission works with other public and semi-public agencies throughout the area to promote orderly growth and redevelopment, and assists other Sangamon County communities with their planning needs. Through its professional staff, the SSCRPC provides overall planning services related to land use, housing, recreation, transportation, economics, environment, and special projects. It also houses the Sangamon County Department of Zoning which oversees the zoning code and liquor licensing for the County.

The Commission prepares area-wide planning documents and assists the County, cities, and villages, as well as special districts, with planning activities. The staff reviews all proposed subdivisions and makes recommendations on all Springfield and Sangamon County zoning and variance requests. The agency serves as the county's Plat Officer, Floodplain Administrator, Census coordinator, and local A-95 review clearinghouse to process and review all federally funded applications for the county. The agency also maintains existing base maps, census tract maps, township and zoning maps and the road name map for the county.

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The Effect of Wind Development on Local Property Values

REPP

Renewable Energy Policy Project

George Sterzinger
Fredric Beck
Damian Kostiuk

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Authors

George Sterzinger, REPP Executive Director
gsterzinger@repp.org

Fredric Beck, REPP Research Manager
fbeck@repp.org

Damian Kostiuk, REPP Research & Communications Specialist
dkostiuk@repp.org

All authors can be reached at REPP's offices: (202) 293-2898

Notice

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Renewable Energy Policy Project
1612 K Street, NW, Suite 202
Washington, D.C. 20006
Tel: (202) 293-2898
Fax: (202) 293-5857
www.repp.org

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Chapter I. Project Overview

The Claim Against Wind Development

Wind energy is the fastest growing domestic energy resource. Between 1998 and 2002 installed capacity grew from 1848 MW to 4685 MW, a compound growth rate of 26 percent. Since wind energy is now broadly competitive with many traditional generation resources, there is wide expectation that the growth rate of the past five years will continue. (Source for statistics: www.awea.org).

As the pace of wind project development has increased, opponents have raised claims in the media and at siting hearings that wind development will lower the value of property within view of the turbines. This is a serious charge that deserves to be seriously examined.

No Existing Empirical Support

As a result of the expansion of capacity from 1998 to 2002, it is reasonable to expect any negative effect would be revealed in an analysis of how already existing projects have affected property values. A search for either European or United States studies on the effect of wind development on property values revealed that no systematic review has as yet been undertaken.

As noted above, the pace of development and siting hearings is likely to continue, which makes it important to do systematic research in order to establish whether there is any basis for the claims about harm to property values. (For recent press accounts of opposition claims see: The Charleston Gazette, WV, March 30, 2003; and Copley News Service. Ottawa, IL, April 11, 2003).

This REPP Analytical Report reviews data on property sales in the vicinity of wind projects and uses statistical analysis to determine whether and the extent to which the presence of a wind power project has had an influence on the prices at which properties have been sold. The hypothesis underlying this analysis is that if wind development can reasonably be claimed to hurt property values, then a careful review of the sales data should show a negative effect on property values within the viewshed of the projects.

A Serious Charge Seriously Examined

The first step in this analysis required assembling a database covering every wind development that came on-line after 1998 with 10 MW installed capacity or greater. (Note: For this Report we cut off projects that came on-line after 2001 because they would have insufficient data at this time to allow a reasonable analysis. These projects can be added in future Reports, however.) For the purposes of this analysis, the wind developments were considered to have a visual impact for the area within five miles of the turbines. The five mile threshold was selected because review of the literature and field experience suggests that although wind turbines may be visible beyond five miles, beyond this distance, they do not tend to be highly noticeable, and they have relatively little influence on the landscape's overall character and quality. For a time period covering roughly six years and straddling the on-line date of the projects, we gathered the records for all property sales for the view shed and for a community comparable to the view shed.

For all projects for which we could find sufficient data, we then conducted a statistical analysis to determine how property values changed over time in the view shed and in the comparable community. This database contained more than 25,000 records of property sales within the view shed and the selected comparable communities.

Three Case Examinations

REPP looked at price changes for each of the ten projects in three ways: Case 1 looked at the changes in the view shed and comparable community for the entire period of the study; Case 2 looked at how property values changed in the view shed before and after the project came on-line; and Case 3 looked at how property values changed in the view shed and comparable community after the project came on-line.

Case 1 looked first at how prices changed over the entire period of study for the view shed and comparable region. Where possible, we tried to collect data for three years preceding and three years following the on-line date of the project. For the ten projects analyzed, property values increased faster in the view shed in eight of the ten projects. In the two projects where the view shed values increased slower than for the comparable community, special circumstances make the results questionable. Kern County, California is a site that has had wind development since 1981. Because of the existence of the old wind machines, the site does not provide a look at how the new wind turbines will affect property values. For Fayette County, Pennsylvania the statistical explanation was very poor. For the view shed the statistical analysis could explain only 2 percent of the total change in prices.

Case 2 compared how prices changed in the view shed before and after the projects came on-line. For the ten projects analyzed, in nine of the ten cases the property values increased faster after the project came on line than they did before. The only project to have slower property value growth after the on-line date was Kewaunee County, Wisconsin. Since Case 2 looks only at the view shed, it is possible that external factors drove up prices faster after the on-line date and that analysis is therefore picking up a factor other than the wind development.

Finally, **Case 3** looked at how prices changed for both the view shed and the comparable region, but only for the period after the projects came on-line. Once again, for nine of the ten projects analyzed, the property values increased faster in the view shed than they did for the comparable community. The only project to see faster property value increases in the comparable community was Kern County, California. The same caution applied to Case 1 is necessary in interpreting these results.

If property values had been harmed by being within the view-shed of major wind developments, then we expected that to be shown in a majority of the projects analyzed. Instead, to the contrary, we found that for the great majority of projects the property values actually rose more quickly in the view shed than they did in the comparable community. Moreover, values increased faster in the view shed after the projects came on-line than they did before. Finally, after projects came on-line, values increased faster in the view shed than they did in the comparable community. In all, we analyzed ten projects in three cases; we looked at thirty individual analyses and found that in twenty-six of those, property values in the affected view shed performed better than the alternative.

This study is an empirical review of the changes in property values over time and does not attempt to present a model to explain all the influences on property values. The analysis we conducted was done solely to determine whether the existing data could be interpreted as supporting the claim that wind development harms property values. It would be desirable in future studies to expand the variables incorporated into the analysis and to refine the view shed in order to look at the relationship between property values and the precise distance from development. However, the limitations imposed by gathering data for a consistent analysis of all major developments done post-1998 made those refinements impossible for this study. The statistical analysis of all property sales in the view shed and the comparable community done for this Report provides no evidence that wind development has harmed property values within the view shed. The results from one of the three Cases analyzed are summarized in Table 1 and Figure 1 below.

REGRESSION ANALYSIS

REPP used standard simple statistical regression analyses to determine how property values changed over time in the view shed and the comparable community. In very general terms, a regression analysis "fits" a linear relationship, a line, to the available database. The calculated line will have a slope, which in our analysis is the monthly change in average price for the area and time period studied. Once we gathered the data and conducted the regression analysis, we compared the slope of the line for the view shed with the slope of the line for the comparable community (or for the view shed before and after the wind project came on-line).

TABLE 1: SUMMARY OF STATISTICAL MODEL RESULTS FOR CASE 1

Project/On-Line Date	Monthly Average Price Change ($/month)	
	View Shed	Comparable
Riverside County, CA	$1,719.65	$814.17
Madison County, NY (Madison)	$576.22	$245.51
Carson County, TX	$620.47	$296.54
Kewaunee County, WI	$434.48	$118.18
Searsburg, VT	$536.41	$330.81
Madison County, NY (Fenner)	$368.47	$245.51
Somerset County, PA	$190.07	$100.06
Buena Vista County, IA	$401.86	$341.87
Kern County, CA	$492.38	$684.16
Fayette County, PA	$115.96	$479.20

While regression analysis gives the best fit for the data available, it is also important to consider how "good" (in a statistical sense) the fit of the line to the data is. The regression will predict values that can be compared to the actual or observed values. One way to measure how well the regression line fits the data calculates what percentage of the actual variation is explained by the predicted values. A high percentage number, over 70%, is generally a good fit. A low number, below 20%, means that very little of the actual variation is explained by the analysis. Because this initial study had to rely on a database constructed after the fact, lack of data points and high variation in the data that was gathered meant that the statistical fit was poor for several of the projects analyzed. If the calculated linear relationship does not give a good fit, then the results have to be looked at cautiously.

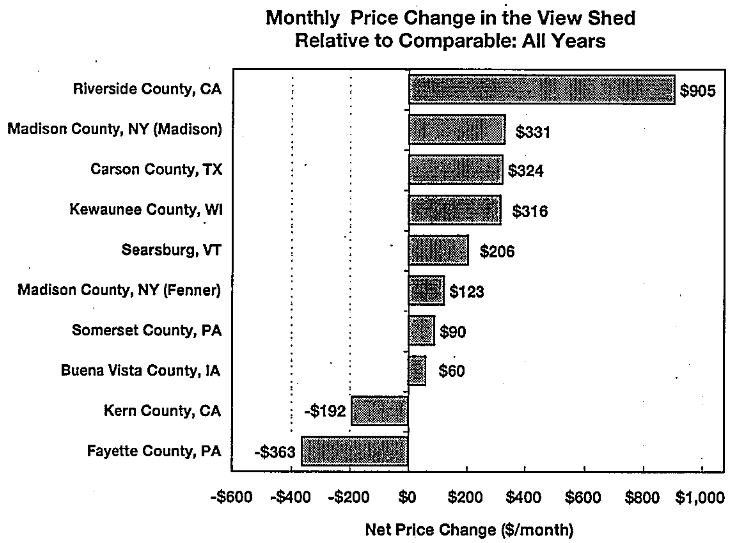

Figure 1: Monthly Price Change in the View Shed
Relative to Comparable: All Years

Case Result Details

Although there is some variation in the three Cases studied, the results point to the same conclusion: the statistical evidence does not support a contention that property values within the view shed of wind developments suffer or perform poorer than in a comparable region. For the great majority of projects in all three of the Cases studied, the property values in the view shed actually go up faster than values in the comparable region. Analytical results for all three cases are summarized in Table 2 below.

Table 2: Detailed Statistical Model Results

Location: Buena Vista County, IA
Project: Storm Lake I & II

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Oct 02 Jan 96 - Oct 02	$401.86 $341.87	0.67 0.72	The rate of change in average view shed sales price is 18% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - Apr 99 May 99 - Oct 02	$370.52 $631.12	0.51 0.53	The rate of change in average view shed sales price is 70% greater after the on-line date than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 99 - Oct 02 May 99 - Oct 02	$631.12 $234.84	0.53 0.23	The rate of change in average view shed sales price after the on-line date is 2.7 times greater than the rate of change of the comparable after the on-line date.

Location: Carson County, TX
Project: Llano Estacado

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 98 - Dec 02 Jan 98 - Dec 02	$620.47 $296.54	0.49 0.33	The rate of change in average view shed sales price is 2.1 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 98 - Oct 01 Nov 01 - Dec 02	$553.92 $1,879.76	0.24 0.83	The rate of change in average view shed sales price after the on-line date is 3.4 times greater than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	Nov 01 - Dec 02 Nov 01 - Dec 02	$1,879.76 -$140.14	0.83 0.02	The rate of change in average view shed sales price after the on-line date increased at 13.4 times the rate of decrease in the comparable after the on-line date.

Location: Fayette County, PA
Project: Mill Run

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Dec 97-Dec 02 Dec 97-Dec 02	$115.96 $479.20	0.02 0.24	The rate of change in average view shed sales price is 24% of the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Dec 97 - Nov 01 Oct 01-Dec 02	-$413.68 $1,562.79	0.19 0.32	The rate of change in average view shed sales price after the on-line date increased at 3.8 times the rate of decrease before the on-line date.
Case 3	View shed, after Comparable, after	Oct 01-Dec 02 Oct 01-Dec 02	$1,562.79 $115.86	0.32 0.00	The rate of change in average view shed sales price after the on-line date is 13.5 times greater than the rate of change of the comparable after the on-line date.

Location: Kern County, CA
Project: Pacific Crest, Cameron Ridge, Oak Creek Phase II

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Dec 02 Jan 96 - Dec 02	$492.38 $684.16	0.72 0.74	The rate of change in average view shed sales price is 28% less than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96-Feb 99 Mar 99 - Dec 02	$568.15 $786.60	0.44 0.75	The rate of change in average view shed sales price is 38% greater after the on-line date than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	Mar 99 - Dec 02 Mar 99 - Dec 02	$786.60 $1,115.10	0.75 0.95	The rate of change in average view shed sales price after the on-line date is 29% less than the rate of change of the comparable after the on-line date.

Location: Kewaunee County, WI
Project: Red River (Rosiere), Lincoln (Rosiere), Lincoln (Gregorville)

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Sep 02 Jan 96 - Sep 02	$434.48 $118.18	0.26 0.05	The rate of change in average view shed sales price is 3.7 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - May 99 Jun 99 - Sep 02	-$238.67 $840.03	0.02 0.32	The increase in average view shed sales price after the on-line date is 3.5 times the decrease in view shed sales price before the on-line date.
Case 3	View shed, after Comparable, after	Jun 99 - Sep 02 Jun 99 - Sep 02	$840.03 -$630.10	0.32 0.37	The average view shed sales price after the on-line date increases 33% quicker than the comparable sales price decreases after the on-line date.

Location: Madison County, NY
Project: Madison

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 97 - Jan 03 Jan 97 - Jan 03	$576.22 $245.51	0.29 0.34	The rate of change in average view shed sales price is 2.3 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 97 - Aug 00 Sep 00 - Jan 03	$129.32 $1,332.24	0.01 0.28	The rate of change in average view shed sales price after the on-line date is 10.3 times greater than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	Sep 00 - Jan 03 Sep 00 - Jan 03	$1,332.24 -$418.71	0.28 0.39	The rate of change in average view shed sales price after the on-line date increased at 3.2 times the rate of decrease in the comparable after the on-line date.

Location: Madison County, NY
Project: Fenner

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 97 - Jan 03 Jan 97 - Jan 03	$368.47 $245.51	0.35 0.34	The rate of change in average view shed sales price is 50% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 97 - Nov 01 Dec 01 - Jan 03	$587.95 -$418.98	0.50 0.04	The rate of decrease in average view shed sales price after the on-line date is 29% lower than the rate of sales price increase before the on-line date.
Case 3	View shed, after Comparable, after	Dec 01 - Jan 03 Dec 01 - Jan 03	-$418.98 -$663.38	0.04 0.63	The rate of decrease in average view shed sales price after the on-line date is 37% less than the rate of decrease of the comparable after the on-line date.

Location: Riverside County, CA
Project: Cabazon, Enron, Energy Unlimited, Mountain View Power Partners I & II, Westwind

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Nov 02 Jan 96 - Nov 02	$1,719.65 $814.17	0.92 0.81	The rate of change in average view shed sales price is 2.1 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - Apr 99 May 99 - Nov 02	$1,062.83 $1,978.88	0.68 0.81	The rate of change in average view shed sales price is 86% greater after the on-line date than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 99 - Nov 02 May 99 - Nov 02	$1,978.88 $1,212.14	0.81 0.74	The rate of change in average view shed sales price after the on-line date is 63% greater than the rate of change of the comparable after the on-line date.

Location: Bennington and Windham Counties, VT
Project: Searsburg

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 94 - Oct 02 Jan 94 - Oct 02	$536.41 $330.81	0.70 0.45	The rate of change in average view shed sales price is 62% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 94 - Jan 97 Feb 97 - Oct 02	-$301.52 $771.06	0.88 0.71	The rate of change in average view shed sales price after the on-line date increased at 2.6 times the rate of decrease before the on-line date.
Case 3	View shed, after Comparable, after	Feb 97 - Oct 02 Feb 97 - Oct 02	$771.06 $655.20	0.71 0.78	The rate of change in average view shed sales price after the on-line date is 18% greater than the rate of change of the comparable after the on-line date.

Location: Somerset County, PA
Project: Excelon, Green Mountain

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 97 - Oct 02 Jan 97 - Oct 02	$190.07 $100.06	0.30 0.07	The rate of change in average view shed sales price is 90% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 97 - Apr 00 May 00 - Oct 02	$277.99 $969.59	0.37 0.62	The rate of change in average view shed sales price after the on-line date is 3.5 times greater than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 00 - Oct 02 May 00 - Oct 02	$969.59 -$418.73	0.62 0.23	The rate of change in average view shed sales price after the on-line date increased at 2.3 times the rate of decrease in the comparable after the on-line date.

Each of the three Cases takes a different approach to evaluating the price changes in the view shed and comparable community. By finding consistent results in all three Cases, the different approaches help to address concerns that could be raised about individual approaches. The selection of the comparable community is based upon a combination of demographic statistics and the impressions of local assessors and is inherently subjective. It is possible that arguments about the legitimacy of the selection of the comparable could arise and be used to question the legitimacy of the basic conclusion. However, since Case 2 looks only at the view shed and since the results of the Case 2 analysis are completely consistent with the other Cases, the selection of the comparable community will not be crucial to the legitimacy of the overall conclusion. To take another example, Case 1 uses data from the entire time period, both before and after the on-line date. We anticipate possible criticisms of this Case as masking the "pure" effect of the development that would only occur after the project came on-line. However, Cases 2 and 3 look separately at the before and after time periods and produce results basically identical to the Case 1 results. Because all three Cases produce similar results, Cases 2 and 3 answer the concerns about Case 1.

The Database

The results of the analysis depend greatly upon the quality of the database that supports the analysis. The Report is based on a detailed empirical investigation into the effects of wind development on property values. The study first identified the 27 wind projects over 10 MW installed capacity that have come on-line since 1998. REPP chose the 1998 on-line date as a selection criterion for the database because it represented projects that used the new generation of wind machines that are both taller and quieter than earlier generations. (REPP did not consider projects that came on-line in 2002 or after since there would be too little data on property values after the on- line date to support an analysis. These projects can be added to the overall database and used for subsequent updates of this analysis, however.) REPP chose the 10 MW installed capacity as the other criterion because if the presence of wind turbines is having a negative affect it, should be more pronounced in projects with a large rather than small number of installations. In addition, we used the 10 MW cut-off to assure that the sample of projects did not include an over-weighting of projects using a small number of turbines.

Of the 27 projects that came on-line in 1998 or after and that were 10MW or larger installed capacity, for a variety of reasons, 17 had insufficient data to pursue any statistical analysis. For six of the 17 projects we acquired the data, but determined that there were too few sales to support a statistical analysis. For two of the remaining 11, state law prohibited release of property sales information. The remaining nine projects had a combination of factors such as low sales, no electronic data, and paper data available only in the office. (For a project-by-project explanation, see Chapter 2 of the Report.)

For each of the remaining ten projects, we assembled a database covering roughly a six-year period from 1996 to the present. For each of these projects we obtained individual records of all property sales in the "view shed" of the development for this six-year period. We also constructed a similar database for a "comparable community" that is a reasonably close community with similar demographic characteristics. For each of the projects, we selected the comparable community on the basis of the demographics of the community and after discussing the appropriateness of the community with local property assessors. As shown in Table 3 below, the database of view shed and comparable sales included more than 25,000 individual property sales. The initial included database of view shed and comparable sales included over 25,000 individual property sales. After review and culling, the final data set includes over 24,300 individual property sales, as shown in Table 3 below.

TABLE 3: NUMBER OF PROPERTY SALES ANALYZED, BY PROJECT

Project/On-Line Date	Viewshed Sales	Comparable Sales	Total Sales
Searsburg, VT / 1997	2,788	552	3,340
Kern County, CA / 1999	745	2,122	2,867
Riverside County, CA / 1999	5,513	3,592	9,105
Buena Vista County, IA / 1999	1,557	1,656	3,213
Howard County, TX / 1999*	2,192	n/a	2,192
Kewaunee County, WI / 1999	329	295	624
Madison Co./Madison, NY / 2000	219	591	810
Madison Co./Fenner, NY / 2000**	453	591	1,044
Somerset County, PA / 2000	962	422	1,384
Fayette County, PA / 2001	39	50	89
Carson County, TX / 2001	45	224	269
TOTAL	14,842	9,504	24,346

*Howard County, TX comparable data not received at time of publication.

**Both wind projects in Madison County, NY, use the same comparable. Column totals adjusted to eliminate double counting.

RECOMMENDATIONS

The results of this analysis of property sales in the vicinity of the post-1998 projects suggest that there is no support for the claim that wind development will harm property values. The data represents the experience up to a point in time. The database will change as new projects come on-line and as more data becomes available for the sites already analyzed. In order to make the results obtained from this initial analysis as useful as possible to siting authorities and others interested in and involved with wind development, it will be important to maintain and update this database and to add newer projects as they come on-line.

Gathering data on property sales after the fact is difficult at best. We recommend that the database and analysis be maintained, expanded and updated on a regular basis. This would entail regularly updating property sales for the projects already analyzed and adding new projects when they cross a predetermined threshold, for example financial closing. In this way the results and conclusions of this analysis can be regularly and quickly updated.

CHAPTER II. METHODOLOGY

The work required to produce this report falls into two broad categories – data collection and statistical analysis. Each of these areas in turn required attention to several issues that determine the quality of the result.

According to the American Wind Energy Association (AWEA), approximately 225 wind projects were completed or under development in the United States as of 2002. The first wave of major wind project development in the United States took place between approximately 1981 and 1995. Wind farm development slowed considerably in 1996, with only three wind projects installed, the largest of which was 600 kW. The first major post-1996 project was the 6 MW Searsburg site in Bennington County, Vermont, which came on-line in 1997.

A. PROJECT SELECTION CRITERIA

This report focuses on major wind farm projects that constitute the second wave of wind farm development. This second wave of projects employs modern wind turbine technology likely to be installed over the next several years as part of continuing U.S. wind farm development. Compared to the previous generation of wind turbines, modern wind turbines generally have greater installed capacities, taller towers, larger turbine blades, lower rotational speeds and reduced gearbox noise.

In addition to the 6 MW Searsburg wind farm, this report analyses potential property value effects for wind farms of 10 MW capacity or greater installed from 1998 through 2001. Projects completed in 2002 and later are excluded from this analysis because not enough time has elapsed to collect sufficient data to statistically determine post-installation property value effects. To determine property value trends prior to wind farm installation, we collected property sales data from three years prior to the on-line year to the present for each of the wind farms analyzed.

Twenty-seven wind farm projects met the project selection criteria.

B. DATA COMPILATION

Once the projects were selected for analysis, the process of acquiring data was initiated through phone calls to county assessment offices. For each project, varying sources of data and information were available, ranging from websites with on-line data, purchased data on CD-ROM or via e-mail from government offices, purchased data from private vendors or postal carried paper records. In many cases data was only available in paper, but not by mail – a person would physically have to appear before the assessment office clerk and search storage boxes, which in some cases had been archived to remote locations for long-term storage. Many states do not require local offices to retain records past certain age limits, often between one to five years. After that, files may be destroyed, and in some cases had been.

Where paper records were obtained, data was transferred into electronic form through scanning or manual data entry. In many cases, both with paper and/or electronic data, the fields we received did not provide good geographic specificity. For example, in some cases, townships and/or cities, but not street addresses were identified. Where street addresses were included, in some cases not all properties had street addresses given, or street addresses were truncated or otherwise incomplete.

Out of the 27 counties with wind farms meeting the project selection criteria, ten sites were selected for statistical analysis based on availability of property sales data. The other 17 eligible sites were excluded from statistical analysis for a number of reasons, including insufficient sales to perform statistical analysis (for example, one site had only five sales in five years), lack of readily available data (data requiring in-person visits to the Assessors Office to manually go through paper files), and two cases where state law prohibited the Assessors Office from releasing property sales data to the public.

This report contains one section for each of the ten sites analyzed, with project site and community descriptions, view shed and comparable selection details, and analytical results and discussion. In addition, the report contains one section providing detailed explanations of why each of the 17 other sites are excluded from analysis. The dataset used in this report, exclusive of proprietary data, is available on the REPP web site at www.repp.org, or by request from REPP.

C. View Shed Definition

In order to determine whether the presence of a wind farm has an adverse effect on property values in the wind farm's vicinity, the area potentially affected by the wind farm must be defined. In this report, the area in which potential property value effects are being tested for is termed the "view shed."

How the view shed is defined will affect the type of data required to test for property value effects, as well as the analytical model employed. Choosing the value of the appropriate radius for such a view shed is subjective. To help determine the radius, numerous studies regarding line-of-sight impacts were reviewed, and interviews with a power industry expert on visual impacts of transmission lines were conducted. In the end, three separate resources for estimates of visual impact were used to support defining the view shed as the area within a five-mile radius of the wind farms. These resources are:

- The U.S. Department of Agriculture (USDA). In a handbook titled "National Forest Landscape Management" (1973) developed for the Forest Service by the USDA, three primary zones of visual impact are defined: foreground, middleground and background. These zones relate to the distance from an object in question, be it a fire lookout tower, tall tree, or mountain in the distance. In this definition, foreground is 0 to 1/2 mile, middleground is 1/4 to 5 miles and background is 3 to 5 miles. The USDA handbook states that for foreground objects people can discern specific sensory experiences such as sound, smell and touch, but for background objects little texture or detail are apparent, and objects are viewed mostly as patterns of light and dark.

- The Sinclair-Thomas Matrix. This is a subjective study of the visual impact of wind farms published in the report Wind Power in Wales, UK (1999). Visual impact is defined in a matrix of distance from a wind turbine versus tower hub height. At the highest hub height considered in the matrix, 95 meters [312 feet], the visual impact of wind towers is estimated to be moderate at a distance of 12 km [7.5 miles]. The matrix estimates that not until a distance of 40 km [25 miles] is there "negligible or no" visual impact from wind turbines under any atmospheric condition. Of the ten sites considered in this REPP report, the majority of towers have hub heights of 60 to 70 meters, which, according to the Sinclair-Thomas matrix, corresponds to moderate visual impact at a distance of 9 to 10 km [5.6– 6.2 miles].

- Interviews with Industry Experts. A power industry analyst with extensive experience in quantitative analysis of visual impacts of transmission lines stated in an interview that a rule of thumb used for the zone of visual influence of installations such as transmission lines and large wind turbines is a distance of approximately five miles.

There are other possible definitions of the view shed. At present, new proposals are sometimes required to conduct a Zone of Visual Influence (ZVI) analysis to determine the extent of visibility of a development. The zone comprises a visual envelope within which it is possible to view the development, notwithstanding the presence of any intervening obstacles such as forests, buildings, and other objects. Digital terrain computer programs are used to calculate and plot the areas from which the wind farm can be seen on a reference grid that indicates how many turbines can be seen from a given point. One weakness of the standard ZVI analysis is that all turbines are given equal weight of visual impact. That is, a turbine 20 miles from the viewer is assigned the same visual impact as a turbine one mile away.

Possible definitions for view sheds include the set of real properties that have a view of one or more wind turbines from inside the residence, that have a view of one or more turbines from any point on the property, or that are simply within some defined distance from the wind turbines, whether there is a view from each property in that area or not. In the last case, it is assumed that property owners in the area will still be potentially affected by views of the wind farms, as they will see them while traveling and conducting business in their vicinity.

Because this project lacked the resources to determine (through site visits, interviews, or other means) whether or not individual properties in the vicinity of the ten selected wind farms have a direct view of the wind turbines, the view shed is defined as all properties within a given radius of the outermost wind turbines in a wind farm. The value of this radius will clearly affect the results of the analysis. If the radius is too large, including many properties not potentially affected will overshadow the potential effect of the presence of wind turbines on property values. If the radius is too small, not all potentially effected properties will be accounted for in the analysis, and the number of data points gathered may be too small to yield valid statistical results.

D. Comparable Criteria

With the view shed of the wind farm defined, a set of neighboring communities outside of the view shed is selected to evaluate trends in residential house sales prices without the potential effects of wind farms on property values. These townships and incorporated cities are required to be clearly outside of the view shed area and not containing any large wind turbines. This selection is the "comparable" region. To define the comparable REPP consulted with local County Assessors and analyzed 1990 and 2000 U.S. Census data for the townships and incorporated cities under consideration.

Criteria used in selection of comparable communities include economic, demographic, and geographic attributes and trends. The goal in selecting comparable communities is to have communities that are as similar as possible with respect to variables that might affect residential house values, with the exception of the presence or absence of wind farms. When possible, comparable communities are selected in the same county as the wind farm location. If this is not possible due to placement of wind farm or availability of suitable data, comparable communities are selected from counties immediately adjacent to the county containing the wind farm.

After considering a number of criteria, including population, income level, poverty level, educational attainment, number of homes, owner occupancy rate, occupants per household, and housing value, five criteria from 1990 and 2000 U.S. Census were selected for evaluation:

- Population
- Median Household Income
- Ratio of Income to Poverty Level
- Number of Housing Units
- Median Value of Owner-occupied Housing Units

Data for these criteria is obtained for both the wind farm and comparable communities. Percent change from 1990 to 2000 for each criterion is calculated for each township or city considered as potentially comparable areas. The criteria are used in the following manner:

a) Change in population is calculated to identify any communities that had excessively large changes in population relative to the change in population from 1990 to 2000 in the wind farm area. Such large changes could indicate either a major construction boom, or major exodus of habitants from an area, which could skew comparisons in residential home values over the period in question. These communities are eliminated as possible comparables.

b) The average median household income in the wind farm communities in 1990 and 2000 is calculated. The first criterion is that comparable communities should have similar median household incomes in 2000. The second criterion is that median incomes should not have changed at significantly different rates from 1990 to 2000 between wind farm and comparable communities. Communities that meet both criteria are considered as potential comparables.

c) The percent of the population whose income is below poverty level is calculated from the ratio of income to poverty level. Absolute poverty levels and percent changes in poverty levels from 1990 to 2000 are compared. Communities that have significantly different poverty levels or rates of change of these levels as compared to the wind farm areas are eliminated as possible comparables.

d) Change in the number of housing units is used to identify any communities that had excessively large changes in housing relative to the change in housing from 1990 to 2000 in the wind farm area. Such large changes could indicate a major construction boom, or reduction in housing stock, which could skew comparisons in residential home values over the period in question. These communities are eliminated as possible comparables.

e) The average median house value in the wind farm communities in 1990 and 2000 is obtained from Census data. These values are owner-reported, and therefore may not accurately reflect actual market value of the properties. The criterion is that comparable communities should have similar median house values. Communities meeting these criteria are considered as potential comparables.

Communities that meet all five of the above criteria are selected for consideration as comparable communities. In addition to analysis of Census data, interviews with County Assessors, other local and state officials, and in some cases with knowledgeable real estate agents are taken into account in the selection of comparables.

E. Analysis

i. Literature Review

In selecting the type of analysis to use in determining whether there is any statistical evidence that wind farms negatively affect property values, we first conducted literature research to identify any studies previously conducted for this purpose. We found only four studies relating wind and property value effects, three of which are only qualitative.

A 1996 quantitative study, Social Assessment of Wind Power (Institute of Local Government Studies, Denmark), applied regression analysis to determine the effect of individual wind turbines, small wind turbine clusters, and larger wind parks on residential property values. The regression used the hedonic method, discussed in more detail below, in which site-specific data on a number of quantitative and qualitative variables is used to predict housing values. The study concluded that homes close to a wind turbine or turbines ranged in value from DKK 16,200 to 94,000 [approximately $2,900 to $16,800] less than homes further away. The study had a number of weaknesses, including a lack of definition of the distance from turbines, lack of specification of the size and number of turbines, and regression on a very small data sample. In contrast, a 2002 qualitative study, Public Attitudes Towards Wind Power (Danish Wind Industry Association), quoted the 1997 Sydthy Study as concluding that residents closer than 500 meters to the nearest wind turbine tend to be more positive about wind turbines than residents further away.

A 2001 qualitative study, Social Economics and Tourism (Sinclair Knight Mertz), said that for highly sought after properties along Salmon Beach, Australia closer than 200 meters from wind turbines, the general consensus among local real estate agents is that "property prices next to generators have stayed the same or increased after installation." However, the study concluded that while properties with wind turbines on them may increase in value, other properties may be adversely affected if within sight or audible distance of the wind turbines. Finally, the 2002 qualitative study, Economic Impacts of Wind Power in Kittitas County (ECO Northwest), concluded from interviews with assessors around the United States that there is no evidence of a negative impact on property values from wind farms. The weakness of the study is that it relies on subjective comment to arrive at its conclusion.

We also reviewed several studies that attempt to quantify the visual and property value impacts of electric transmission towers and lines. There is a large body of information on this subject, as transmission lines have been the subject of scrutiny and regulation for many years.

A 1992 study, The Effects of Overhead Transmission Lines on Property Values (C.A. Kroll and T. Priestley), reviews the methodology and conclusions of a number of studies on overhead transmission lines and property values over the 15 year period of 1977 through 1992. This study was very helpful in identifying the types of analysis, and their strengths and weaknesses, which could be adopted for use in this REPP report. The study concluded that appraisal offices have the longest history of studying and evaluating line impacts, but lack in-depth statistical analysis to verify obtained results. Data collected from face-to-face conversation and through surveys attempts to ascertain the attitudes and reactions of property owners to transmission equipment, but personal opinions were found to produce widely varying results. Statistical analysis of appraiser findings provided a better interpretation of appraiser information, but produced varying results due to different methodologies.

ii. Choice of Analytic Method

A number of analytic methods may be used to assess property value impacts from wind farms, ranging from interviews with assessors and surveys of residents to simple regression models and hedonic regression analysis. In order to produce results that could determine whether or not there was statistical evidence that wind farms have a negative impact on property values, simple linear regression analysis on property sales price as a function of time was selected.

A more complex method, hedonic regression analysis, can also be used to gauge property value impacts. Hedonic analysis, used in a number of studies on visual impacts of transmission lines, employs both quantitative and qualitative values to describe the property and local, regional, and even national parameters that may influence housing values. Property data such as number of bedrooms and bathrooms, linoleum or tile floors, modern appliances, kitchen cabinets or not are collected for each property in the study area, as well community information such as school district quality, subjective criteria derived from interviews with every resident in a study area, and other parameters. However, because this report is based on historic data, much of the detail needed for a hedonic analysis may not be available. An important consideration for this analysis, given the limits of the data, was to apply a consistent methodology to the site analyses. The only data consistent across all sites is sales date and sales price.

iii. Data Analysis

The key variables used in this analysis are sale price, sale date, and one locational attribute allowing data to be separated into view shed and comparable data sets. The first step of analysis was to remove any erroneous data from the dataset. Sales with incomplete information, duplicate sales, and zero price were removed. Parcel sales under $1,000 were also removed, as they often represent transfer within a family or business, rather than a bona fide sale. Finally, any sales with values much higher than any other sales were researched to determine whether or not that sale was bona fide. Interviews with assessors with knowledge of the properties in question were used to determine whether these high value sales were erroneous. Where they were, they were removed.

The second step in data analysis was to reduce cyclic effects of the real estate market on sales prices, as well as to reduce the high variability and heterogeneity of the data when viewed on a day sale basis. First, for each month, we calculated the monthly average sales price for each month to eliminate the variability of day-to-day sales. In some cases data supplied was already in monthly averaged form. Second, a six-month trailing average of the average monthly sales price is used to smooth out seasonal fluctuations in the real estate market. The averaging technique used the current month sales plus the previous six months of sales to compute trailing averages.

Third, a unit of analysis is defined. Because this project generally lacks resources to identify properties by street address, the smallest units of geographical analysis used are townships and incorporated cities within each county. Townships that are partly but not fully within the view shed radius are excluded from the view shed. In some cases zip code 4-digit ZIP+4 regions are used to identify location, and in some cases where the data offered no other alternative, individual street locations were manually identified in order to define the location of properties within the view shed and comparable.

Fourth, as stated above, linear regression is selected as the method to test for potential property value impacts. A least-squares linear regression of the six-month trailing average price is constructed for the view shed and comparable areas to determine the magnitude and rate of change in property sales price for each of the areas. The regression yields an equation for the line that best fits the data. The slope of this line gives the month-by-month expected change in the price of homes in the view shed and comparable areas. The regression also yields a value for "R2."

The R2 value measures the goodness of fit of the linear relationship to the data, and equals the percentage of the variance (change over time) in the data that is described by the regression model. The value of R2 ranges from zero to one. If R2 is small, say less than 0.2 to 0.3, the model explains only 20 to 30 percent of the variance in the data and the slope calculated is a poor indicator of the change in sales price over time. If R2 is large, say 0.7 or greater, then the model explains 70 percent or more of the variance in the data, and the slope of the regression line is a good indicator for quantifying the change in sales price over time. Regression models with low R2 values must be interpreted with caution. Often, knowledge and examination of factors not included in the regression model can help one understand why the regression provides a poor fit.

iv. Case I, II, and III Definitions

This report tests for effects of wind farms on property sales prices using three different models, or cases. All employ linear regression on six-month trailing averaged monthly residential sales data as outlined above.

Case 1 compares changes in the view shed and comparable community sales prices for the entire period of the study. If wind farms have a negative effect, we would expect to see prices increase slower (or decrease faster) in the view shed than in the comparable. Case 1 takes into account the wind farm on-line date only in that the data set begins three years before the on-line date. An appropriate comparable is important in this case in order that meaningful comparison of sale price changes over time can be made.

Case 2 compares property sales prices in the view shed before and after the wind farm in question came on-line. If wind farms have a negative effect, we would expect to see prices increase slower (or decrease faster) in view shed after the wind farm went on-line than before. Case 2 is susceptible to effects of macro-economic trends and other pressures on housing prices not taken into account in the model. Because Case 2 looks only at the view shed, it is possible that external factors change prices faster before or after the on-line date, and the analysis may therefore pick up factors other than the wind development.

Case 3 compares property sales prices in the view shed and comparable community, but only for the period after the projects came on-line. If wind farms have a negative effect, we would expect to see prices increase slower (or decrease faster) in view shed than comparable after the on-line date. Again, an appropriate comparable is important in this case in order that meaningful comparison of sale price changes over time can be made.

Chapter III. Site Reports

Site Report 1: Riverside County, California

A. Project Description

The topography ranges from desert flats to arid mountains with views of snow capped peaks in winter – all of which encompass areas both in and out of the view shed.

The area has extreme elevation changes from the Palm Springs flats at an elevation of 450 feet, to the San Gorgonio Pass at an elevation of 2,500 feet. The Pass cuts through the two peaks of Mt. San Gorgonio to the north and Mt. San Jacinto to the southeast, and is five miles from the western edge of Palm Springs (15 to downtown), and about 80 miles east of Los Angeles.

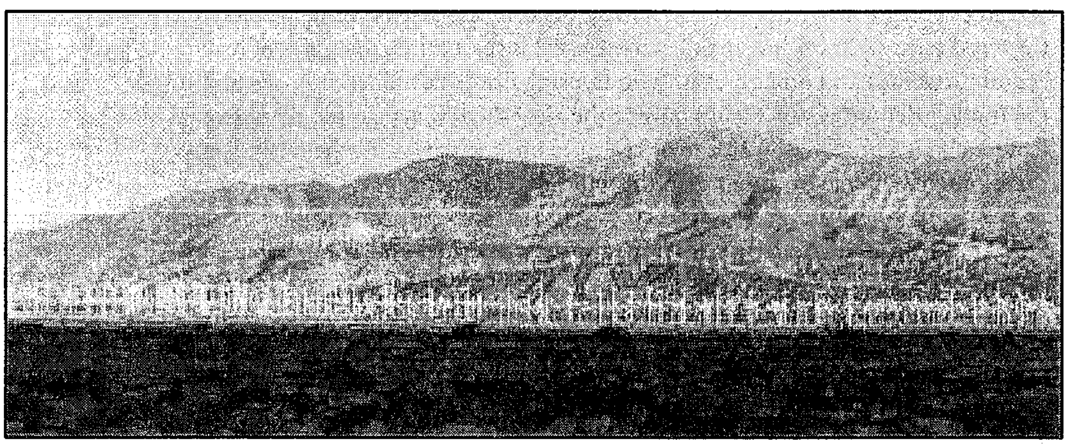

Figure 1.1 View of wind farms at San Gorgonio Pass, Riverside County, CA
Photo by David F. Gallagher, 2001 - www.lightningfield.com

The projects are located in the San Gorgonio Pass immediately west of the Palm Springs area in Riverside County, California. Developers installed 3,067 turbines from 1981 to 2001, with the tallest turbine at 63 meters (207 feet). Repowering projects built 130 modern turbines. They begin northwest of Palm Spring heading up Interstate 10 from Indian Avenue; then they extend more than 10 miles along the flats up into the San Gorgonio Mountains, along the Pass, and stop shortly before reaching Cabazon.

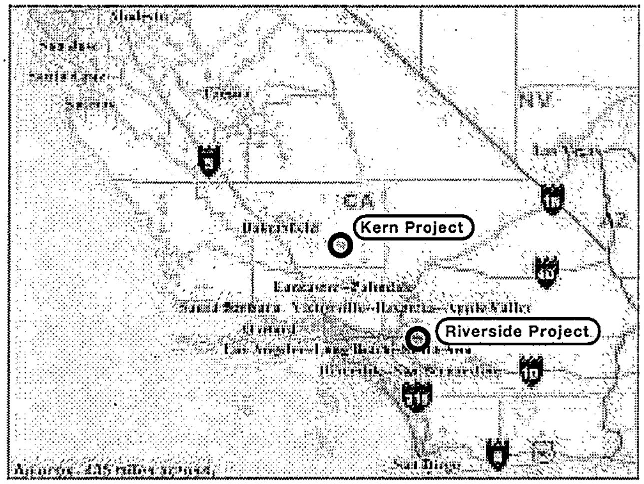

Figure 1.2 Regional Wind Project Location

(Dots approximate wind farm locations)

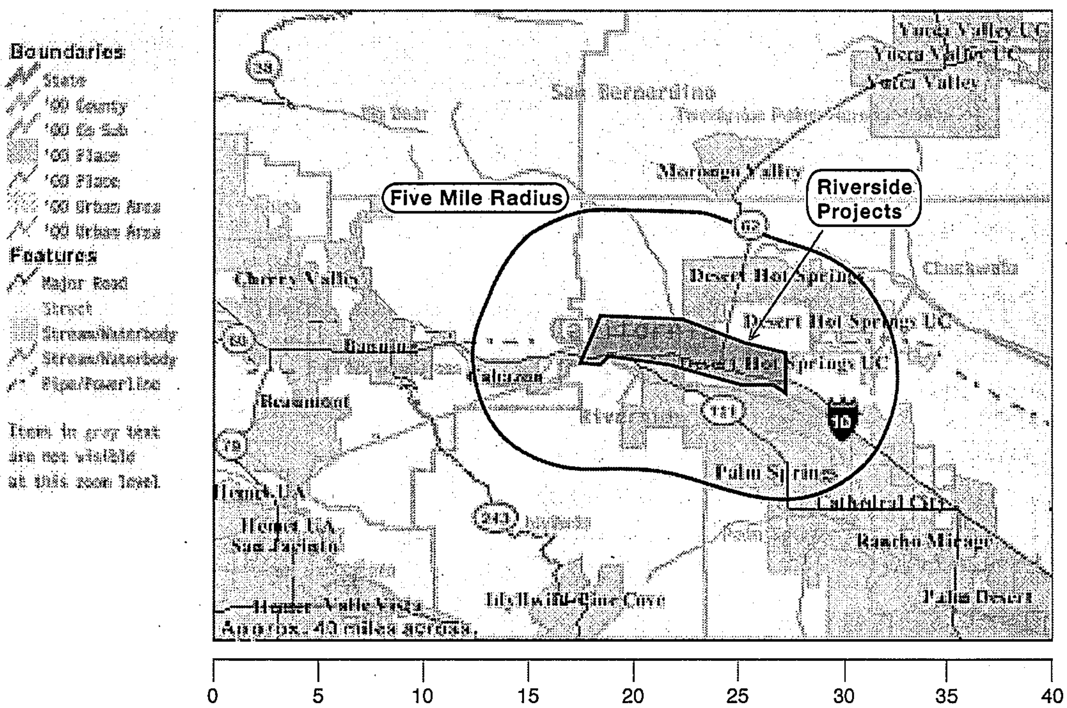

Figure 1.3 San Gorgonio, Riverside County, California View shed

(5 Mile Radius from project edge)

Map Source: U.S. Census Bureau Website

Project Location Details: Interviews and Aerial Photographs

The county is considered a metro area with 1 million population or more, but that is due to the population of the Los Angeles area. See Appendix 1 for a definition of rural urban continuum codes. The view shed represents fewer than 30,000 people.

B. Project Timeline

Table 1.1 Wind Project History, San Gorgonio, CA

Project Name	Completion Date	Capacity (MW)	Project Name	Completion Date	Capacity (MW)
Mountain View Power Partners I	2001	44.4	Altech 3	1981-1995	21.7
Mountain View Power Partners II	2001	22.2	Westwind Trust	1981-1995	15.7
Enron Earth Smart/Green Power	1999	16.5	Painted Hills B & C	1981-1995	15.3
Energy Unlimited	1999	10.0	Difwind, Ltd.	1981-1995	15.0
Pacific West I	1999	2.1	Energy Unlimited	1981-1995	14.5
Westwind-Repower	1999	47.3	Edom Hill	1981-1995	11.0
Cabazon-Repower	1999	39.8	So. Cal. Sunbelt	1981-1995	10.5
Westwind - PacifiCorp-Repower	1999	1.5	Difwind V	1981-1995	7.9
East Winds-Repower	1997	4.2	Meridian Trust	1981-1995	7.5
Karen Avenue-Repower	1995	3.0	Kenetech/Wintec	1981-1995	7.3
Dutch Pacific	1994	10.0	San Jacinto	1981-1995	5.0
Kenetech (various)	1981-1995	30.3	Painted Hills B & C	1981-1995	4.0
Zond-PanAero Windsystems	1981-1995	29.9	Altech 3	1981-1995	3.3
Alta Mesa	1981-1995	28.2	San Gorgonio Farms	1981-1995	3.2
Section 28 Trust	1981-1995	26.2	San Gorgonio Farms	1981-1995	2.0
San Gorgonio Farms	1981-1995	26.1			

C. Analysis

i. Data

Real property sales data for 1996 to 2002 was obtained from First American Real Estate Solutions in Anaheim, CA. The dataset is quite detailed and contains many property and locational attributes, among them nine-digit zip code (ZIP+4) locations. Sales data was purchased for four zip codes encompassing the wind farm area and surrounding communities. These zip codes are Palm Springs (92262), White Water (92282), Cabazon (92230), and Banning (92220).

Sales for the following residential property types were included in the analysis: Condominiums, Duplexes, Mobile Homes, and Single-Family Residences. Upon initial analysis, of the 9105 data points analyzed, approximately 10 sales in the view shed had unusually high prices. Conversations with the Assessors Office confirmed these were incorrect values for the data points. Correct values were obtained and the data corrected.

Projects that went on-line during the study period are the Cabazon, Enron, Energy Unlimited, Mountain View Power Partners I & II, and Westwind sites. Of these, two sites added 87 MW of repowered capacity in May 1999, two sites added 27 MW of new capacity in June 1999, and two sites added 66 MW of new capacity in October 2001.

ii. View shed Definition

All ZIP+4 regions within five miles of the wind turbines define the view shed. The location of the ZIP+4 regions were derived from the latitude and longitude of the ZIP+4 areas obtained from the U.S. Census TIGER database. The view shed includes the northwest portion of Palm Springs, Desert Hot Springs, and Cabazon, and 5,513 sales from 1996 to 2002. The view shed portion of northwest Palm Springs corresponds very closely to the boundaries of Palm Springs zip code 92262.

Interviews with State of California Palm Springs Regional Assessors Office were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Assessment District Supervisor Gary Stevenson's opinion, over 80 percent of Cabazon properties can see some wind turbines; over 80 percent of Desert Hot Springs properties can see some wind turbines; almost all of the properties on the outer edge of northwest Palm Springs can see some wind turbines, but due to foliage (mainly palm trees) and tall buildings, only five percent or less of the properties in the interior of Pam Springs can see any wind turbines.

iii. Comparable Selection

The comparable community was selected through interviews with State of California San Gorgonio Regional Assessors Office personnel, as well as analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Selection of the comparable in this case was difficult, as the eastern side of the view shed is close to downtown Palm Springs, which is growing fairly quickly, while the western portion of the view shed, including Cabazon, is not growing quickly and has more stable housing sales prices. Tables 1.2 and 1.3 summarize the Census data reviewed. Because Census data by zip code is not available for 1990, we were unable to determine 1990 demographic statistics for the Palm Springs view shed, as it is not separable from the Palm Springs non-view shed area.

Based on his extensive experience in the area, Assessment District Supervisor Gary Stevenson suggested Banning and Beaumont in Riverside County, to the west of the wind farms, and Morongo Valley in San Bernardino County, to the north of the wind farms as appropriate comparables to the view shed area. Banning and Beaumont are visually separated from the wind farm area by a ridge, and Morongo Valley is separated by approximately seven miles distance.

In order to determine the most appropriate comparable community we looked at the demographics of 10 surrounding areas. The 92264 zip code area of Palm Springs to the south of northwest Palm Springs was initially considered as a comparable, but Supervisor Stevenson said that this area was closer to the metropolitan center and had significantly different demographics than the view shed area. Towns adjacent to Banning and Beaumont, including Hemet, San Jacinto, and Cherry Valley, were considered but rejected for use after discussion with Supervisor Stevenson. Upon examination of Census data, sales data availability, and review of Assessor comments, Banning was selected as the comparable, with a total of 3,592 sales from 1996 to 2002.

Table 1.2 Riverside County, California: 1990 Census Data

Year	View shed	Location	Population	Median Household Income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Cabazon CDP	1,588	$13,830	19%	754	$64,000
1990	Y	Palm Springs City*	n/a	n/a	n/a	n/a	n/a
1990	Y	White Water**	n/a	n/a	n/a	n/a	n/a
1990	VIEW SHED DEMOGRAPHICS		n/a	n/a	n/a	n/a	n/a
1990	COMP	Banning City	20,570	$22,514	17%	8,278	$89,300
1990	COMPARABLE DEMOGRAPHICS		20,570	$22,514	17%	8,278	$89,300
1990	N	Beaumont City	9,685	$22,331	23%	3,718	$89,700
1990	N	Cathedral City	30,085	$30,908	13%	15,229	$114,200
1990	N	Cherry Valley CDP	5,945	$29,073	9%	2,530	$127,500
1990	N	Hemet City	36,094	$20,382	14%	19,692	$90,700
1990	N	Idyllwild-Pine Cove CDP	2,937	$31,507	4%	3,635	$147,200
1990	N	Morongo Valley CDP***	1,554	$38,125	23%	827	$74,100
1990	N	Rancho Mirage City	9,778	$45,064	7%	9,360	$252,400
1990	N	San Jacinto City	16,210	$20,810	16%	6,845	$90,200
1990	N	Valle Vista CDP	8,751	$22,138	8%	4,444	$125,500

*Census data by zip code not available for 1990. Unable to determine demographics of view shed as the Palm Springs view shed area is not separable from the Palm Springs non-view shed area.
**White Water not listed in 1990 U.S. Census.
***San Bernardino County.

Table 1.3 Riverside County, California: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Cabazon-- Zip Code 92230	2,442	$22,524	32%	884	$48,200
2000	Y	Palm Springs- Zip Code 92262	24,774	$32,844	18%	15,723	$133,100
2000	Y	White Water-- Zip Code 92282	903	$35,982	23%	380	$82,400
2000	VIEW SHED DEMOGRAPHICS		28,119	$30,450	24%	16,987	$87,900
2000	COMP	Banning City—Zip Code 92220	23,443	$32,076	20%	9,739	$97,300
2000	COMPARABLE DEMOGRAPHICS		23,443	$32,076	20%	9,739	$97,300
2000	N	Beaumont City	11,315	$29,721	20%	4,258	$93,400
2000	N	Cathedral City	42,919	$38,887	14%	17,813	$113,600
2000	N	Cherry Valley CDP	5,857	$39,199	6%	2,633	$121,700
2000	N	Hemet City	58,770	$26,839	16%	29,464	$69,900
2000	N	Idyllwild-Pine Cove CDP	3,563	$35,625	13%	4,019	$164,700
2000	N	Morongo Valley CDP*	2,035	$36,357	19%	972	$73,300
2000	N	Rancho Mirage City	12,973	$59,826	6%	11,643	$251,700
2000	N	San Jacinto City	23,923	$30,627	20%	9,435	$78,500
2000	N	Valle Vista CDP	10,612	$32,455	12%	4,941	$76,500

*San Bernardino County.

iv. Analytical Results and Discussion

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values. For Cases II and III, the on-line date is defined as the month the first wind project came on-line during the study period, May 1999.

In Case I, the monthly sales price change in the view shed is twice the monthly sales price change of the comparable over the study period. The Case I model provides a good fit to the data, with over 80 percent of the variance in the data explained by the linear regression. In Case II, the monthly sales price change in the view shed is 86 percent greater after the on-line date than before the on-line date. The Case II model provides a good fit to the data, with over two-thirds of the variance in the data explained by the linear regression. In Case III, the monthly sales price change in the view shed after the on-line date is 63 percent greater than the monthly sales price change of the comparable after the on-line date. The data for the full study period is graphed in Figure 1.4, and regression results for all cases are summarized in Table 1.4 below.

TABLE 1.4 RIVERSIDE COUNTY, CALIFORNIA: REGRESSION RESULTS

Projects: Cabazon, Enron, Energy Unlimited, Mountain View Power Partners I & II, Westwind

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Nov 02 Jan 96 - Nov 02	$1,719.65 $814.17	0.92 0.81	The rate of change in average view shed sales price is 2.1 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - Apr 99 May 99 - Nov 02	$1,062.83 $1,978.88	0.68 0.81	The rate of change in average view shed sales price is 86% greater after the on-line date than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 99 - Nov 02 May 99 - Nov 02	$1,978.88 $1,212.14	0.81 0.74	The rate of change in average view shed sales price after the on-line date is 63% greater than the rate of change of the comparable after the on-line date.

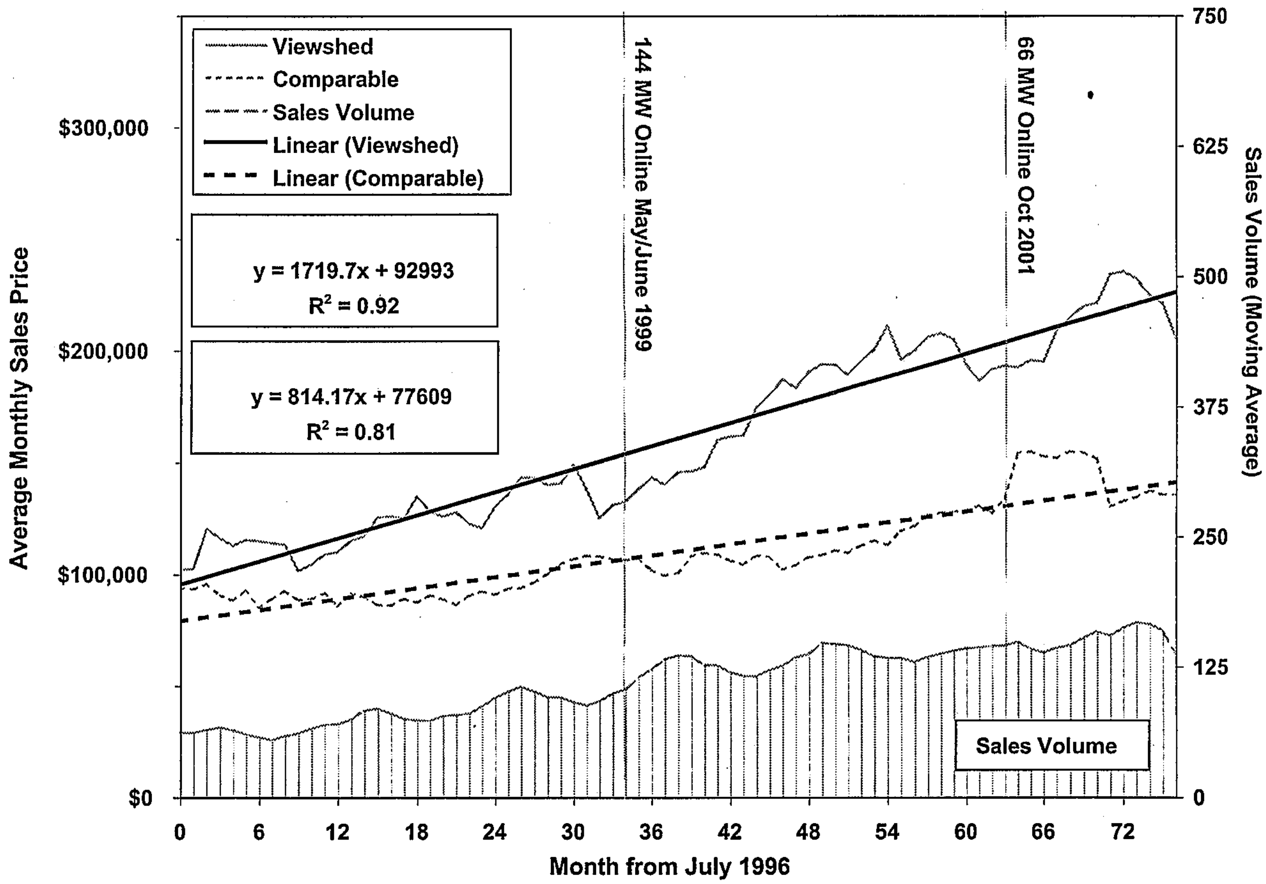

FIGURE 1.4 AVERAGE RESIDENTIAL HOUSING SALES PRICE
RIVERSIDE COUNTY, CALIFORNIA 1996-2002

D. Additional Interviewee Comments

Jack Norie of Desert Hot Springs, who provides tours of the wind projects, said that since 1998 there has been a discernable sense that more turbines were in the area. Norie felt that the 41 new turbines built high up along the nearest peaks facing Palm Springs near the intersection of Highway 111 and Interstate 10 on the north side, contributed to this impression. (These are possibly the Mountain View Power Partners II project with 37 turbines). Mr. Norie's descriptions of project locations and aerial photographs available from Microsoft's Terraserver and Mapquest, allowed us to determine project locations.

Site Reports 2.1 and 2.2: Madison County, New York

A. Project Description

Madison County has two wind farms meeting the criteria for analysis, Madison and Fenner. Because they are separated by distance, and have different on-line dates, each wind farm is analyzed separately. However, since they are in the same county and share the same comparable region, both analyses are presented in this section.

The Fenner turbines are seated in a primarily agricultural region southeast of Syracuse and southwest of Utica, with 20 turbines at 100 meters (328 feet). The Madison project is about 15 miles southeast of Fenner, and 2.5 miles east of Madison town with seven turbines standing 67 meters (220 feet).

Madison County is classified as a "county in a metro area with 250,000 to 1 million population." See Appendix 1 for a definition of rural urban continuum codes. The view shed areas have a population less than 8,000.

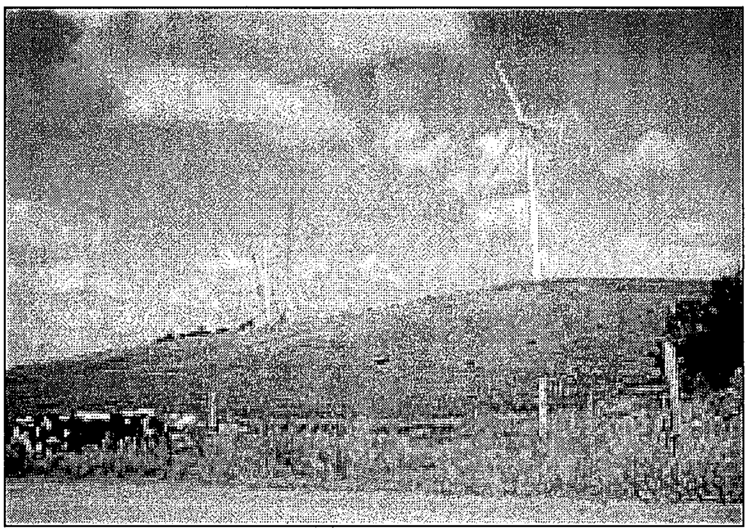

Figure 2.1 View of Fenner wind farm.

Photo Courtesy: New York State Energy Research and Development Authority (NYSERDA)

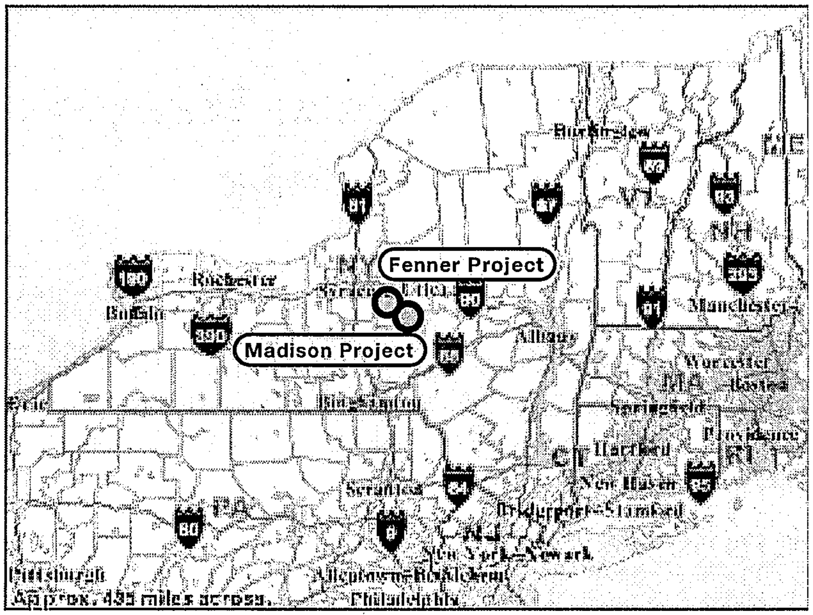

Figure 2.2. Regional Wind Project Location
(Dots approximate wind farm locations)

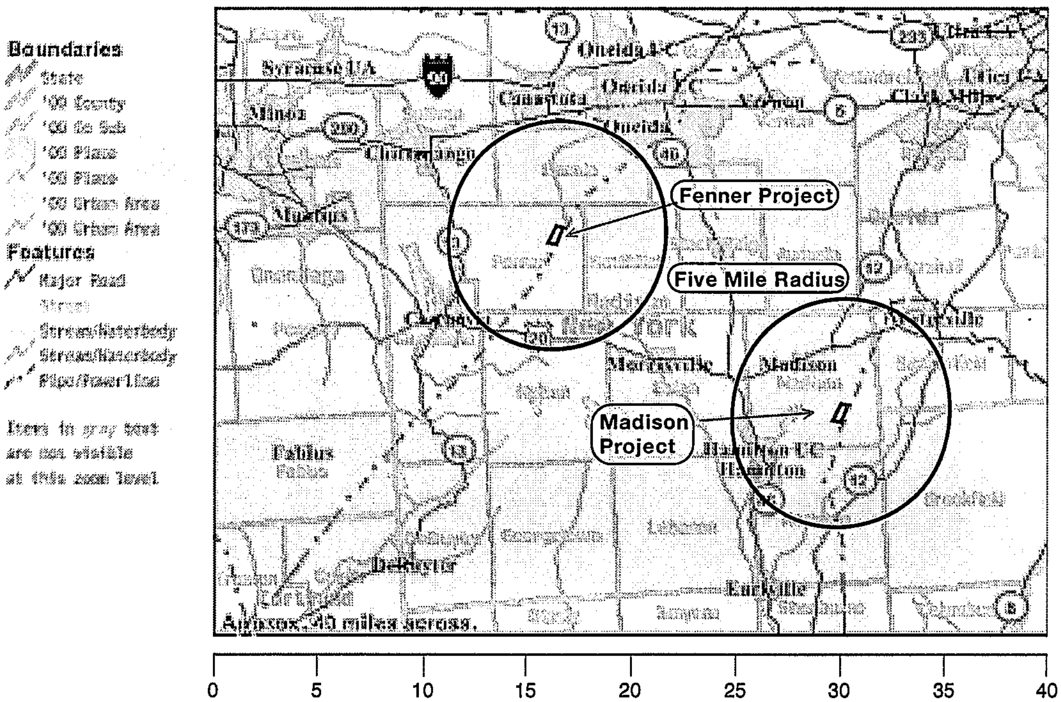

Figure 2.3. Location of Wind Projects in Madison County
Site Locations Source: Madison Assessors Office
Base Map Source: U.S. Census Bureau

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B. Project Timeline

Table 2.1 Wind Project History, Madison County, NY

Project Name	Completion Date	Capacity (MW)
Fenner Wind Power Project	2001	30.0
Madison Windpower	2000	11.6

C. Analysis

i. Data

Real property sales data for 1997 to 2002 was purchased on CD-ROM from Madison County Real Property Tax Services in Wampsville, NY. The sales data was purchased for the townships and cities encompassing the wind farm areas and surrounding communities. The unit of analysis for this dataset is defined by either township or incorporated city boundaries. Though street addresses are included in the dataset, this analysis lacked the resources to identify the location of properties by street address.

In addition to basic sales data, the dataset included property attributes such as building style, housing quality grade, and neighborhood ratings. The CD-ROMs contained four files that required merging on a common field to create the composite database of all sales. A significant number of redundant, incomplete, and blank entries were deleted prior to analysis. Sales for the following residential property types were included in the analysis: one-, two-, and three-family homes, rural residences on 10+ acres, and mobile homes.

Upon initial analysis, of the 1,263 data points analyzed, approximately six sales in the Madison view shed had unusually high prices. Conversations with the Assessors Office confirmed four of these were valid sales, but that two were not. The invalid sales were eliminated from the analysis.

Projects that went on-line during the study period are the Madison wind farm, which went on-line September 2000 with a capacity of 11.6 MW, and the Fenner wind farm, which went on-line December 2001 with a capacity of 30 MW. The wind farms are approximately 15 miles apart.

ii. View Shed Definition

Two separate view sheds are defined for Madison County, one for each wind farm. A five-mile radius around the Madison wind farm encompasses the town of Madison and over 95 percent of Madison Township. The view shed also encompasses portions of three townships in Oneida County. However, due to lack of resources to identify the location of individual properties within townships, the Oneida townships were excluded from the analysis. The Madison view shed is defined as Madison town and all of Madison Township. The Fenner view shed is defined as all of Fenner, Lincoln, and Smithfield Townships, which are fully within a five-mile radius around the Fenner wind farm, with the exception of a small corner of Smithfield Township. The Madison and Fenner view sheds accounts for 219 and 453 sales over the study period, respectively.

Interviews with the State of New York Madison County Assessors Office were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Fenner Assessment District Supervisor Russell Cary's opinion, over 80 to 85 percent of Fenner properties can see some wind turbines, over 85 percent of Lincoln properties can see some wind turbines, over 75 percent of Madison properties can see some wind turbines, and approximately 60 percent of Smithfield properties can see some wind turbines. Cary said that in his opinion, only a few properties in Fenner Township, near Route 13, could not see some wind turbines.

iii. Comparable Selection

The comparable community was selected through interviews with State of New York Madison County Assessors Office personnel, as well as analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 2.2 and 2.3 summarize the Census data reviewed. In order to determine the most appropriate comparable community, we looked at the demographics of 13 surrounding areas. Based on his experience in the area, Assessment District Supervisor Russell Cary suggested Lebanon, Deruyter and Stockbridge Townships along with villages of Deruyter, Munnsville and Hamilton, all in Madison County, as appropriate comparables for both view sheds. However, Cary added that Hamilton has higher property values than Madison because it is home to Colgate University. Upon examination of Census data, sales data availability, and review of Assessor comments, Lebanon, Deruyter, Hamilton, Stockbridge Townships, and the Villages of Deruyter and Munnsville were selected as the comparable for both view sheds, with a total of 591 sales from 1997 to 2002.

Table 2.2 Madison County, New York: 1990 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Fenner town	1,694	$31,875	13%	609	$73,700
1990	Y	Lincoln town	1,669	$32,073	8%	587	$63,900
1990	Y	Smithfield town	1,053	$23,355	13%	380	$52,200
FENNER DEMOGRAPHICS			4,416	$29,101	11%	1,576	$63,267
1990	Y	Madison town	2,774	$29,779	10%	1,239	$65,200
1990	Y	Madison village	316	$26,250	12%	135	$50,000
MADISON DEMOGRAPHICS			3,090	$28,015	11%	1,374	$57,600
1990	COMP	DeRuyter town	1,458	$26,187	11%	811	$51,800
1990	COMP	DeRuyter village	568	$24,125	10%	218	$52,200
1990	COMP	Hamilton town	6,221	$28,594	17%	1,820	$69,800
1990	COMP	Lebanon town	1,265	$26,359	12%	581	$49,600
1990	COMP	Munnsville village	438	$23,194	15%	174	$54,700
1990	COMP	Stockbridge town	1,968	$24,489	11%	723	$53,600
COMPARABLE DEMOGRAPHICS			11,918	$25,491	13%	4,327	$55,283
1990	N	Cazenovia town	6,514	$39,943	4%	2,372	$122,300
1990	N	Cazenovia village	3,007	$31,622	5%	995	$101,100
1990	N	Chittenango village	4,734	$34,459	7%	1,715	$72,400
1990	N	Earlville village	883	$28,839	5%	362	$44,300
1990	N	Georgetown town	932	$25,000	10%	287	$42,700
1990	N	Hamilton village	3,790	$31,960	16%	869	$88,000
1990	N	Morrisville village	2,732	$26,875	30%	443	$55,500

Table 2.3 Madison County, New York: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Fenner town	1,680	$43,846	7%	651	$84,400
2000	Y	Lincoln town	1,818	$46,023	5%	700	$85,000
2000	Y	Smithfield town	1,205	$35,109	16%	446	$61,900
FENNER DEMOGRAPHICS			4,703	$41,659	9%	1,797	$77,100
2000	Y	Madison town	2,801	$35,889	13%	1,325	$77,100
2000	Y	Madison village	315	$27,250	13%	151	$68,400
MADISON DEMOGRAPHICS			3,116	$31,570	13%	1,476	$72,750
2000	COMP	DeRuyter town	1,532	$34,911	12%	867	$68,200
2000	COMP	DeRuyter village	531	$31,420	12%	231	$70,300
2000	COMP	Hamilton town	5,733	$38,917	14%	1,725	$79,300
2000	COMP	Lebanon town	1,329	$34,643	14%	631	$62,900
2000	COMP	Munnsville village	437	$35,000	15%	176	$66,400
2000	COMP	Stockbridge town	2,080	$37,700	13%	802	$67,900
COMPARABLE DEMOGRAPHICS			11,642	$35,432	13%	4,432	$69,167
2000	N	Cazenovia town	6,481	$57,232	4%	2,567	$142,900
2000	N	Cazenovia village	2,614	$43,611	7%	1,031	$115,200
2000	N	Chittenango village	4,855	$43,750	6%	1,968	$75,700
2000	N	Earlville village	791	$32,500	12%	329	$51,400
2000	N	Georgetown town	946	$37,963	11%	315	$54,600
2000	N	Hamilton village	3,509	$36,583	19%	785	$104,600
2000	N	Morrisville village	2,148	$34,375	20%	398	$73,900

iv. Analytical Results and Discussion

In five of the six regression models, monthly average sales prices grew faster or declined slower in the view shed than in the comparable area. However, in the case of the underperformance of the view shed, the explanatory power of the model is very poor. Thus, there is no significant evidence in these cases that the presence of the wind farms had a negative effect on residential property values.

Madison View shed

In Case I, the monthly sales price change in the view shed is 2.3 times the monthly sales price change of the comparable over the study period. However, the Case I model provides a poor fit to the data, with approximately 30 percent of the variance in the data explained by the linear regression. In Case II, the monthly sales price change in the view shed is 10.3 times greater after the on-line date than before the on-line date. However, the Case II model provides a poor fit to the data, with less than 30 percent of the variance in the data after the on-line date, and only 1 percent of the variance before the on-line date explained by the linear regression. In Case III, average monthly sales prices increase in the view shed after the on-line date, but decrease in the comparable region. The average view shed sales price after the on-line date increased at 3.2 times the rate of decrease in the comparable after the on-line date. The Case III model describes less than 30 percent of the variance in the view shed, but almost 40 percent of the variance in the comparable. The poor fit of the models, at least for the view shed, is partly due to a handful of property sales that were significantly higher than the typical view shed property sale. The data for the full study period is graphed in Figure 2.4, and regression results for all cases are summarized in Table 2.4 below.

Table 2.4 Madison County, New York: Regression Results
Project: Madison

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data	Jan 97 - Jan 03	$576.22	0.29	The rate of change in average view shed sales price is 2.3 times greater than the rate of change of the comparable over the study period.
	Comparable, all data	Jan 97 - Jan 03	$245.51	0.34	
Case 2	View shed, before	Jan 97 - Aug 00	$129.32	0.01	The rate of change in average view shed sales price after the on-line date is 10.3 times greater than the rate of change before the on-line date.
	View shed, after	Sep 00 - Jan 03	$1,332.24	0.28	
Case 3	View shed, after	Sep 00 - Jan 03	$1,332.24	0.28	The rate of change in average view shed sales price after the on-line date increased at 3.2 times the rate of decrease in the comparable after the on-line date.
	Comparable, after	Sep 00 - Jan 03	-$418.71	0.39	

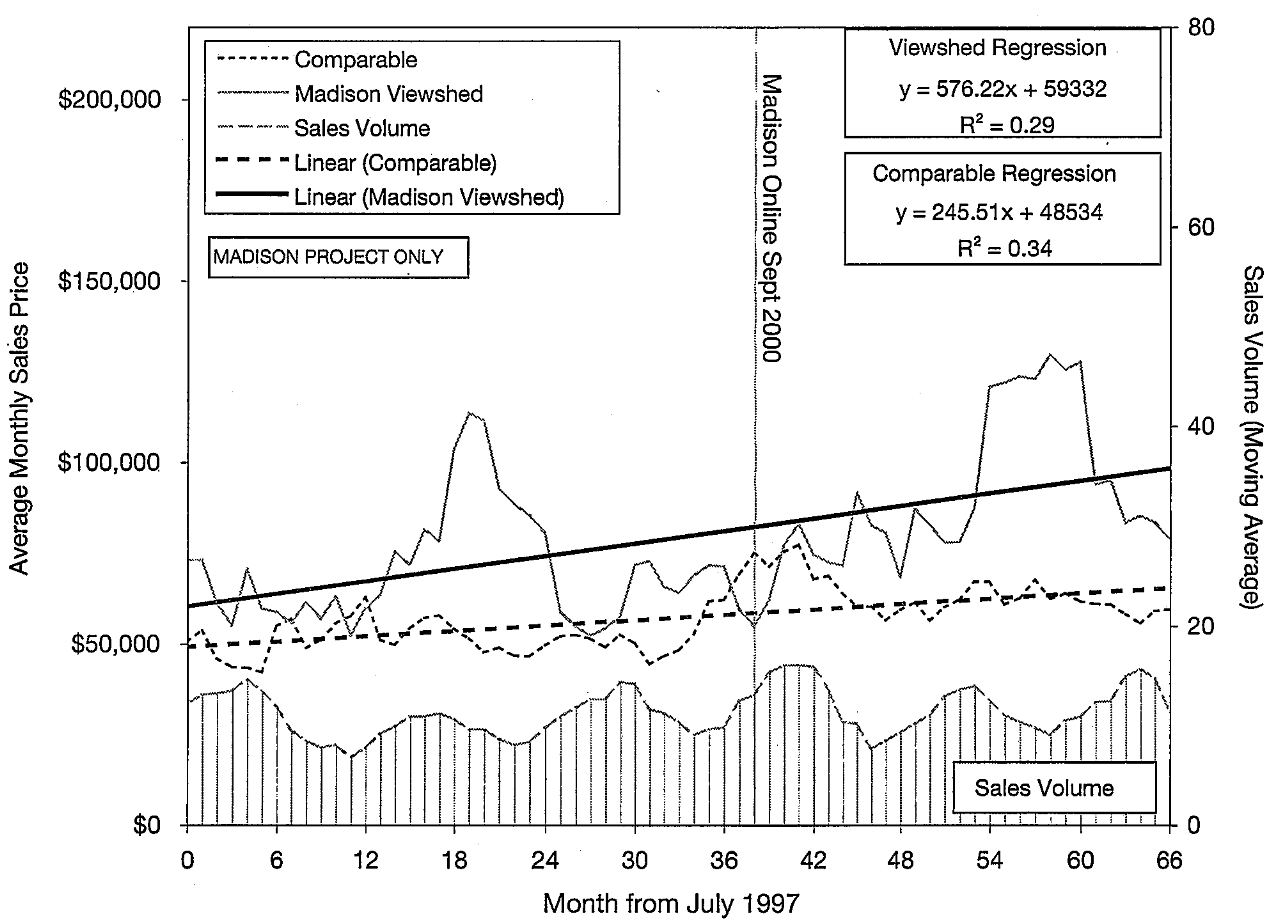

Figure 2.4 Average Residential Housing Sales Price For Madison Project
Madison County, New York 1997-2002

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Fenner View shed

In Case I, the monthly sales price change in the view shed is 50 percent greater than the monthly sales price change of the comparable over the study period. The Case I model explains approximately one-third of the variance in the data. In Case II, average monthly sales prices increase in the view shed prior to the on-line date, but decrease after the on-line date. The average view shed sales price after the on-line date decreased at 29 percent of the rate of increase before the on-line date. The Case II model provides a fair fit to the data before the on-line date, with half of the variance in the data explained by the linear regression, but a poor fit after the on-line date, explaining only 4 percent of the variance in the data. The poor fit is partly due to having only 14 months of data after the on-line date, which may not be enough data establish clear price trends in a housing market that exhibits significant price fluctuations over time. In Case III, average monthly sales prices decrease in both the view shed and comparable after the on-line date, with the view shed decreasing less quickly. The decrease in average view shed sales price after the on-line date is 37 percent less than the decrease of the comparable after the on-line date. The Case III model again describes only 4 percent of the variance in the view shed, but over 60 percent of the variance in the comparable. The data for the full study period is graphed in Figure 2.5, and the regression results are summarized in Table 2.5.

Table 2.5 Madison County, New York: Regression Results
Project: Fenner

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 97 - Jan 03 Jan 97 - Jan 03	$368.47 $245.51	0.35 0.34	The rate of change in average view shed sales price is 50% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 97 - Nov 01 Dec 01 - Jan 03	$587.95 -$418.98	0.50 0.04	The rate of decrease in average view shed sales price after the on-line date is 29% lower than the rate of sales price increase before the on-line date.
Case 3	View shed, after Comparable, after	Dec 01 - Jan 03 Dec 01 - Jan 03	-$418.98 -$663.38	0.04 0.63	The rate of decrease in average view shed sales price after the on-line date is 37% less than the rate of decrease of the comparable after the on-line date.

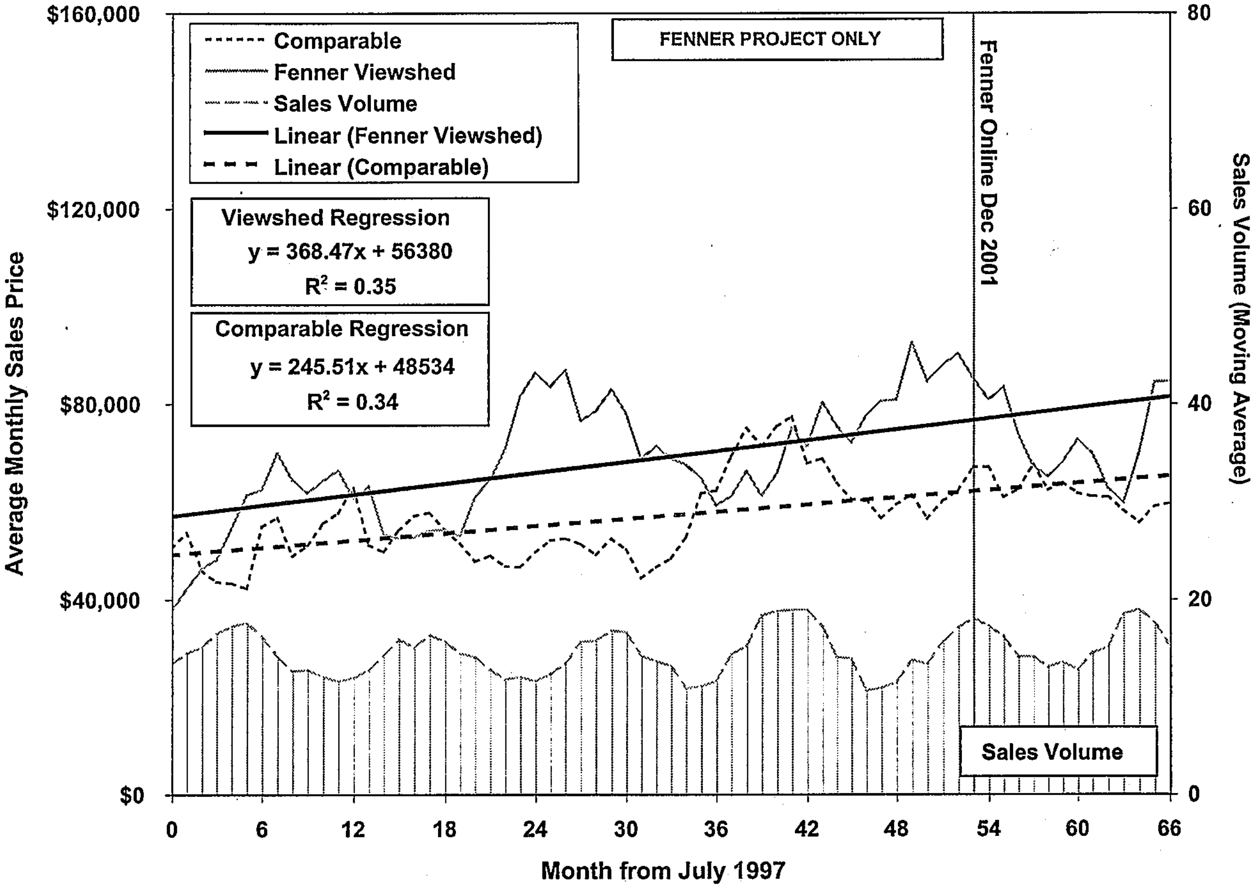

Figure 2.5 Average Residential Housing Sales Price For Fenner Project
Madison County, New York 1997-2002

D. Additional Interviewee Comments

Madison County assessors Carol Brophy and Priscilla Suits said they have not seen any impact of the turbines on property values, and Suits added, "There's been no talk of any impact on values." Assessor Russell Cary noted that there were worries about views of the turbines, and that the project siting was designed such that the town of Cazenovia could not see the project – it rests just outside the five-mile perimeter view shed this study designated.

Site Report 3: Carson County, Texas

A. Project Description

Situated in the middle of the Texas panhandle among large agricultural farms and small herds of cattle on fallow, 80 turbines stand at 70 meters (230 feet) high. Southwest of the project by 2.5 miles is White Deer town, which is 41 miles northeast of Amarillo.

The area is just about dead flat since Carson is right on the edge of the Texas High Plains. The general classification of the county is "completely rural or less than 2,500 urban population, but adjacent to a metro area." See Appendix 1 for a definition of rural urban continuum codes. The view shed represents fewer than 1,200 people.

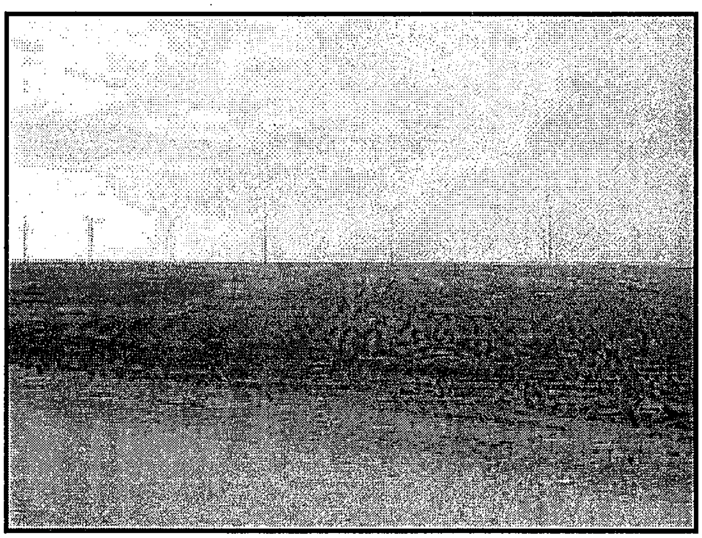

Figure 3.1 : White Deer Wind Farm
Photo Courtesy: Ted Carr © 2003

B. Project Timeline

Table 3.1 Wind Project History, Carson County, TX

Project Name	Completion Date	Capacity (MW)
Llano Estacado Wind Ranch	2001	80

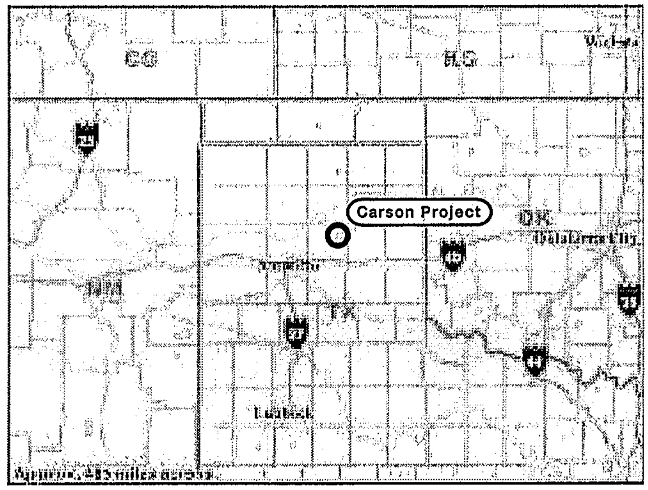

Figure 3.2. Regional Wind Project Location

(Dots approximate wind farm locations)

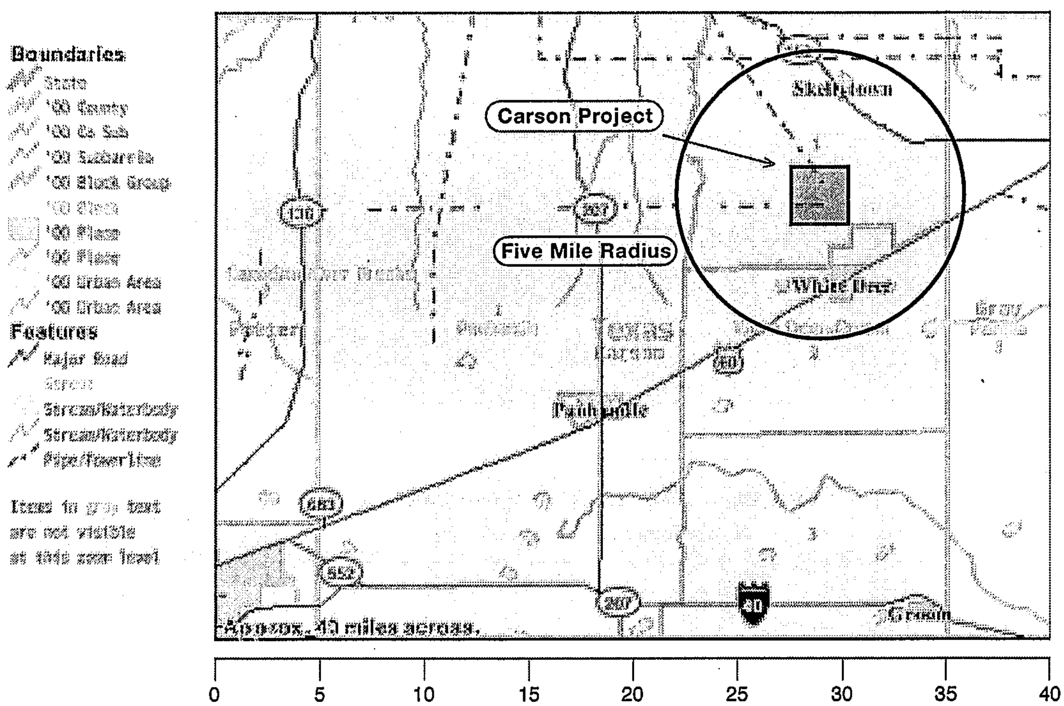

Figure 3.3. Carson County, Texas View shed

Site Location Source: Carson Appraisal District

Base Map Source: U.S. Census Bureau

C. Analysis

i. Data

Real property sales data for 1998 to 2002 was purchased in paper format from Carson County Appraisal District in Panhandle, TX. The sales data was purchased for the entire county, including the wind farm area and surrounding communities.. The unit of analysis for this dataset is defined by census block and section and incorporated city boundaries. A detailed landowners map from for the County that identified every parcel, section, and block in the county was purchased. The Appraiser marked the exact parcel locations of the wind farms on the map, eliminating any estimation of the actual wind farm location.

The dataset included only a few property attributes, such as residence square footage and age of home. While the dataset included all sales of land, commercial property, and residential property, the analysis included only improved lots with residential housing, with a total of 269 sales over the study period. While there were no questions about unusual data points, the view shed had only 45 sales over the five years of data analyzed. This meant that many months had no sales in the view shed. While the six-month trailing average smoothed out most of the gaps, there was a seven-month gap in view shed data from August 2001 through February 2002. As a proxy for the missing data, the average of the two previous months with sales was used to fill in the gap. In addition, a few low value sales and a number of months with no sales contributed to a very low average sale price in the view shed between July 2000 and May 2001.

ii. View Shed Definition

View shed definition using the five-mile radius was straightforward given the land owner map, exact wind farm location, and one-mile reference scale on the map. The town of White Deer lies entirely within the view shed. The region of Skellytown lies just outside the edge of the five-mile radius, too far to be defined as view shed, but too close given the flat land and easily seen wind turbines to be considered as part of the comparable. Thus Skellytown, with a total of 16 sales, was excluded from the analysis. The view shed accounts for 45 sales over the study period.

Interviews with the State of Texas Carson County Appraisal District officers were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Appraiser Mike Darnell's opinion, 90 to 100 percent of White Deer residents can see the project.

iii. Comparable Selection

The comparable community was selected through interviews with State of Texas Carson County Appraisal District personnel, as well as analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 3.2 and 3.3 summarize the Census data reviewed. In order to determine the most appropriate comparable community we looked at the demographics of three remaining residential areas in the county that were not part of the view shed and not excluded by being too close to the view shed.

Based on his experience in the area, Appraiser Mike Darnell suggested that Groom would be an appropriate comparable to the view shed area. However, Darnell said that homes in Fritch and Panhandle are more expensive, and have been increasing in value faster over time. Upon examination of Census data, sales data availability, and review of Assessor comments, all three residential areas, Fritch, Groom, and Panhandle were selected as the comparable, with a total of 224 sales from 1998 to 2002.

TABLE 3.2 CARSON COUNTY, TEXAS: 1990 CENSUS DATA

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	White Deer-Groom division	2,863	$23,883	8%	1,319	$34,700
1990	N	Panhandle division	3,713	$28,569	10%	1,537	$44,100
1990 COUNTY DEMOGRAPHICS			6,576	$26,226	9%	2,856	$39,400

TABLE 3.3 CARSON COUNTY, TEXAS: 2000 CENSUS DATA

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	White Deer-Groom CCD	2,702	$36,117	9%	1,261	$46,900
2000	N	Panhandle CCD	3,814	$43,349	6%	1,554	$59,400
2000 COUNTY DEMOGRAPHICS			6,516	$39,733	7%	2,815	$53,150

iv. Analytical Results and Discussion

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values.

In Case I, the monthly sales price change in the view shed is 2.1 times the monthly sales price change of the comparable over the study period. The Case I model provides a fair fit to the view shed data, with almost half of the variance in the data explained by the linear regression. However, the model only explains one-third of the variance in the comparable data. In Case II, the monthly sales price change in the view shed is 3.4 times greater after the on-line date than before the on-line date. The Case II model provides a poor fit to the data prior to the on-line date, with a quarter of the variance in the data explained by the linear regression. However, the fit after the on-line date is good, with over 80 percent of the variance explained. In Case III, average monthly sales prices increase in the view shed after the on-line date, but decrease in the comparable region. The average view shed sales price after the on-line date increased at 13.4 times the rate of decrease in the comparable after the on-line date. The Case III model describes over 80 percent of the variance in the view shed, but provides a very poor fit with only 2 percent of the variance explained in the comparable. The data for the full study period is graphed in Figure 3.4, and regression results for all cases are summarized in Table 3.4 below.

Table 3.4 Carson County, Texas: Regression Results
Project: Llano Estacado Wind Ranch

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 98 - Nov 02 Jan 98 - Nov 02	$620.47 $296.54	0.49 0.33	The rate of change in average view shed sales price is 2.1 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 98 - Oct 01 Nov 01 - Nov 02	$553.92 $1,879.76	0.24 0.83	The rate of change in average view shed sales price after the on-line date is 3.4 times greater than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	Nov 01 - Nov 02 Nov 01 - Nov 02	$1,879.76 -$140.14	0.83 0.02	The rate of change in average view shed sales price after the on-line date increased at 13.4 times the rate of decrease in the comparable after the on-line date.

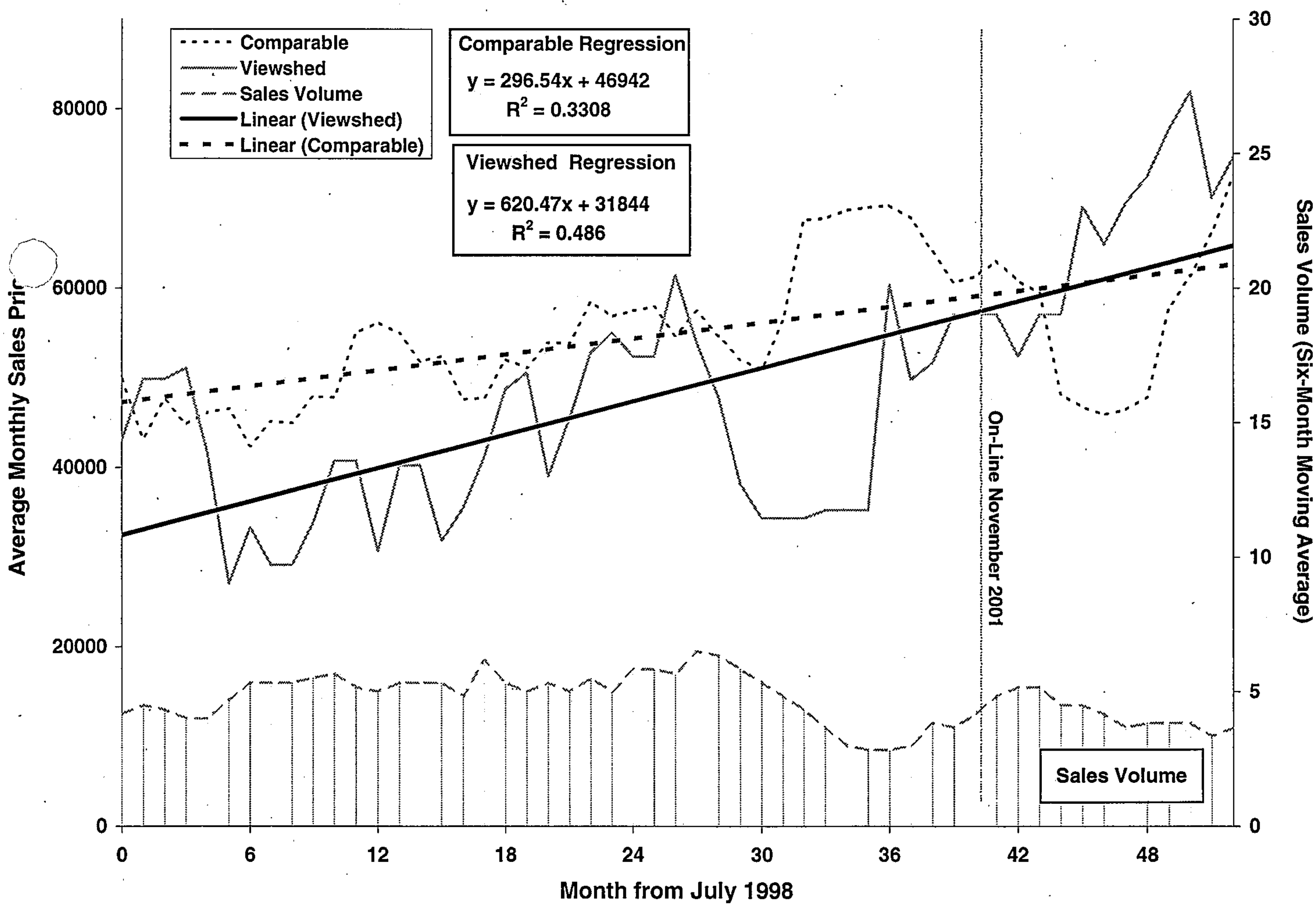

Figure 3.4 Average Residential Housing Sales Price
Carson County, Texas 1998-2002

D. Additional Interviewee Comments

Carson County officers Mike Darnell, appraisal district office, and Barbara Cosper, tax office, said most of the land in the view shed were farms, and that most residents in White Deer worked on the farms. Therefore, White Deer residents' interest in housing values was wholly dependent on their proximity to farms with no concern for the wind towers, she said. Darnell added that most residents in White Deer liked the turbines because they brought new jobs to the area, and there has been no talk of discontent with the turbines.

The county's main claim to fame is it's the home of Pantex; the only nuclear armament production and disassembly facility in the U.S., according to Department of Energy's www.pantex.com website.

Site Report 4: Bennington County, Vermont

A. Project Description

One mile due south of Searsburg, atop a ridge, stand 11 turbines with 40-meter (131 foot) hub heights in a line running north-south. The solid, white, conical towers rise well above dense woods, but the black painted blades are virtually invisible – especially when in motion. The site is in Bennington County less than a mile west of Windham County, and is midway between the two medium-size towns of Bennington and Brattleboro.

The area is defined as a non-metro area adjacent to a metro area, though not completely rural and with a population between 2,500 and 19,999. See Appendix 1 for a definition of rural urban continuum codes. The view shed has a population of fewer than 4,000.

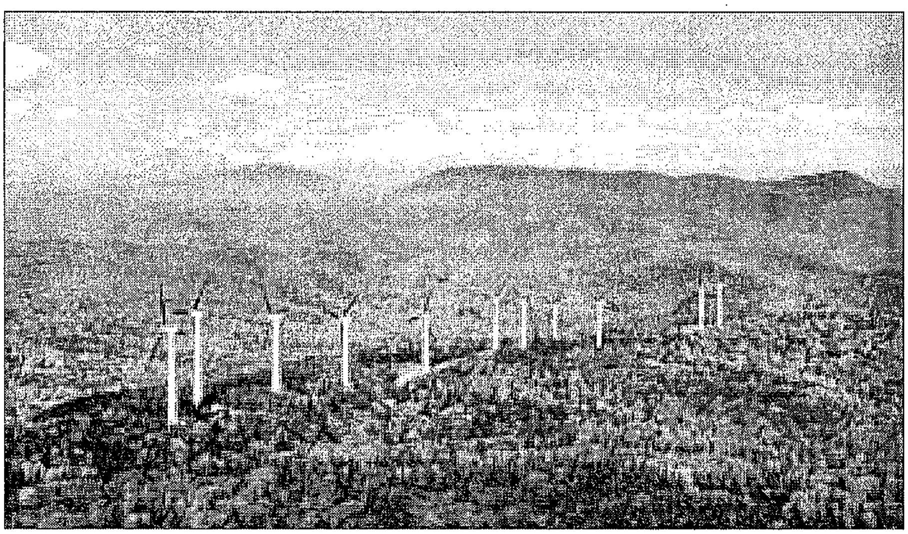

Figure 4.1 Searsburg wind project turbines
Photo courtesy Vermont Environmental Research Associates, 2002. www.northeastwind.com

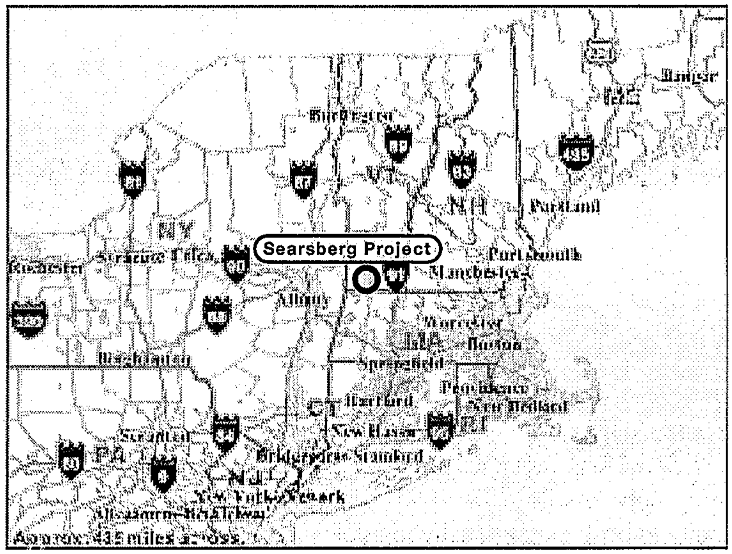

Figure 4.2 The Searsburg wind project is located in Southern Vermont
Base map image source: U.S. Census Bureau

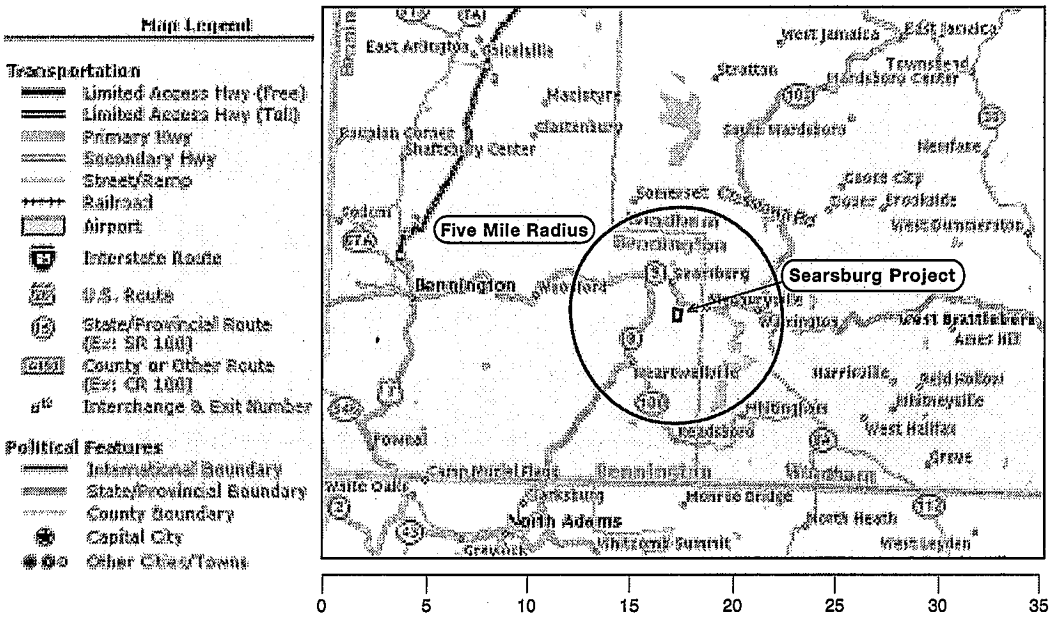

Figure 4.3. Searsburg, Vermont area View shed
Location Source: Vermont Environmental Associates

Base Map Source: MapQuest.com

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B. Project Timeline

Table 4.1 Wind Project History, Bennington County, VT

Project Name	Completion Date	Capacity (MW)
Searsburg	1997	6

C. Analysis

i. Data

Real property sales data for 1994 to 2002 was purchased in electronic form from Phil Dodd of VermontProperty.com in Montpelier, VT. Sales data was purchased for the townships and cities encompassing the wind farm area and surrounding communities, and was provided in two separate datasets. The first dataset, covering years 1994 through 1998, contained only annual average property sale prices and sales volumes, by town. No other locational data or property attributes were included. Property types from this dataset used in the analysis are primary residences and vacation homes, accounting for 1,584 sales.

The second dataset, contained information on individual property sales from May 1998 through October 2002, and accounted for 2,333 sales. The unit of analysis for the second dataset is towns. Some street addresses were included in the property descriptions, but many of these were only partial addresses. Property types from this dataset used in the analysis are primary homes, primary condominiums, vacation condominiums, and camp or vacation homes. The Searsburg wind farm went on-line in February 1997, with a capacity of 6 MW, during the time when only annually averaged sales data was available.

ii. View Shed Definition

The view shed is defined by a five-mile radius around the wind farm, and encompasses four incorporated towns: Searsburg in Bennington county, and Dover, Somerset, and Wilmington in Windham County. Interviews with the State of Vermont Windham County Listers Office were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. According to Newfane town Lister Doris Knechtel, approximately 10 percent of the Searsburg homes can see the wind farm. Listers were unable to estimate what percentage of properties could see the wind farms in the other view shed towns. The final view shed dataset contained 1,055 sales from 1994 to 1998 and 1,733 sales for 1999 to 2002, for a total of 2,788 sales.

iii. Comparable Selection

The comparable community was selected through interviews with Phil Dodd of VermontProperty.com, interviews with State of Vermont Listers, as well as analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 4.2 and 4.3 summarize the census data reviewed. In order to determine the most appropriate comparable community, we looked at the demographics of seven surrounding areas. Upon examination of Census data, sales data availability, and review of interview comments, Newfane and Whitingham in Windham County were selected as the comparable. The final comparable dataset contained 288 sales from 1994 to 1998 and 264 sales for 1999 to 2002, for a total of 552 sales from 1994 to 2002.

iv. Analytical Results and Discussion

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values.

Table 4.2 Bennington and Windham Counties, Vermont: 1990 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Searsburg village, Bennington Cty.	85	$26,875	9%	92	$61,500
1990	Y	Dover village, Windham Cty.	994	$30,966	7%	2450	$103,000
1990	Y	Wilmington village, Windham Cty.	1,968	$27,335	6%	2,176	$110,600
1990 VIEW SHED DEMOGRAPHICS			3,047	$28,392	7%	4,718	$91,700
1990	COMP	Newfane town, Windham Cty.	1,555	$31,935	7%	974	$103,000
1990	COMP	Whitingham village, Windham Cty.	1,177	$28,580	8%	737	$88,500
1990 COMPARABLE DEMOGRAPHICS			2,732	$30,258	8%	1,711	$95,750
1990	N	Halifax village, Windham Cty.	588	$23,750	15%	473	$81,600
1990	N	Readsboro village, Bennington Cty.	762	$25,913	12%	478	$65,400
1990	N	Stratton village, Windham Cty.	121	$31,369	2%	864	$162,500
1990	N	Woodford village, Bennington Cty.	331	$24,118	18%	267	$75,000
1990	N	Marlboro village, Windham Cty.	924	$29,926	10%	474	$103,300

Table 4.3 Bennington and Windham Counties, Vermont: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Searsburg village, Bennington Cty.	114	$17,500	18%	65	$86,700
2000	Y	Dover village, Windham Cty.	1410	$43,824	10%	2749	$143,300
2000	Y	Wilmington village, Windham Cty.	2,225	$37,396	9%	2,232	$120,100
2000 VIEW SHED DEMOGRAPHICS			3,749	$32,907	12%	5,046	$116,700
2000	COMP	Newfane town, Windham Cty.	1,680	$45,735	5%	977	$123,600
2000	COMP	Whitingham village, Windham Cty.	1,298	$37,434	8%	802	$111,200
2000 COMPARABLE DEMOGRAPHICS			2,978	$41,585	6%	1,779	$117,400
2000	N	Halifax village, Windham Cty.	782	$36,458	16%	493	$98,800
2000	N	Readsboro village, Bennington Cty.	803	$35,000	7%	464	$78,600
2000	N	Stratton village, Windham Cty.	136	$39,688	5%	1,091	$125,000
2000	N	Woodford village, Bennington Cty.	397	$33,929	17%	355	$91,300
2000	N	Marlboro village, Windham Cty.	963	$41,429	4%	495	$150,000

In Case I, the monthly sales price change in the view shed is 62 percent greater than the monthly sales price change of the comparable over the study period. The Case I model provides a reasonable fit to the view shed data, with 70 percent of the variance in the data for the view shed and 45 percent of the variance in the data for the comparable explained by the linear regression. In Case II, sales prices decreased in the view shed prior to the on-line date, and increased after the on-line date. The average view shed sales price after the on-line date increased at 2.6 times the rate of decrease in the view shed before the on-line date. The Case II model provides a good fit to the data, with 71 percent of the variance in the data for the view shed after the on-line date and 88 percent of the variance in the data before the on-line date explained by the linear regression. In Case III, average view shed sales prices after the on-line date are 18 percent greater than in the comparable. The Case III model describes over 70 percent of the variance in the data. The data for the full study period is graphed in Figure 4.4, and regression results for all cases are summarized in Table 4.4 below.

D. Additional Interviewee Comments

Newfane town Lister[1] Doris Knechtel said the area has a wide cross section of home values, styles, and uses (permanent residential and vacation homes). The other primary community in the view shed was Wilmington, which Knechtel said was a resort destination with more turnover than Searsburg.

Table 4.4 Regression Results, Bennington and Windham Counties, VT
Project: Searsburg

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 94 - Oct 02 Jan 94 - Oct 02	$536.41 $330.81	0.70 0.45	The rate of change in average view shed sales price is 62% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 94 - Jan 97 Feb 97 - Oct 02	-$301.52 $771.06	0.88 0.71	The rate of change in average view shed sales price after the on-line date increased at 2.6 times the rate of decrease before the on-line date.
Case 3	View shed, after Comparable, after	Feb 97 - Oct 02 Feb 97 - Oct 02	$771.06 $655.20	0.71 0.78	The rate of change in average view shed sales price after the on-line date is 18% greater than the rate of change of the comparable after the on-line date.

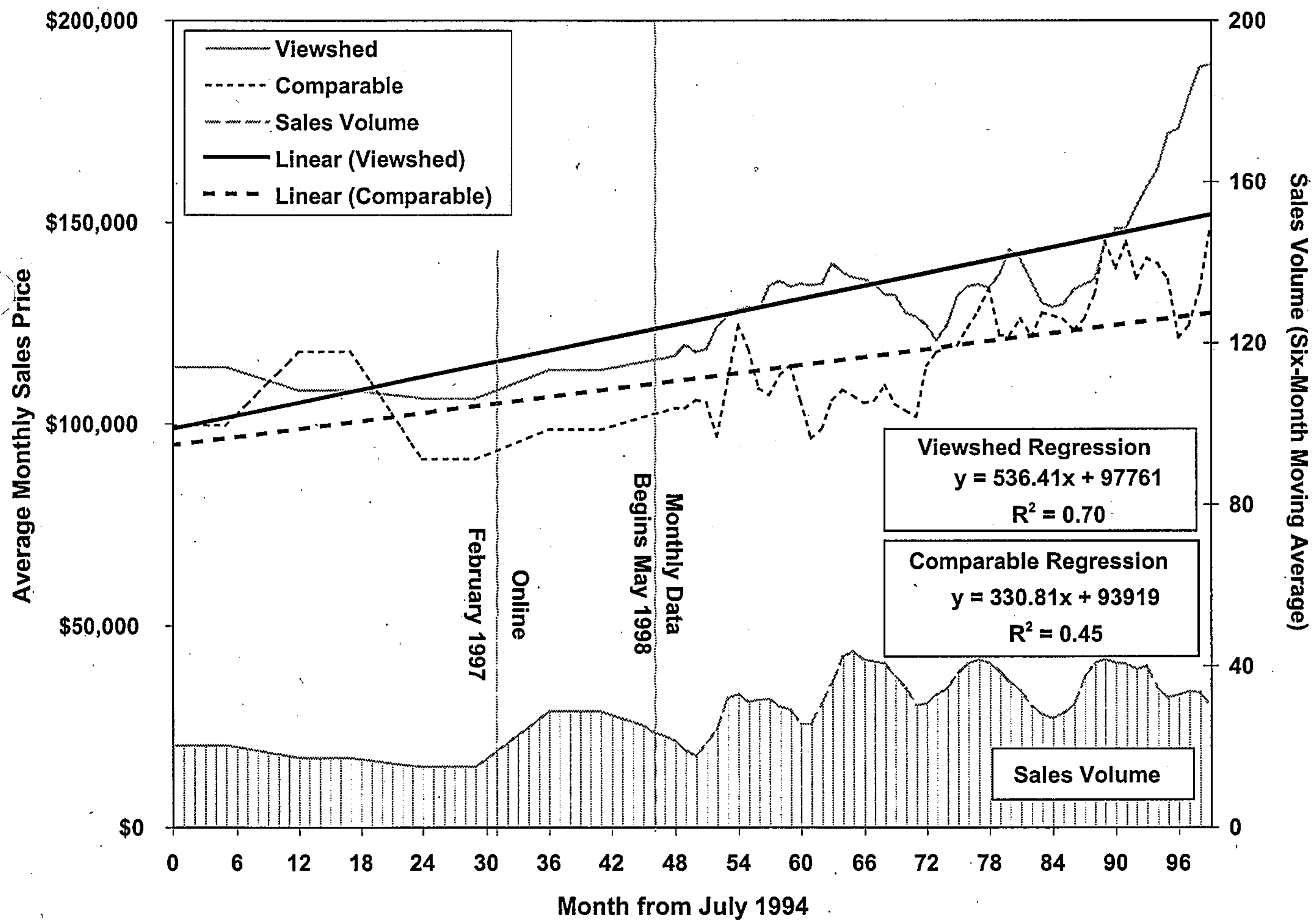

Figure 4.4 Average Residential Housing Sales Price
Bennington and Windham Counties, Vermont 1994-2002

1 Vermont property assessors are organized differently from any other state researched for this analysis. Assessors are called "listers" and operate per town – not on a township or county level. With small tax regions to support officials, local town offices are infrequently available, and in many cases neither had answering machines nor computers. The county government office confirmed that many Vermont offices didn't have computers, but were in the process of receiving them as of October 2002.

SITE REPORT 5: KEWAUNEE COUNTY, WISCONSIN

A. PROJECT DESCRIPTION

The regional topography has slight elevation changes with some rolling hills, but is mostly cleared agricultural land with intermittent groves. The two major wind farm projects occupy three sites that are all within five miles of each other, two in Lincoln Township and one in Red River Township. There are several small communities in Red River and Lincoln Townships that primarily work the agricultural lands.

The projects, installed in 1999, consist of 31 turbines with hub heights of 65 meters (213 feet). The nearest incorporated towns are Algoma to the east, Kewaunee to the southeast, and Luxemburg to the southwest. The wind farms are roughly 15 miles from the center of the Green Bay metropolitan area, and 10 miles from the outer edges of the city. The area is defined as a non-metro area adjacent to a metro area, though not completely rural and with a population between 2,500 and 19,999. See Appendix 1 for a definition of rural urban continuum codes. The view shed has a population of approximately 3,000.

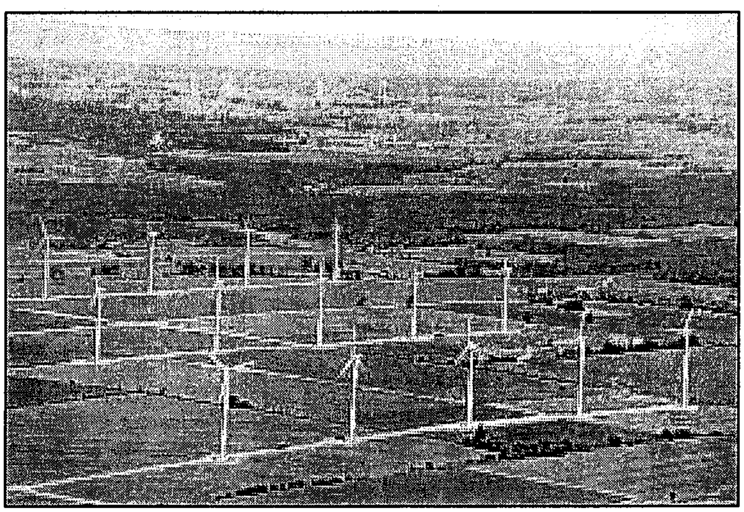

FIGURE 5.1 WIND PROJECTS IN RED RIVER AND LINCOLN TOWNSHIPS
PHOTO COURTESY WISCONSIN PUBLIC SERVICE CORPORATION

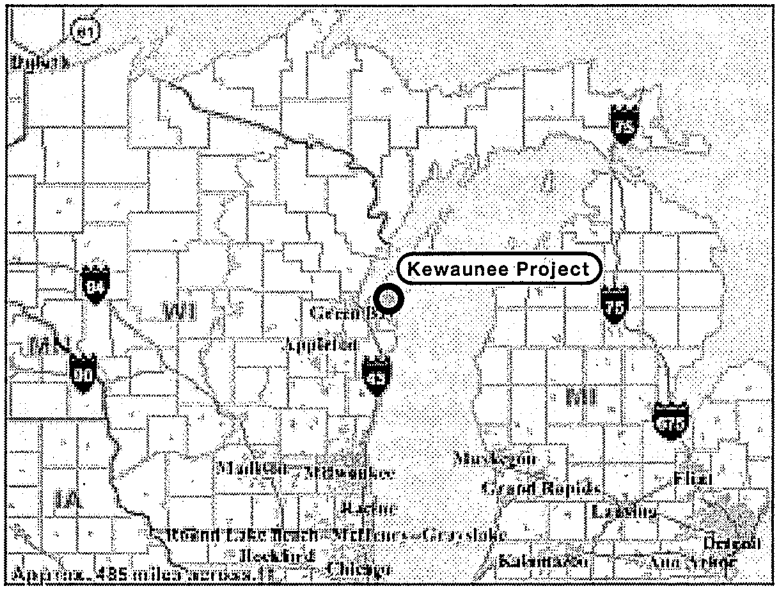

Figure 5.2 Location of Kewaunee County wind projects
Base map image source: U.S. Census Bureau

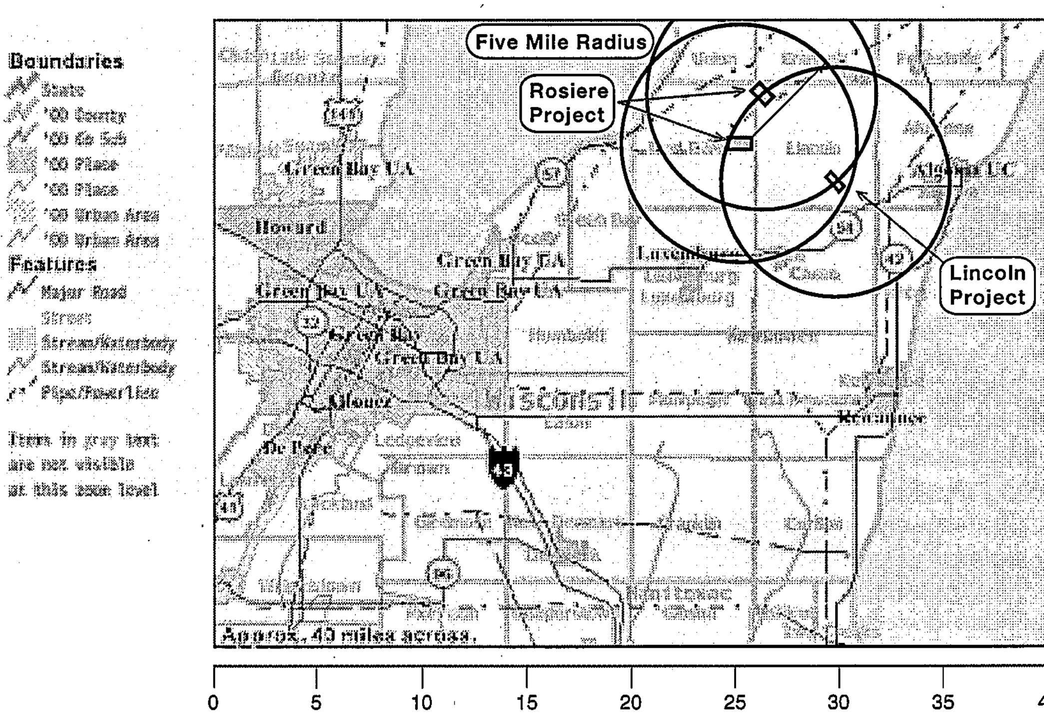

Figure 5.3. Kewaunee County View shed
Location Source: Kewaunee County Assessors Office
Base Map Source: U.S. Census Bureau

B. Project Timeline

Table 5.4 Wind Project History, Kewaunee County, WI

Project Name	Completion Date	Capacity (MW)
Lincoln (Gregorville, Lincoln Township)	1999	9.2
Rosiere (Lincoln and Red River Townships)	1999	11.2

C. Analysis

i. Data

Real property sales data for 1996 to 2002 was purchased in paper and electronic form from the State of Wisconsin Department of Revenue Bureau of Equalization Green Bay Office. Sales data was obtained for the townships and cities encompassing the wind farm area and surrounding communities, and was provided in two separate datasets. The first dataset consisted of paper copy of Detailed Sales Studies for residential properties from 1994 to 1999. These contained individual property sales by month, year, and township or district. Parcel numbers were included, but no other locational data or property attributes were available. The second dataset consisted of electronic files containing residential property sales data for 2000 to 2002. This dataset contained no detailed property attributes, and only partial street addresses. The units of analysis for the combined dataset are townships and villages. After discussion with the Property Assessment Specialist, three unusually high value sales were removed from the view shed dataset. The final dataset included 624 sales from 1996 to 2002.

The Lincoln wind farm near Gregorville and the Rosiere wind farm on the Lincoln/Red River Township Border both went on-line June 1999, with capacities of 9.2 MW and 11.2 MW, respectively.

ii. View Shed Definition

The view shed is defined by a five-mile radius around the wind farms. Because the view sheds of the individual wind farm sites overlap, and because all wind farms went on-line at the same time, a single view shed was defined. It encompasses all of Lincoln and Red River Townships, and the incorporated town of Casco in Casco Township. To assist in the view shed definition, detailed Plat maps for Lincoln and Red River Townships were obtained from the State of Wisconsin Bureau of Equalization Green Bay Office. These maps indicated every block and parcel in each township, and provided a one square mile grid to allow distance measurements. The location of each wind farm was marked on the map by the Bureau, and detailed aerial photos of each wind farm were also provided. This information allowed concise definition of the view shed area. Because only portions of Ahnapee, Luxemborg, and Casco Townships are in the view shed, these townships were excluded from consideration for either the view shed or comparable. The final view shed dataset contained 329 sales from 1996 to 2002.

Interviews with Kewaunee County Assessors were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. Assessor Dave Dorschner said 20 to 25 percent of Red River Township properties have views of the turbines. No one interviewed was able to estimate the percentage of properties in Lincoln Township or Casco Village with a view of the wind farms.

iii. Comparable Selection

The comparable community was selected through interviews with James W. Green, Bureau of Equalization Property Assessment Specialist, and analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 5.2 and 5.3 summarize the Census data reviewed. In order to determine the most appropriate comparable community, we looked at the demographics of eight surrounding areas. Upon examination of Census

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data, sales data availability, and review of interview comments, Carlton, Montpelier, and West Kewaunee Townships were selected as the comparable. The final comparable dataset contained 295 sales from 1996 to 2002.

Table 5.2 Kewaunee County, Wisconsin: 1999 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Casco village	544	$25,313	6%	223	$54,200
1990	Y	Lincoln town	996	$28,958	7%	338	$44,800
1990	Y	Red River town	1,407	$32,614	3%	552	$60,600
VIEW SHED DEMOGRAPHICS			2,947	$28,962	6%	1,113	$53,200
1990	COMP	Carlton town	1,041	$30,385	8%	383	$42,600
1990	COMP	Montpelier town	1,369	$31,600	8%	457	$61,300
1990	COMP	West Kewaunee town	1,215	$31,094	8%	451	$51,300
COMPARABLE DEMOGRAPHICS			3,625	$31,026	8%	1,291	$51,733
1990	N	Ahnapee town	941	$26,850	7%	406	$47,500
1990	N	Algoma City	3,353	$21,393	8%	1,564	$44,000
1990	N	Casco town	1,010	$33,807	4%	344	$57,200
1990	N	Franklin town	990	$32,625	14%	360	$53,300
1990	N	Kewaunee City	2,750	$22,500	14%	1,213	$46,600
1990	N	Luxemburg town	1,387	$35,125	5%	424	$60,600
1990	N	Luxemburg village	1,151	$24,702	6%	460	$58,200
1990	N	Pierce town	724	$25,812	12%	369	$60,400

Table 5.3 Kewaunee County, Wisconsin: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Casco village	572	$44,583	4%	236	$88,700
2000	Y	Lincoln town	957	$42,188	9%	346	$100,000
2000	Y	Red River town	1,476	$47,833	6%	601	$117,900
VIEW SHED DEMOGRAPHICS			3,005	$44,868	6%	1,183	$102,200
2000	COMP	Carlton town	1,000	$50,227	3%	383	$98,900
2000	COMP	Montpelier town	1,371	$51,000	4%	492	$112,000
2000	COMP	West Kewaunee town	1,287	$47,059	6%	485	$101,300
COMPARABLE DEMOGRAPHICS			3,658	$49,429	4%	1,360	$104,067
2000	N	Ahnapee town	977	$47,500	3%	426	$95,200
2000	N	Algoma City	3,357	$35,029	5%	1,632	$74,500
2000	N	Casco town	1,153	$46,250	4%	404	$107,800
2000	N	Franklin town	997	$52,019	2%	359	$114,900
2000	N	Kewaunee City	2,806	$36,420	11%	1,237	$79,700
2000	N	Luxemburg town	1,402	$54,875	1%	459	$121,600
2000	N	Luxemburg village	1,935	$45,000	6%	754	$105,100
2000	N	Pierce town	897	$43,000	15%	407	$98,900

iv. Analytical Results and Discussion

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values. However, the fit of the linear regression is poor for all cases analyzed. Very low sales volumes, averaging 3.6 sales per month from 1996 to 1999, lead to large fluctuations in average sales prices from individual property sales. This contributes to the low R2 values.

In Case I, the monthly sales price change in the view shed is 3.7 times the monthly sales price change of the comparable over the study period. However, the Case I model provides a poor fit to the view shed data, with 26 percent and 5 percent of the variance in the data explained by the linear regression in the view shed and comparable, respectively. In Case II, sales prices decreased in the view shed prior to the on-line date, and increased after the on-line date. The average view shed sales price after the on-line date increased at 3.5 times the rate of decrease in the view shed before the on-line date. The Case II model provides a poor fit to the data, with 32 percent of the variance in the data for the view shed after the on-line date and 2 percent of the variance in the data before the on-line date explained by the linear regression. In Case III, average monthly sales prices increase in the view shed after the on-line date, but decrease in the comparable region. The average view shed sales price after the on-line date increases 33 percent quicker than the comparable sales price decreases after the on-line date. The Case III model describes approximately a third of the variance in the data. The data for the full study period is graphed in Figure 5.4, and regression results for all cases are summarized in Table 5.4 below.

TABLE 5.4 REGRESSION RESULTS, KEWAUNEE COUNTY, WI
PROJECTS: RED RIVER (ROSIERE), LINCOLN (ROSIERE), LINCOLN (GREGORVILLE)

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Sep 02 Jan 96 - Sep 02	$434.48 $118.18	0.26 0.05	The rate of change in average view shed sales price is 3.7 times greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - May 99 Jun 99 - Sep 02	-$238.67 $840.03	0.02 0.32	The increase in average view shed sales price after the on-line date is 3.5 times the decrease in view shed sales price before the on-line date.
Case 3	View shed, after Comparable, after	Jun 99 - Sep 02 Jun 99 - Sep 02	$840.03 -$630.10	0.32 0.37	The average view shed sales price after the on-line date increases 33% quicker than the comparable sales price decreases after the on-line date.

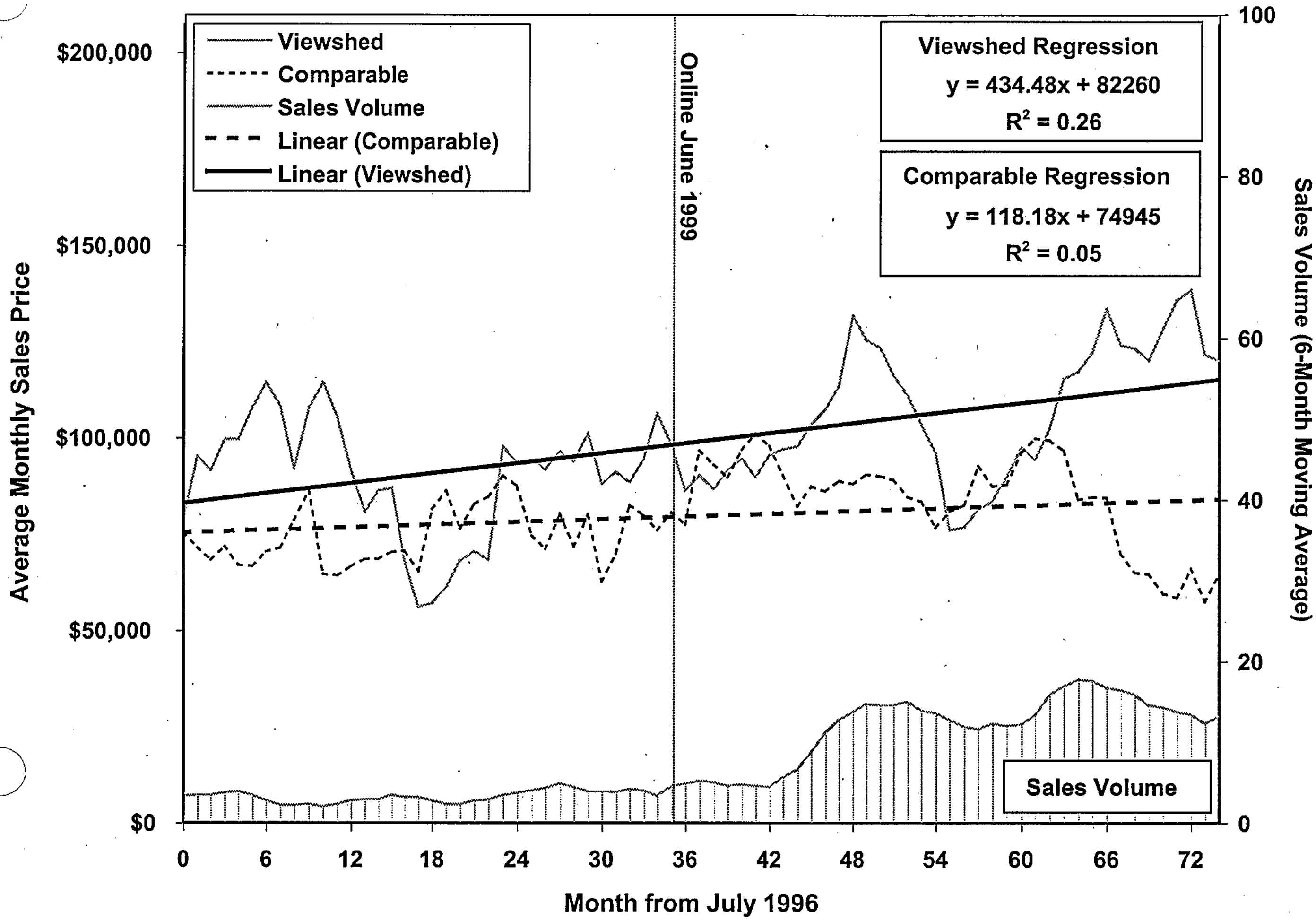


Figure 5.4 Average Residential Housing Sales Price
Kewaunee County, Wisconsin 1996-2002

D. Additional Interviewee Comments

Assessor Dave Dorschner said he has not seen an impact on property values except for those immediately neighboring the project sites. In the cases of neighboring property, he said some homes were sold because of visual and/or auditory distraction, but some of the properties were purchased speculatively in hope that a tower might be built on the property.

James W. Green, Wis. Bureau of Equalization property assessment specialist, also said he has not seen any impact of the turbines on property values. He added that he has seen greater property value increases in the rural areas than in the city because people were moving out of the Green Bay area opting for rural developments or old farmhouses.

Site Report 6: Somerset County, Pennsylvania

A. Project Description

There are two major wind farms in Somerset County, Somerset and Green Mountain. They are about 20 miles due east of the wind farm in Fayette County, PA. The Somerset project has six turbines 64 meters (210 feet) high along a ridge crest east Somerset town. The Green Mountain project has eight turbines at 60 meters (197 feet). They are about 10 miles southwest of the Somerset project, and a mile west of Garret town.

The area is almost the same as Fayette County, but slightly less hilly – dense populations of tall trees, frequent overcast, and primarily rural development. The area is classified as a "county in a metro area with fewer than 250,000." See Appendix 1 for a definition of rural urban continuum codes. The view shed has a population of approximately 19,000.

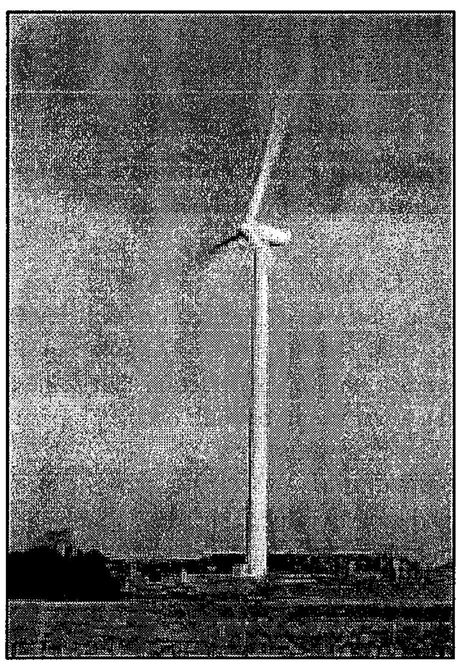


Figure 6.1 Somerset wind tower

Photo courtesy GE Wind Energy © 2002

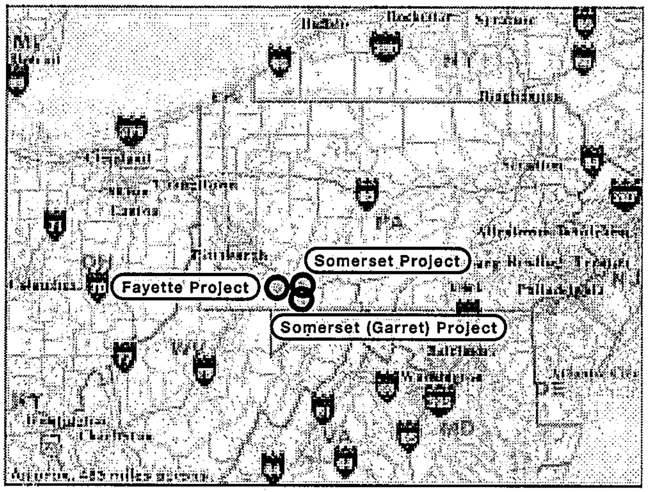


FIGURE 6.2 GENERAL LOCATION OF SOMERSET AND FAYETTE COUNTY WIND PROJECTS
BASE MAP IMAGE SOURCE: U.S. CENSUS BUREAU

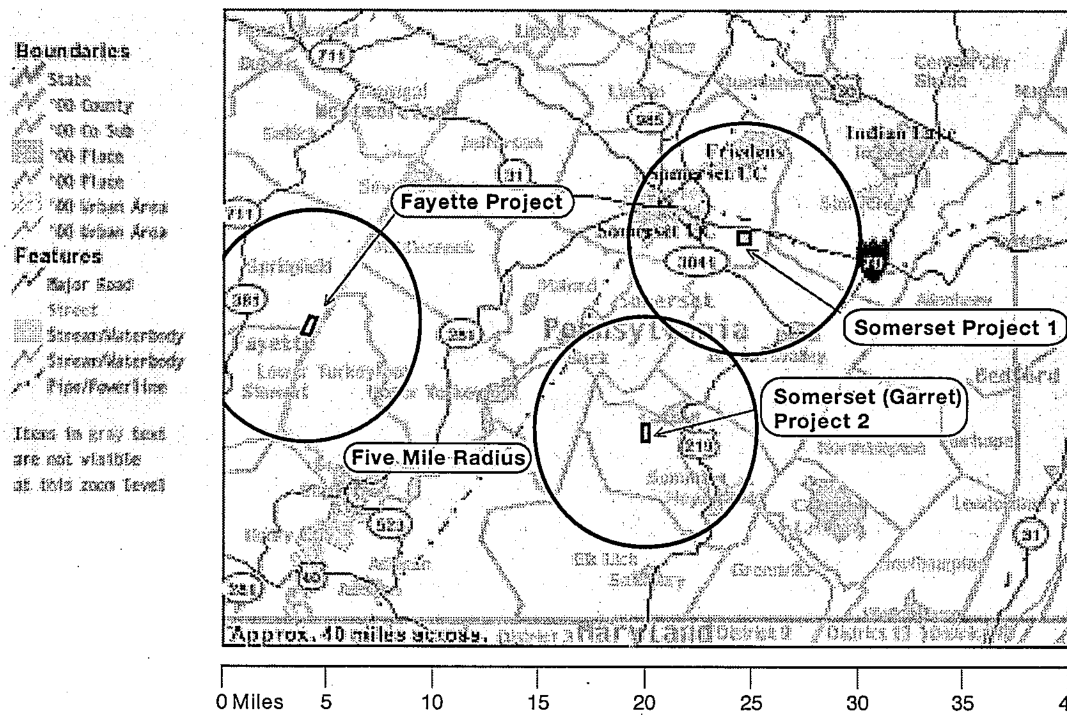


FIGURE 6.3. SOMERSET COUNTY, PENNSYLVANIA VIEW SHED
LOCATION SOURCE: SOMERSET COUNTY ASSESSORS OFFICE

BASE MAP SOURCE: U.S. CENSUS BUREAU

B. PROJECT TIMELINE

TABLE 6.1 WIND PROJECT HISTORY, SOMERSET COUNTY, PA

Project Name	Completion Date	Capacity (MW)
Somerset	2001	9.0
Green Mountain Wind Farm	2000	10.4

C. Analysis

i. Data

Real property sales data for 1997 to 2002 was obtained in electronic form from the State of Pennsylvania Somerset County Assessment Office in Somerset, PA. Sales data was obtained for the townships and cities encompassing the wind farm area and surrounding communities. The electronic files contain residential property sales data for 2000 to 2002. Residential types included in the analysis are homes, homes converted to apartments, mobile homes with land, condominiums, townhouses, and one mobile home on leased land. The dataset contained lot acreages and brief building descriptions, and some, but not all, records provided additional property attributes. As street addresses were not provided, the units of analysis for the dataset are townships and villages. The final dataset included 1,506 residential property sales from 1997 to 2002.

The Somerset wind farm went on-line October 2001 and the Green Mountain wind farm near Garrett went on-line May 2000, with capacities of 9.0 MW and 10.4 MW, respectively.

ii. View Shed Definition

The view shed is defined by a five-mile radius around the wind farms. Because the view sheds of the individual wind farm sites overlap, a single view shed was defined. It encompasses all of Somerset and Summit Townships, and the Garrett and Somerset Boroughs within these townships. Locational data for the wind farm's was obtained from utility and wind industry web sites, and used in conjunction with maps and interviews with the Somerset County Mapping Department to identify the exact location and extent of the wind farms and view shed. Townships only partially within the view shed were excluded from consideration for either the view shed or comparable. The final view shed dataset contains 962 sales from 1997 to 2002.

Interviews with Somerset County Assessors were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Assessor Hudack's opinion, 10 percent of Somerset properties can see the turbines, and roughly 20 percent of Garrett properties have a view.

iii. Comparable Selection

The comparable community was selected through interviews with Assessors John Riley and Joe Hudack of the State of Pennsylvania Somerset County Assessment Office, and analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 6.2 and 6.3 summarize the Census data reviewed. In order to determine the most appropriate comparable community we looked at the demographics of three surrounding areas. Upon examination of Census data, sales data availability, and review of interview comments, Conemaugh Township was selected as the comparable. The final comparable dataset contained 422 sales from 1997 to 2002.

iv. Analytical Results and Discussion

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values.

In Case I, the monthly sales price change in the view shed is 90 percent greater than the monthly sales price change of the comparable over the study period. The Case I model provides a poor fit to the view shed data, with 30 percent of the variance in the data for the view shed and 7 percent of the variance in the data for the comparable explained by the linear regression. In Case II, the monthly sales price change in the view shed is 3.5 times greater after the on-line date than before the on-line date. The Case II model provides a poor fit to the data prior to the on-line date, with 37 percent, of the variance in the data explained by the linear regression, but a reasonable fit after the on-line date, with 62 percent of the variance explained. In Case III, average monthly sales prices increase in the view shed after the on-line date, but decrease in the comparable region. The average view shed sales price after the on-line date increased at 2.3 times the rate of decrease in the comparable after the on-line date. The Case III model describes 62 percent of the variance in the view shed, but only 23 percent of the variance in the comparable. The data for the full study period is graphed in Figure 6.4, and regression results for all cases are summarized in Table 6.4 below.

Table 6.2 Somerset County, Pennsylvania: 1990 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Garrett Borough	520	$16,071	26%	218	$27,100
1990	Y	Somerset Borough	6,454	$19,764	18%	3,100	$58,800
1990	Y	Somerset Twsp	8,732	$25,631	10%	3,296	$57,100
1990	Y	Summit Twsp	2,495	$22,868	17%	942	$40,800
VIEW SHED DEMOGRAPHICS			18,201	$21,084	18%	7,556	$45,950
1990	COMP	Conemaugh Twsp	7,737	$25,025	8%	3,070	$43,100
COMPARABLE DEMOGRAPHICS			7,737	$25,025	8%	3,070	$43,100
1990	N	Boswell Borough	1,485	$16,128	29%	670	$39,700
1990	N	Milford Twsp	1,544	$24,821	9%	666	$47,400

Table 6.3 Somerset County, Pennsylvania: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Garrett Borough	449	$24,609	16%	180	$38,600
2000	Y	Somerset Borough	6,762	$29,050	12%	3,313	$87,200
2000	Y	Somerset Twsp	9,319	$33,391	9%	3,699	$76,300
2000	Y	Summit Twsp	2,368	$32,115	17%	930	$67,700
VIEW SHED DEMOGRAPHICS			18,898	$29,791	13%	8,122	$67,450
2000	COMP	Conemaugh Twsp	7,452	$30,530	7%	3,089	$61,800
COMPARABLE DEMOGRAPHICS			7,452	$30,530	7%	3,089	$61,800
2000	N	Boswell Borough	1,364	$20,875	29%	681	$54,000
2000	N	Milford Twsp	1,561	$34,458	14%	658	$75,300

TABLE 6.4 REGRESSION RESULTS, SOMERSET COUNTY, PA
PROJECTS: SOMERSET, GREEN MOUNTAIN

Model	Dataset	Dates	Rate of Change ($/ month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 97 - Oct 02 Jan 97 - Oct 02	$190.07 $100.06	0.30 0.07	The rate of change in average view shed sales price is 90% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 97 - Apr 00 May 00 - Oct 02	$277.99 $969.59	0.37 0.62	The rate of change in average view shed sales price after the on-line date is 3.5 times greater than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 00 - Oct 02 May 00 - Oct 02	$969.59 -$418.73	0.62 0.23	The rate of change in average view shed sales price after the on-line date increased at 2.3 times the rate of decrease in the comparable after the on-line date.

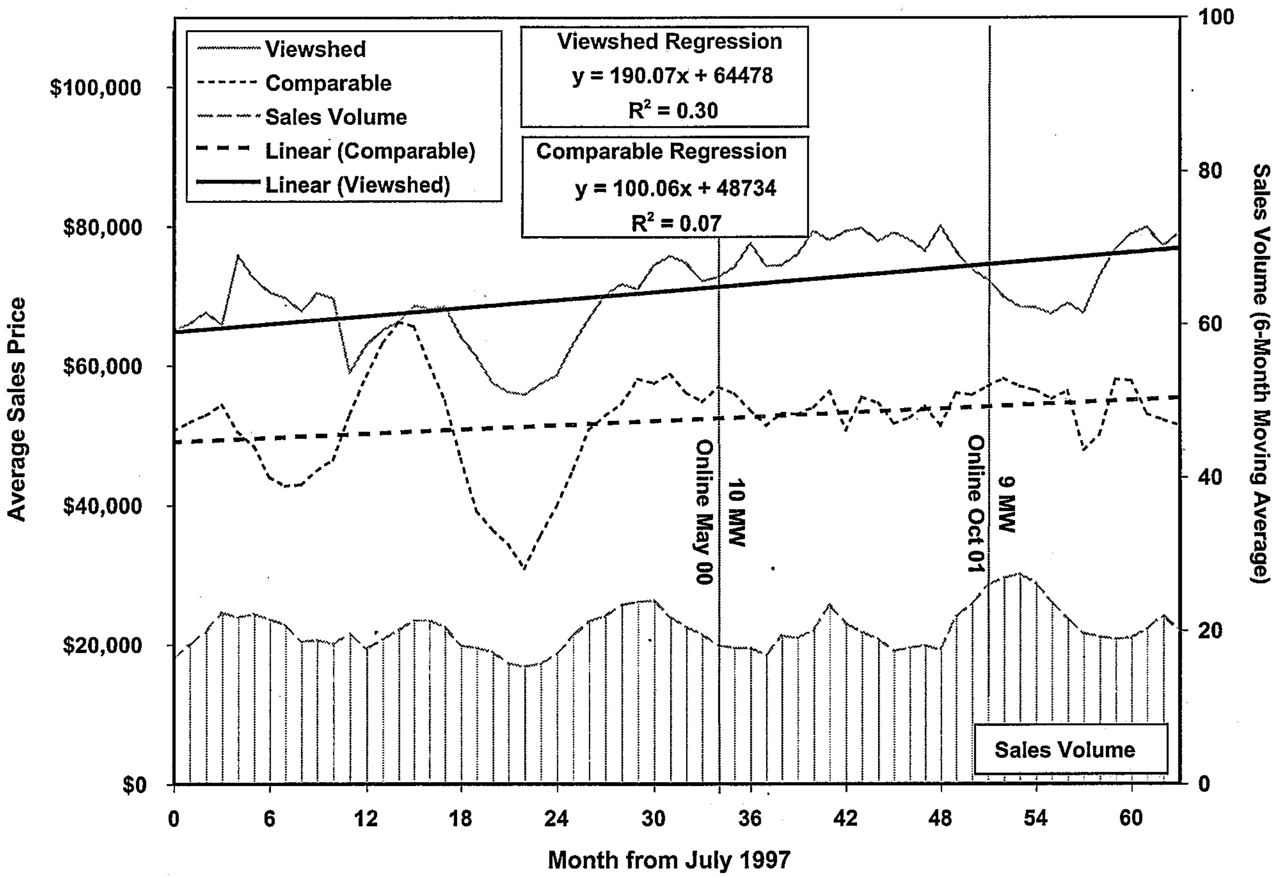


FIGURE 6.4 AVERAGE RESIDENTIAL HOUSING SALES PRICE
SOMERSET COUNTY, PENNSYLVANIA 1997-2002

D. ADDITIONAL INTERVIEWEE COMMENTS

Assessor Joe Hudack said he has not seen any impact on property values from wind farms. The turbines outside Somerset were also "not glaring," but could be seen from the PA Turnpike. The Green Mountain turbines outside Garret were noticeable, but because there were so few people residing there, he hasn't seen much housing turnover to base an opinion, he said.

Site Report 7: Buena Vista County, Iowa

A. Project Description

The geography of the view shed and comparable regions is flat with minimal elevation changes. The region is mostly cleared land for agricultural production, with trees along irrigation ditches or planted around homes for shade and wind dampening.

Figure 7.1 750 kW Zond wind turbines 1.5 miles east of Alta, Iowa
Photo Courtesy: Waverly Light and Power © 2002

Surrounding Alta, Iowa and west of the town along the Buena Vista and Cherokee counties' border, 257 towers with 63 meter [207 ft] hub heights stand among agricultural farms and scattered homes. Project Storm Lake I comprises 150 towers around Alta extending 1.5-2.5 miles east and west, 1.5 miles south, and five miles north. Throughout the project, the turbines are consistently spaced 3.6 rotor diameters, or about 180 m (590 ft) apart. Project Storm Lake II comprises 107 towers, eight miles northwest of Alta, with several towers over the county border into neighboring Cherokee County. The exact location of all turbines was obtained from the Waverly Power and Light website. All towers have white color blades and hubs with either grey, trussed towers or white solid towers. Solid red lights are required by the FAA on the nacelles of alternate turbines.

Buena Vista County is classified as an "urban population with 2,500 to 19,999 not adjacent to a metro area." See Appendix 1 for a definition of rural urban continuum codes. This analysis defines two possible view sheds, depending on whether Storm Lake City is included in the analysis. Accordingly, the view shed has a population of either 4,000 or 14,000, depending on its definition.

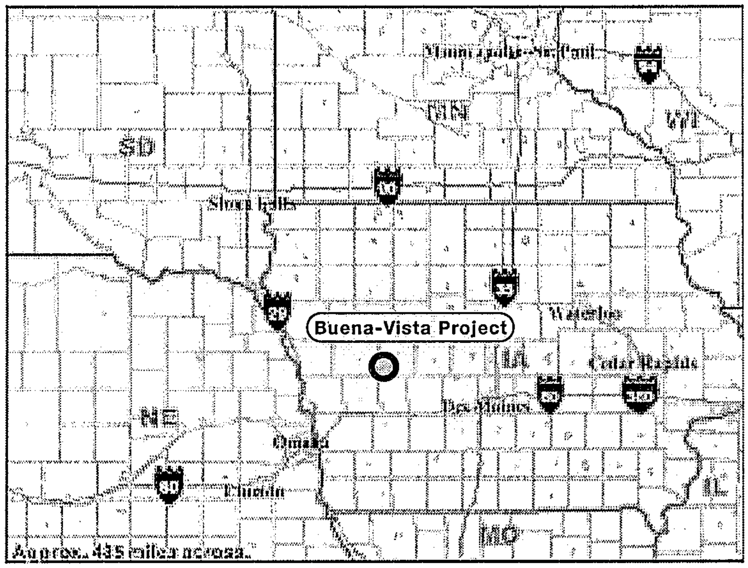


Figure 7.2 Regional Wind Project Location
(Dot approximate wind farm locations)

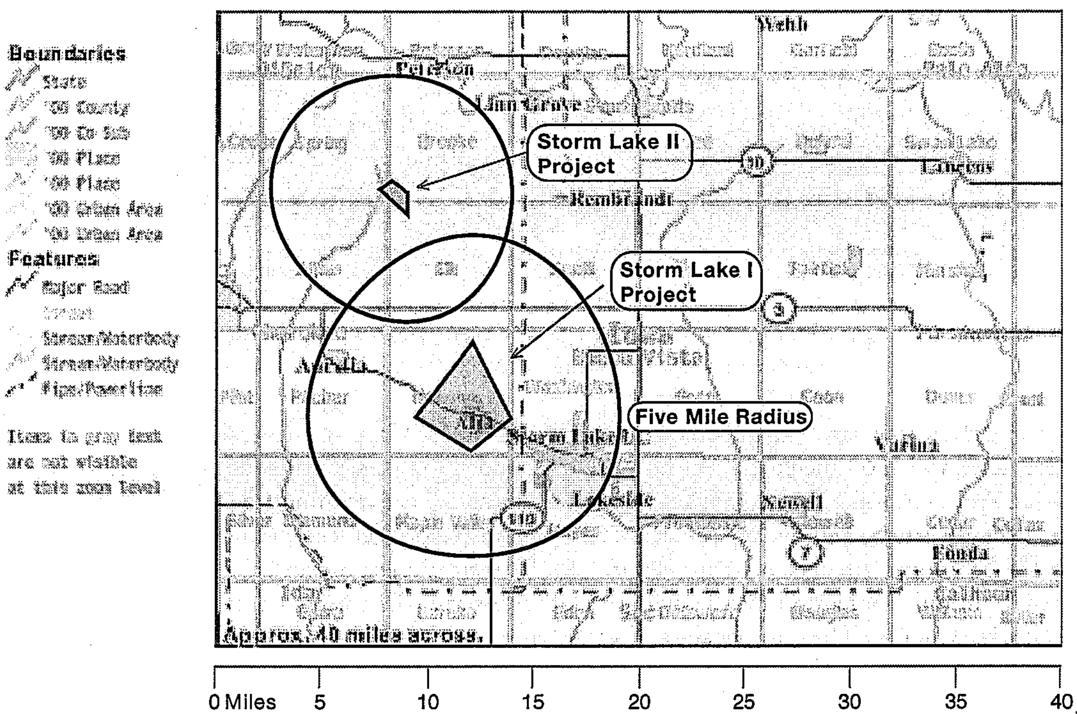


Figure 7.3. Buena-Vista, County, Iowa View shed
Location Source: Buena-Vista County Assessors Office

Base Map Source: U.S. Census Bureau

B. Project Timeline

Table 7.1 Wind Project History, Somerset County, PA

Project Name	Completion Date	Capacity (MW)
Storm Lake I	1999	112.5
Storm Lake II	1999	80.2

C. Analysis

i. Data

Real property sales data for 1996 to 2002 was obtained in electronic form from the Iowa State Assessors Office Website at www.iowaassessors.com. Sales data was obtained for the townships and cities encompassing the wind farm area and surrounding communities. The electronic data gathered contains residential property sales prices, parcel numbers, street addresses, year built and square footage. The unit of analysis for this dataset is defined by either township or incorporated city boundaries. Though street addresses are included in the dataset, this analysis lacked the resources to identify the location of properties by street address. The final dataset included 3,213 residential property sales from 1996 to 2002.

The Storm Lake II wind farm went on-line June 1999 and the Storm Lake I wind farm went on-line May 1999, with capacities of 112.5 MW and 80.2 MW, respectively.

ii. View Shed Definition

The view shed is defined by a five-mile radius around the wind farms. Because the view sheds of the individual wind farm sites overlap, and the on-line dates are within a month of each other, a single view shed was defined. Locational data for the wind farms was obtained from utility and wind industry web sites, and used in conjunction with maps and phone interviews to identify the exact location and extent of the wind farms and view shed. Townships only partially within the view shed were excluded from consideration for either the view shed or comparable.

Interviews with Somerset County Assessors were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Buena Vista County Assessor Ted Van Groteest's opinion, 100 percent of the properties in Alta have views of turbines, 75 percent of Nokomis Township have views, and five to 10 percent of Storm Lake City properties have views. However, he estimated that all the waterfront properties on the southeast side of Storm Lake can see turbines when looking northwest. Storm Lake City has a population of approximately 10,000, while Nokomis Township and Alta City have a combined population of approximately 2,000.

This report examines two cases for Buena Vista County.

Analysis #1: Storm Lake City Excluded from View Shed

For the first analysis, the view shed consists only of the village and township in which the wind turbines are located. In this case approximately 75 to 100 percent of the residential properties sold are within view of the wind farm, and are at most 3.5 miles from wind turbines, and in most cases much closer. We believe that if wind farms negatively effect property values, this effect would be strongest in this smaller radius view shed. The Analysis #1 view shed dataset contains 288 sales from 1996 to 2002.

Analysis #2: Storm Lake City Included in View Shed

For the second analysis, the view shed contains Storm Lake City, which is mainly within the five-mile view shed radius, in addition to Alta City and Nokomis Township as included in Analysis #1. Because Storm Lake City's population is five times larger than that of the Alta and Nokomis combined, and because estimates are that roughly 5 percent of Storm Lake City properties can see the wind farms, we believe that any negative property value effects from the wind farms may be overshadowed by economic and demographic trends in Storm Lake City that are distinct from any effect the wind farms may have. The Analysis #2 view shed dataset contains 1,557 sales from 1996 to 2002.

iii. Comparable Selection

The comparable community was selected through interviews with Buena Vista County Assessor Ted Van Groteest, and analysis of demographic data from the 1990 and 2000 U.S. Census for communities near but outside of the view shed. Tables 7.2 and 7.3 summarize the Census data reviewed. In order to determine the most appropriate comparable community, we looked at the demographics of five comparable communities. Upon examination of Census data, sales data availability, and review of interview comments, one city and four townships in Clay County, just to the north of Buena Vista County, were selected as the comparable. The comparables are Spencer City, and Meadow, Riverton, Sioux, and Summit Townships. The final comparable dataset contained 1,656 sales from 1996 to 2002.

TABLE 7.2 BUENA VISTA COUNTY, IOWA: 1990 CENSUS DATA

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	Y	Nokomis Township, Buena Vista County	2,174	$24,915	10%	872	$41,300
1990	Y	Alta City, Buena Vista County	1,824	$23,043	12%	754	$40,400
VIEW SHED DEMOGRAPHICS #1			3,998	$23,979	11%	1,626	$40,850
1990	Y	Nokomis Township, Buena Vista County	2,174	$24,915	10%	872	$41,300
1990	Y	Storm Lake City, Buena Vista County	8,769	$23,755	9%	3,557	$47,000
1990	Y	Alta City, Buena Vista County	1,824	$23,043	12%	754	$40,400
VIEW SHED DEMOGRAPHICS #2			12,767	$23,904	11%	5,183	$42,900
1990	COMP	Meadow Township, Clay County	432	$24,000	12%	142	$60,500
1990	COMP	Riverton Township, Clay County	323	$26,875	19%	115	$47,500
1990	COMP	Sioux Township, Clay County	348	$35,417	2%	134	$42,100
1990	COMP	Spencer City, Clay County	11,066	$24,573	10%	4,824	$45,200
1990	COMP	Summit Township, Clay County	409	$27,266	5%	201	$30,400
COMPARABLE DEMOGRAPHICS			12,578	$27,626	9%	5,416	$45,140

Table 7.3 Buena Vista County, Iowa: 2000 Census Data

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	Y	Nokomis Township, Buena Vista County	2,261	$33,533	11%	922	$69,800
2000	Y	Alta City, Buena Vista County	1,848	$31,941	11%	791	$66,700
VIEW SHED DEMOGRAPHICS #1			4,109	$32,737	11%	1,713	$68,250
2000	Y	Nokomis Township, Buena Vista County	2,261	$33,533	11%	922	$69,800
2000	Y	Storm Lake City, Buena Vista County	10,150	$35,270	12%	3,732	$70,300
2000	Y	Alta City, Buena Vista County	1,848	$31,941	11%	791	$66,700
VIEW SHED DEMOGRAPHICS #2			14,259	$33,581	11%	5,445	$68,933
2000	COMP	Meadow Township, Clay County	323	$49,167	2%	129	$82,900
2000	COMP	Riverton Township, Clay County	323	$49,200	3%	116	$124,100
2000	COMP	Sioux Township, Clay County	324	$37,417	0%	144	$107,400
2000	COMP	Spencer City, Clay County	11,420	$32,970	10%	5,177	$80,700
2000	COMP	Summit Township, Clay County	411	$36,500	1%	179	$68,000
COMPARABLE DEMOGRAPHICS			12,801	$41,051	3%	5,745	$92,620

iv. Analytical Results and Discussion

Analysis #1: Storm Lake City Excluded from View Shed

In all three of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, indicating that there is no significant evidence that the presence of the wind farms had a negative effect on residential property values.

In Case I, the monthly sales price change in the view shed is 18 percent greater than the monthly sales price change of the comparable over the study period. The Case I model provides a good fit to the data, with over two-thirds of the variance in the data explained by the linear regression. In Case II, the monthly sales price change in the view shed is 70 percent greater after the on-line date than before the on-line date. The Case II model provides a reasonable fit to the data, with over half of the variance in the data explained by the linear regression. In Case III, average view shed sales prices after the on-line date are 2.7 times greater than in the comparable. The Case III model describes over half of the variance in the data for the view shed, but only 23 percent of the variance for the comparable. The data for the full study period is graphed in Figure 7.4, and regression results for all cases are summarized in Table 7.4 below.

Analysis #2: Storm Lake City Included in View Shed

In all three of the regression models, monthly average sales prices grew slower in the view shed than in the comparable area.

In Case I, the monthly sales price change in the view shed is 34 percent less than the monthly sales price change of the comparable over the study period. The Case I model provides a good fit to the data, with over 60 percent of the variance in the data explained by the linear regression. In Case II, the monthly sales price change in the view shed is 59 percent less after the on-line date than before the on-line date. The Case II model explains over half of the variance in the data prior to the on-line date explained, but only 27 percent of the variance after the on-line date. In Case III, average view shed sales prices after the on-line date are 22 percent lower than in the comparable.

The Case III model provides a poor fit to the data, explaining less than 30 percent of the variance for the data. The data for the full study period is graphed in Figure 7.5, and regression results for all cases are summarized in Table 7.5 below.

Table 7.4 Regression Results, Buena Vista County, IA
Projects: Storm Lake I & II (Without Storm Lake City)

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data Comparable, all data	Jan 96 - Oct 02 Jan 96 - Oct 02	$401.86 $341.87	0.67 0.72	The rate of change in average view shed sales price is 18% greater than the rate of change of the comparable over the study period.
Case 2	View shed, before View shed, after	Jan 96 - Apr 99 May 99 - Oct 02	$370.52 $631.12	0.51 0.53	The rate of change in average view shed sales price is 70% greater after the on-line date than the rate of change before the on-line date.
Case 3	View shed, after Comparable, after	May 99 - Oct 02 May 99 - Oct 02	$631.12 $234.84	0.53 0.23	The rate of change in average view shed sales price after the on-line date is 2.7 times greater than the rate of change of the comparable after the on-line date.

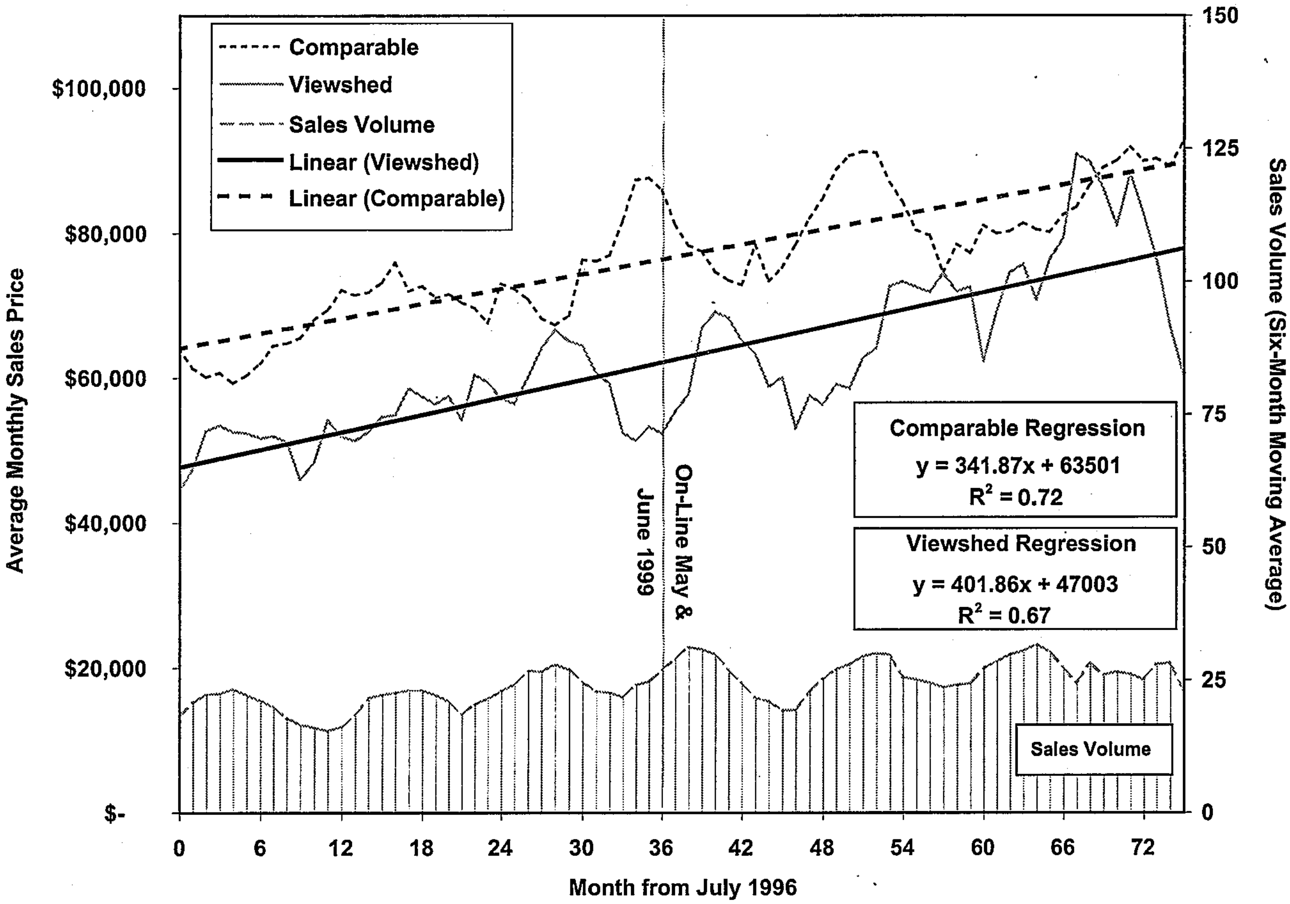


Figure 7.4 Average Residential Housing Sales Price
Analysis #1: Storm Lake City Excluded from View Shed
Buena Vista County, Iowa 1996-2002

Table 7.5 Regression Results, Buena Vista County, IA
Project: Storm Lake I & II (With Storm Lake City)

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data	Jan 96 - Oct 02	225.97	0.60	The rate of change in average view shed sales price is 34% less than the rate of change of the comparable over the study period.
	Comparable, all data	Jan 96 - Oct 02	341.87	0.72	
Case 2	View shed, before	Jan 96 - Apr 99	450.11	0.59	The rate of change in average view shed sales price is 59% less after the on-line date than before the on-line date.
	View shed, after	May 99 - Oct 02	183.92	0.27	
Case 3	View shed, after	May 99 - Oct 02	183.92	0.27	The rate of change in average view shed sales price after the on-line date is 22% lower than the rate of change of the comparable after the on-line date.
	Comparable, after	May 99 - Oct 02	234.84	0.23	

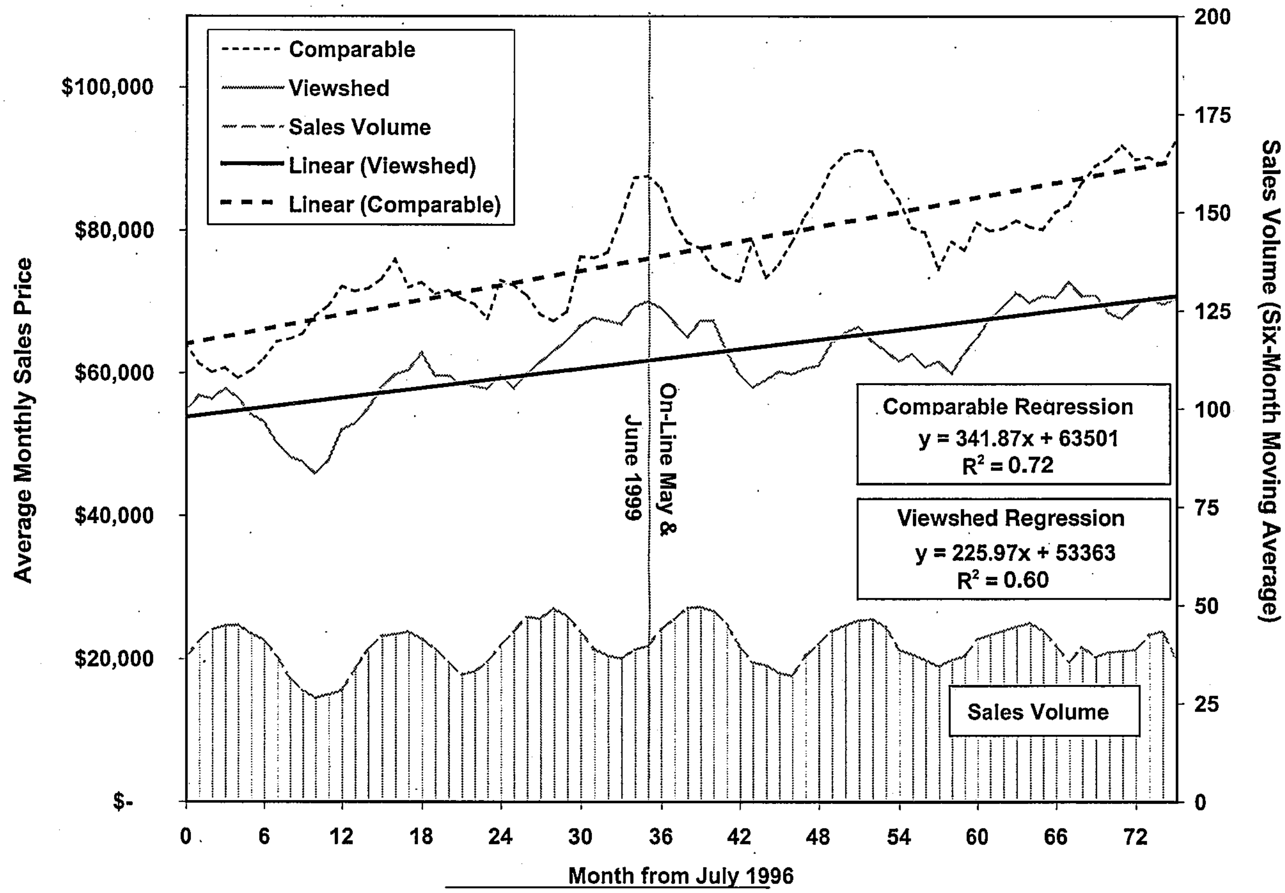


Figure 7.5 Average Residential Housing Sales Price
Analysis #2: Storm Lake City Included in View Shed
Buena Vista County, Iowa 1996-2002

D. Additional Interviewee Comments

Buena Vista County Assessor Ted Van Groteest said the comparable area around Spencer City in the northern neighboring county, Clay, would have higher property values because of its proximity to recreational lakes to the north, but that the two areas' property values rose at equal rates. He added that the predominate business mix was similar, but that the productive value of the land in Clay might be a little higher.

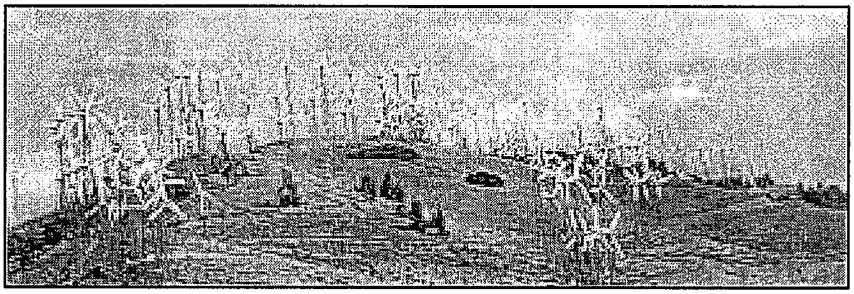
Between October 2002 and March 2003 the following information was obtained through other interviews with Groteest:

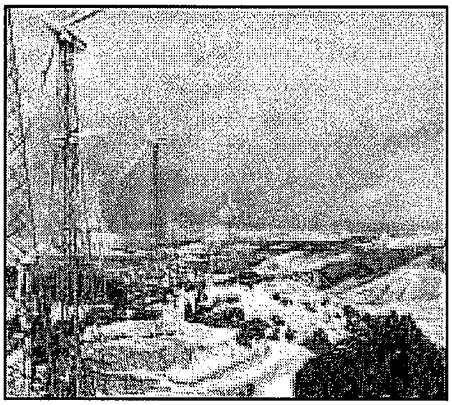
- Most of the residences at the Lake Creek Country Club, a golf course community located just west of Storm Lake City (between the city and the wind farms), have views of the towers. Several towers are one-half mile north and southwest of the Country Club. The assessor owns a home at the Country Club.
- In the assessor's opinion, the wind projects have no impact on property values. According to the assessor, the only issue that influences prices is the school district.
- There is also a hog farm on the west side of Storm Lake – the same direction as the wind projects. Groteest said the property values did not change around the hog farm.

Site Report 8: Kern County, California

A. Project Description

The Tehachapi Mountains stretch northeast and southwest with Tehachapi City and neighboring communities seated within a flat valley inside the range. Despite the arid climate, Tehachapi's elevation of 4,000 feet affords it four seasons. This region is known for its extensive wind farm development, which has been ongoing for over two decades.





Figures 8.1 – 8.2: Views of the Tehachapi region wind farms
Top Photo Courtesy Jean-Claude Criton © 2000 ~ Bottom Photo Courtesy Windland Inc. © 2003

Between 1981 and 2002 developers installed 3,569 towers with varied hub heights up to 55 meters (180.5 feet), and repowered six sites with 199 towers between 1997 and2002. The projects nestle within the Tehachapi pass five miles east of Tehachapi City, through the Tehachapi mountains, and scatter along the east-face just as Highway 58 drops sharply southeast toward Mojave and California cities bordering the Mojave Desert. The wind farm locations are shown in the regional area map, Figure 8.3, and view shed map, Figure 8.4, below.

To the east of the mountains are the cities of Mojave, California, and Rosamond. The incorporated limits of these cities are all approximately three to four miles from the base of the range, where the Mojave Desert begins.

Foliage is patchy with many areas covered in wild, dry grasses, Juniper, and Cottonwood much like the terrain between Albuquerque and Santa Fe, New Mexico. However, there are some green portions with dense grasses allowing for cattle grazing or equestrian spreads.

Although Kern County is classified as a "county in a metro area with 250,000 to 1 million population," the view shed has a population of less than 15,000. See Appendix 1 for a definition of rural urban continuum codes. Also, Tehachapi is 40 miles to the nearest metro area of Bakersfield, and 115 miles to Los Angeles.

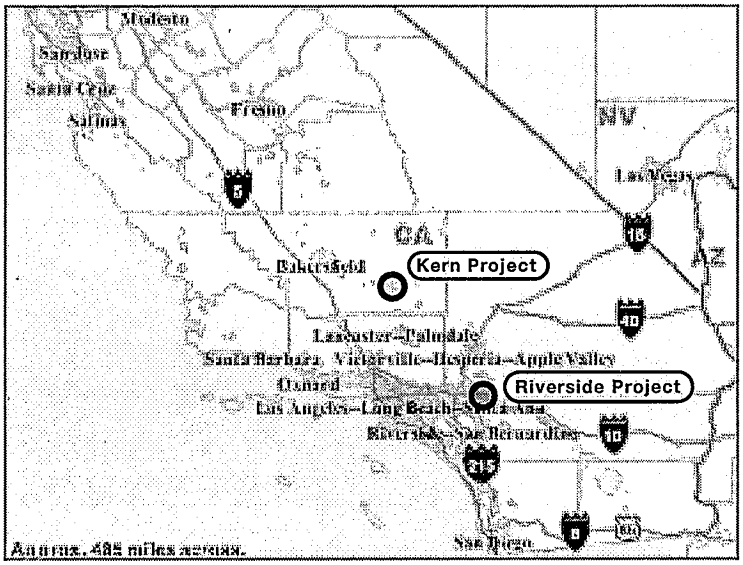


Figure 8.3. Regional Wind Project Location

(Dots approximate wind farm locations)

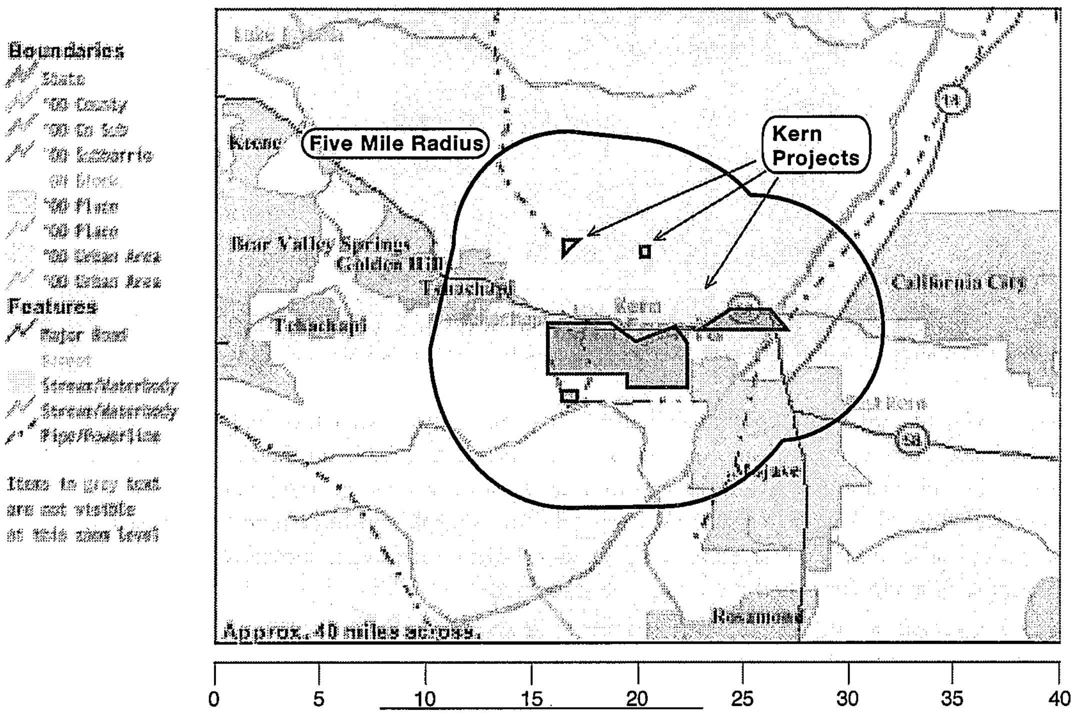


Figure 8.4. Kern County, California View shed

Project Location Source: Kern County Assessors Office

Base Map Source: U.S. Census Bureau

00002643

B. Project Timeline

Table 8.1 Wind Project History, Tehachapi, CA

Project Name	Completion Date	Capacity (MW)	Project Name	Completion Date	Capacity (MW)
Oak Creek	2002	2.5	Coram Energy Group	1981-1995	6.8
Oak Creek-Phase 2A-Repower	1999	0.8	Cannon (various)	1981-1995	4.5
Pacific Crest-Repower	1999	45.5	Mogul Energy .	1981-1995	4.0
Cameron Ridge-Repower	1999	56.0	Coram Energy Group	1981-1995	4.0
Oak Creek Phase 2-Repower	1999	23.1	Windridge	1981-1995	2.3
Victory Gardens -Repower	1999	6.7	Coram Energy Group	1981-1995	1.9
Oak Creek Phase 1-Repower	1997	4.2	Victory Gardens I .& IV	1981-1995	1.0
Mojave 16, 17 & 18	1981-1995	85.0	Sky River	1993	77.0
Mojave 3, 4 & 5	1981-1995	75.0	Victory Gardens Phase IV	1990	22.0
Ridgetop Energy	1981-1995	32.6	Various Names	1982-87	64.0
Calwind Resources	1981-1995	14.1	Various Names	1982-87	24.0
Cannon	1981-1995	13.5	Various Names	1986	0.2
Calwind Resources	1981-1995	8.7	Windland (Boxcar II	Mid-1980s	14.3
AB Energy-Tehachapi	1981-1995	7.0			

C. Analysis

i. Data

Real property sales data for 1996 to 2002 was obtained from First American Real Estate Solutions in Anaheim, CA. The dataset is quite detailed and contains many property and locational attributes, among them 9-digit zip code (ZIP+4) locations. Sales data was purchased for two zip codes encompassing the wind farm area and surrounding communities. These zip codes are Mohave (93501) and Tehachapi (93561).

Sales for the following residential property types were included in the analysis: single-family residences, condominiums, apartments, duplexes, mobile homes, quadruplexes, and triplexes. Of 21 apartment sales in the database, five in the view shed had unusually high sales prices. After discussion with the local Assessor, it was determined that these did not represent single sale data points, and they were eliminated from the analysis. A total of 2,867 properties are used in the analysis.

Projects that went on-line during the study period are the Cameron Ridge, Pacific Crest, and Oak Creek Wind Power Phase II sites. All three are repowering projects, with installed capacities of 56, MW, 45 MW, and 23 MW, respectively. Cameron Ridge went on-line March 1999, and the other two came on-line June 1999.

ii. View Shed Definition

All ZIP+4 regions within 5 miles of the wind turbines define the view shed. The location of the ZIP+4 regions were derived from the latitude and longitude of the ZIP+4 areas obtained from the U.S. Census TIGER database. Because the view sheds of the individual wind farm sites overlap, and because all projects went on-line within three months of each other, a single composite view shed is defined. The view shed is approximated by two rectangles that overlap the combined area swept out by a five-mile radius from each wind farm location.

Locational data for the wind farms was obtained from utility and wind industry web sites, and used in conjunction with detailed block maps, wind farm site maps, topographic maps and interviews to identify the exact location and extent of the wind farms and the composite view shed. The final view shed dataset contains 745 sales from 1996 to 2002.

Interviews with Kern County Assessors were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. Assessor Ron Stout said 50 to 60 percent of residents within Tehachapi City could see the turbines, but the Golden Hills area was too far and had views only if one intentionally tried to see them. He said about 30 percent of residents in the northwest corner of Mojave (north of Purdy Avenue and West of the Airport) could see turbines.

iii. Comparable Selection

The comparable community was selected through extensive interviews with Assessor Ron Stout of the State of California Kern County Assessment Office and analysis of topographic and site maps. Because the U.S. Census does not provide Census data at the resolution of individual ZIP+4 regions, we were unable to use Census data as part of the comparable selection process in this case. Based on review of the Assessor interviews, the ZIP+4 regions in Golden Hills, Bear Valley Springs, Stallion Springs and the central and southeastern portions of Mohave, all within Mohave zip code 93501 and Tehachapi zip code 93561, were selected as the comparable. The final comparable dataset contained 2,122 sales from 1996 to 2002.

iv. Analytical Results and Discussion

In one of the regression models, monthly average sales prices grew faster in the view shed than in the comparable area, and in two of the regression models it did not.

In Case I, the monthly sales price change in the view shed is 28 percent less than the monthly sales price change of the comparable over the study period. The Case I model provides a good fit to the view shed data, with over 70 percent of the variance in the data explained by the linear regression. In Case II, the monthly sales price change in the view shed is 38 percent greater after the on-line date than before the on-line date. The Case II model provides a good fit to the post on-line data, with 75 percent of the variance in the data explained by the linear regression. For the pre-on-line period, the regression explains 44 percent of the variance in the data. In Case III, average view shed sales prices after the on-line date are 29 percent less than in the comparable. The Case III model provides a good fit to the data, with 75 percent of the variance in the view shed data and 95 percent of the variance in the comparable data explained by the regression. The data for the full study period is graphed in Figure 8.4, and regression results for all cases are summarized in Table 8.2 below.

D. Additional Interviewee Comments

Assessor Stout also said that Mojave has not seen any new residential development in eight years. Both Stout and Assessor James Maples said they have not seen any impact of the farms on property values. However, Maples said the area was so agricultural or lightly populated that it would be hard to isolate price changes due to the wind projects. Maples, added that over 30 years of wind project development an industrial cement manufacturer, among other projects, was built close to Tehachapi on the east. The cement plant spewed out dust for 10 years or more until county and federal government inspectors required upgrades 15 years ago, said Stout.

Tehachapi is the busiest single-tracked [locomotive] mainline in the world, according to the Tehachapi Chamber of Commerce. It runs through the Tehachapi Mountains between Mojave and Bakersfield. Of other notable businesses, Tehachapi has a manufacturing plant for GE Wind Energy (formerly Zond) wind turbines.

Table 8.2 Regression Results, Kern County, CA
Projects: Pacific Crest, Cameron Ridge, Oak Creek Phase II

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data	Jan 96 - Dec 02	$492.38	0.72	The rate of change in average view shed sales price is 28% less than the rate of change of the comparable over the study period.
	Comparable, all data	Jan 96 - Dec 02	$684.16	0.74	
Case 2	View shed, before	Jan 96-Feb 99	$568.15	0.44	The rate of change in average view shed sales price is 38% greater after the on-line date than the rate of change before the on-line date.
	View shed, after	Mar 99 - Dec 02	$786.60	0.75	
Case 3	View shed, after	Mar 99 - Dec 02	$786.60	0.75	The rate of change in average view shed sales price after the on-line date is 29% less than the rate of change of the comparable after the on-line date.
	Comparable, after	Mar 99 - Dec 02	$1,115.10	0.95	

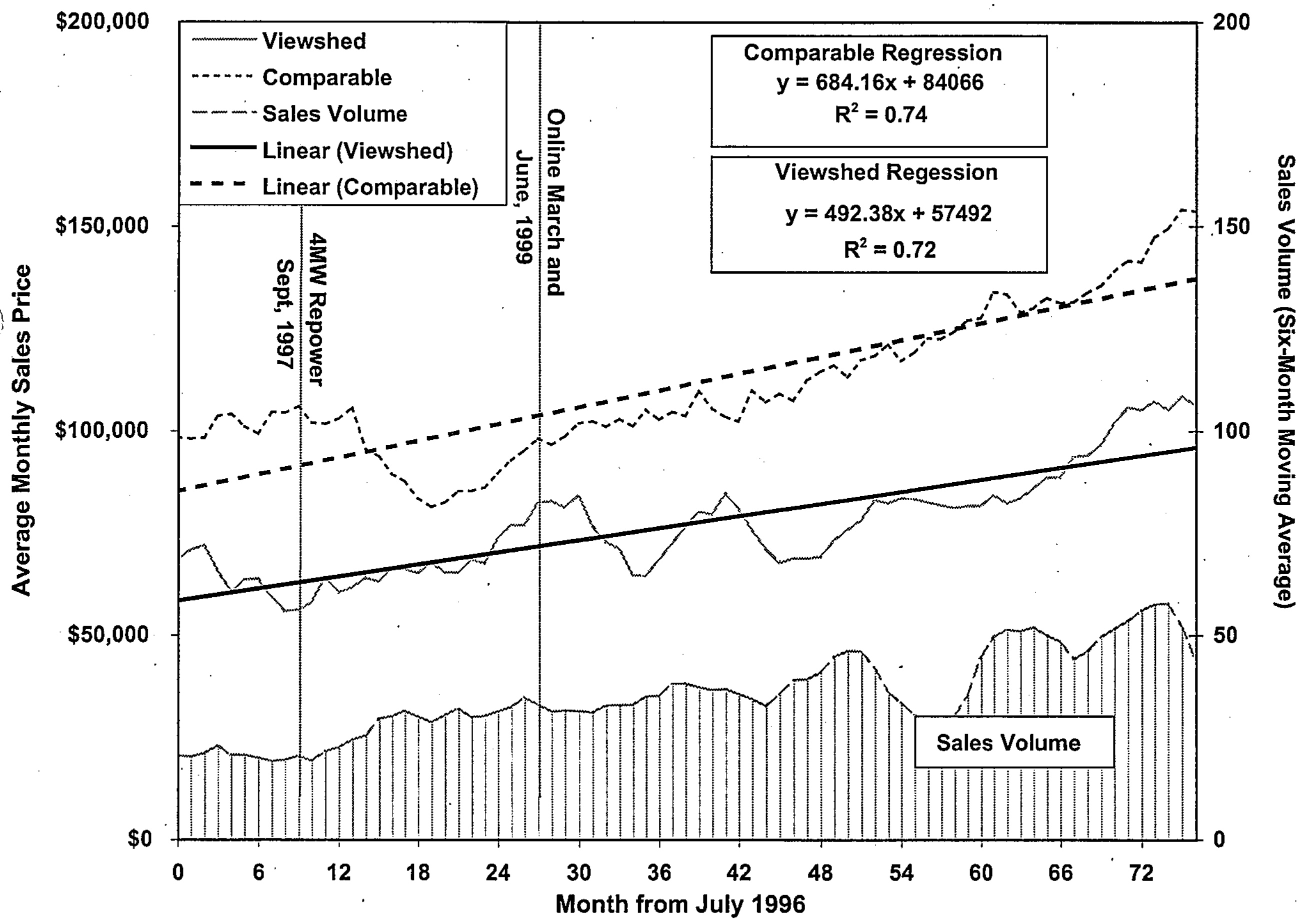


Figure 8.4 Average Residential Housing Sales Price

Kern County, California 1996-2002

SITE REPORT 9: FAYETTE COUNTY, PENNSYLVANIA

A. PROJECT DESCRIPTION

Although the area is famous for being the home of Frank Lloyd Wright's Falling Water House built for a wealthy Pittsburgh family, much of the area is low-income and rural. The 10 turbines rising 70 meters (230 feet) were built along a ridge on the border of Stewart and Springfield Townships, and run north/south against the county border with Somerset. The land is owned primarily by one family who rents some of the acreage to a petroleum pumping company and for the turbines.

The area is very hilly with densely populated tall trees. The project site is approximately 62 miles from Pittsburgh with several ski lodges in the vicinity. The local economy is primarily agricultural or tourism related.

The view shed area of Springfield and Stewart Townships is rural with a combined population less than 2,000 although the county is classified as a "fringe county of a metro area with 1 million population or more." See Appendix 1 for a definition of rural urban continuum codes. This discrepancy is because the southeastern periphery of suburban Pittsburgh creeps a little into northwest Fayette. The view shed is at least 62 miles from downtown Pittsburgh.

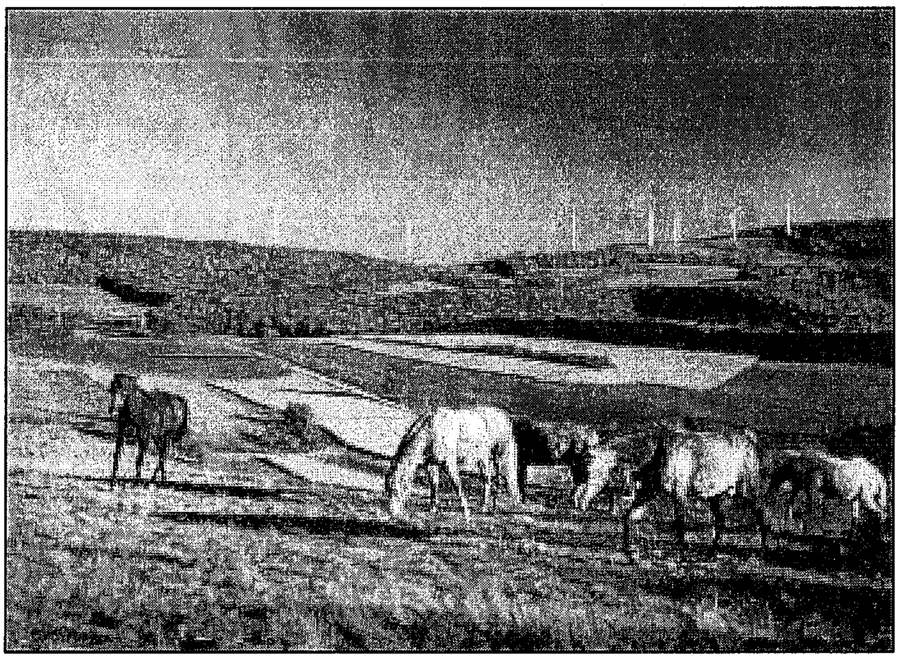


FIGURE 9.1 VIEW OF A MILL RUN TURBINES
PHOTO COURTESY GE WIND ENERGY © 2002

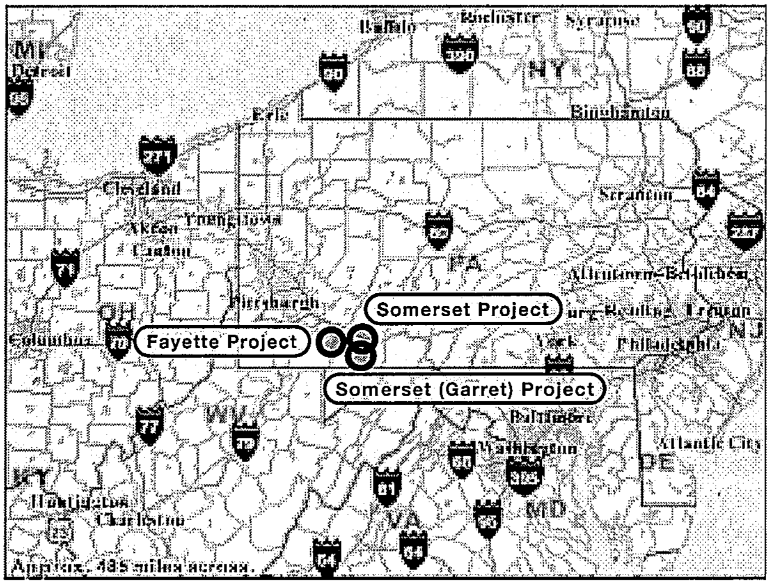


Figure 9.2. Regional Wind Project Location
(Dots approximate wind farm locations)

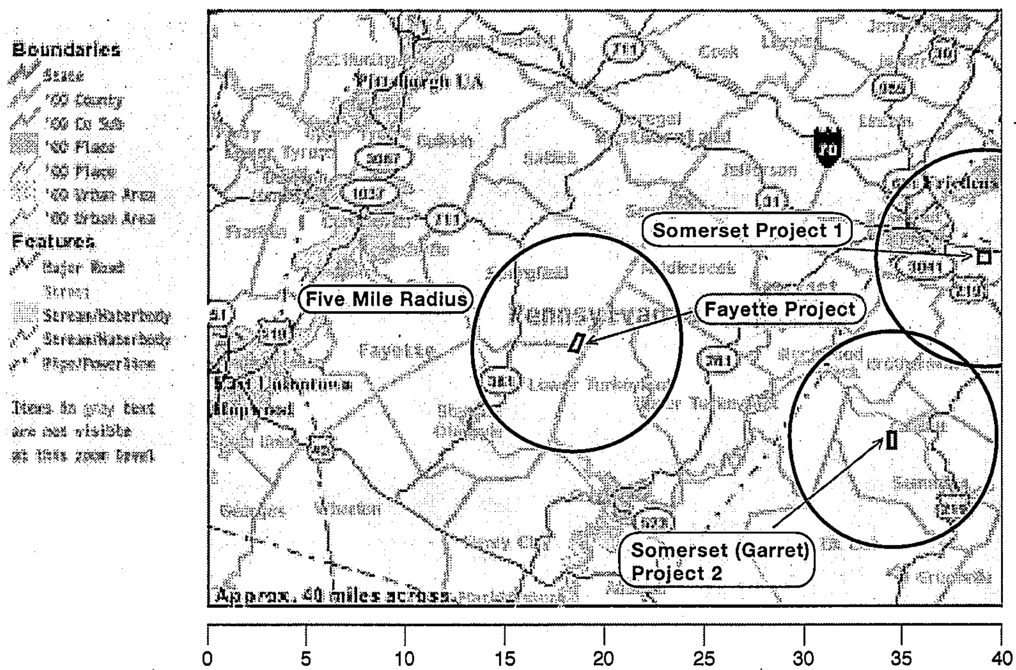


Figure 9.3. Fayette County, Pennsylvania View shed
Project Location Source: Fayette County Assessors Office
Base Map Source: U.S. Census Bureau

B. Project Timeline

Table 9.1 Wind Project History, Fayette County, PA

Project Name	Completion Date	Capacity (MW)
Mill Run Windpower LLC	2001	15.0

C. Analysis

i. Data Source

Real property sales data for 1998 to 2002 was obtained electronically from the Fayette County Assessment Office Website, www.fayetteproperty.org/assessor. The dataset contains all property sales in Stewart and Springfield Townships. The sales volume is the smallest of all sites analyzed, with only 89 sales over the five-year period studied. The wind farm went on-line October 2001, with an installed capacity of 15 MW.

Complete addresses and detailed sales data are available on the website only by clicking on each parcel individually. However, there is no parcel map of the entire township to help identify parcel locations. We combined over 50 local parcel maps into one composite parcel map for the view shed, and used this in combination with street maps to identify the view shed and non-view shed areas.

ii. View Shed Definition

The view shed is defined by a five-mile radius around the wind farm. The view shed covers the eastern portion of both Springfield and Stewart Townships in Fayette County. The five-mile radius also covers portions of Lower Turkey Foot, Upper Turkey Foot, and Middlecreek Townships in Somerset County. Because the Somerset County Townships are only partially in the view shed, and because the Somerset data we obtained is identified primarily by township or city, these areas are not included in the analysis. The view shed is therefore defined as the portions of Springfield and Stewart Townships falling within the five-mile radius. The view shed accounts for 39 sales over the study period.

Interviews with the State of Pennsylvania Fayette County Assessors Office were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Fayette County Chief Assessor James A. Hercik's opinion, 10 to 20 percent of residents have views of the turbines.

iii. Comparable Selection

The comparable community was selected based on the availability of parcel-level data and through interviews with Fayette County Chief Assessor James A. Hercik. Assessor James Hercik said properties to the west of the view shed had no views of the wind turbines. Upon examination of sales data availability and review of Assessor comments, the western portions of Springfield and Stewart Townships, outside the five-mile view shed radius, were selected as the comparable, with a total of 50 sales from 1997 to 2002.

Demographic data from the 1990 and 2000 U.S. Census for Springfield and Stewart Townships was gathered, but not used because both the view shed and comparable are in the same township. Tables 9.2 and 9.3 summarize the Census data reviewed.

TABLE 9.2 FAYETTE COUNTY, PENNSYLVANIA: 1990 CENSUS DATA

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
1990	partial	Springfield Township	2,968	$15,686	28%	1,137	$40,200
1990	partial	Stewart Township	734	$18,235	24%	331	$42,500
VIEW SHED DEMOGRAPHICS			3,702	$16,961	26%	1,468	$41,350

TABLE 9.3 FAYETTE COUNTY, PENNSYLVANIA: 2000 CENSUS DATA

Year	View shed	Location	Population	Median household income	% Population below poverty level	Number housing units	Median value-owner-occupied housing unit
2000	partial	Springfield Township	3,111	$29,133	22%	1,283	$57,400
2000	partial	Stewart Township	743	$32,917	11%	338	$64,000
VIEW SHED DEMOGRAPHICS			3,854	$31,025	16%	1,621	$60,700

iv. Analytic Results and Discussion

In two of the three regression models, monthly average sales prices grew faster or declined slower in the view shed than in the comparable area. However, in the case of the underperformance of the view shed, the explanatory power of the model is very poor. Thus, there is no significant evidence in these cases that the presence of the wind farms had a negative effect on residential property values.

In Case I, the monthly sales price increase in the view shed is only 24 percent that of the comparable over the study period. However, the Case I model provides a poor fit to the view shed data, with only two percent of the variance in the data for the view shed and 24 percent of the variance in the data for the comparable explained by the linear regression. In Case II, sales prices decreased in the view shed prior to the on-line date, and increased after the on-line date. The average view shed sales price after the on-line date increased at 3.8 times the rate of decrease in the view shed before the on-line date. The Case II model provides a poor fit to the data, with less than one-third of the variance in the data explained by the linear regression. In Case III, average view shed sales prices after the on-line date are 13.5 times greater than in the comparable. However, the Case III model describes only 32 percent of the variance in the view shed data, and none of the variance in the comparable data. The data for the full study period is graphed in Figure 9.4, and regression results for all cases are summarized in Table 9.4 below.

The poor fit of the model, as evidenced by the low R2 values, is partly due to the very small sales volume, on average only 2.1 sales per month in the view shed and comparable combined. As can be seen from Figure 9.4, the small sales volume leads to very high variability in average sale price from month to month. In addition, for regressions fit to data after the on-line date, only 13 months' sales data was available, accounting for 18 sales total, which leads to the caveat that these results should be viewed carefully.

Table 9.4 Fayette County, Pennsylvania: Regression Results
Project: Mill Run

Model	Dataset	Dates	Rate of Change ($/month)	Model Fit (R2)	Result
Case 1	View shed, all data	Dec 97-Dec 02	$115.96	0.02	The rate of change in average view shed sales price is 24% of the rate of change of the comparable over the study period.
	Comparable, all data	Dec 97-Dec 02	$479.20	0.24	
Case 2	View shed, before	Dec 97 - Nov 01	-$413.68	0.19	The rate of change in average view shed sales price after the on-line date increased at 3.8 times the rate of decrease before the on-line date.
	View shed, after	Oct 01-Dec 02	$1,562.79	0.32	
Case 3	View shed, after	Oct 01-Dec 02	$1,562.79	0.32	The rate of change in average view shed sales price after the on-line date is 13.5 times greater than the rate of change of the comparable after the on-line date.
	Comparable, after	Oct 01-Dec 02	$115.86	0.00	

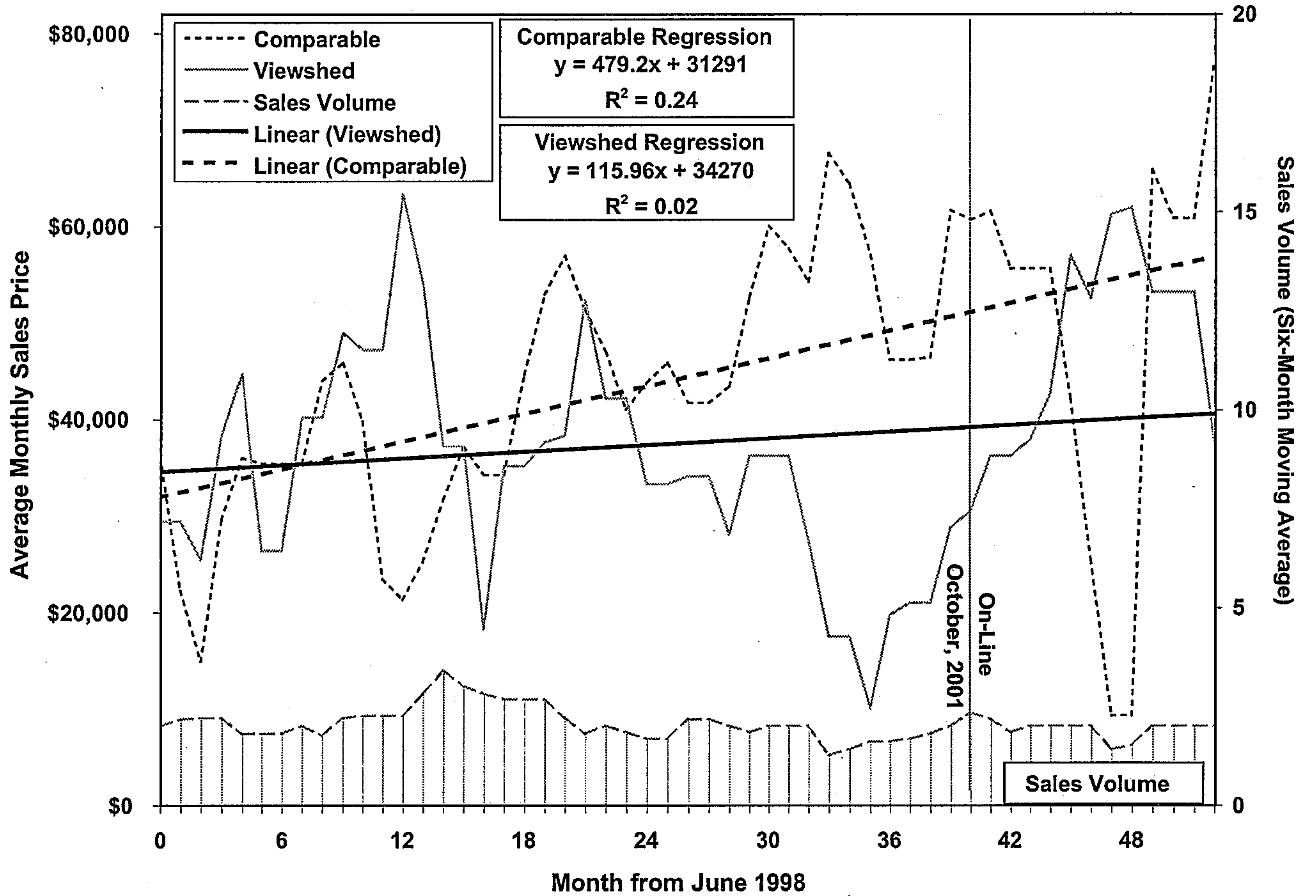


Figure 9.4 Average Residential Housing Sales Price
Fayette County, Pennsylvania 1998-2002

D. Additional Assessor Comments

James A. Hercik, Fayette County chief assessor/director of assessments, said he has not seen any impact of the wind farms on property values, with the exception that the assessed value of properties with turbines went up. He also noted that on the same property as the turbines are on, there are natural gas wells, which additionally impact valuations. Finally, Hercik said that often, sales in the view shed were family-to-family sales that may reflect sales prices lower than assessed value.

Site Report: Projects Excluded From Analyses

Of the 27 projects selected for analysis, four were excluded from analysis because there were not enough sales in the view shed for statistical analysis; one was excluded because comparable data was not available at time of publication of this report; and an additional 12 projects were excluded because property sales data was unavailable, not readily available, or because there were not enough sales in the view shed for statistical analysis. Table S1 below summarizes the reasons for project exclusion from analysis.

Table S1: Summary of Projects Excluded from Analyses

I. Data acquired, but insufficient for analysis

County	State	Reason for Exclusion
Logan	CO	Not enough sales to make a valid judgment (5 Sales)
Worth	IA	Not enough sales to make a valid judgment (38 sales over 7 years)
Umatilla	OR	Not enough sales to make a valid judgment (28 sales)
Howard	TX	Comparable data not acquired at time of publication (1,896 view shed sales)
Upton	TX	Not enough sales to make a valid judgment (7 sales)

II. Data not acquired

County	State	Reason for Exclusion
Weld	CO	Not enough sales to make a valid judgment
Cerro Gordo	IA	No electronic data - accessible in office on paper only
Gray	KS	State law prohibits access to information
Pipestone	MN	No electronic data - accessible in office on paper only - and not enough sales
Lincoln	MN	No electronic data - accessible in office on paper only
Gilliam	OR	No electronic data - accessible in office on paper only
Culberson	TX	No electronic data - accessible in office on paper only
Pecos	TX	No electronic data - accessible in office on paper only - and no sales in view shed
Taylor	TX	No electronic data - accessible in office on paper only
Benton	WA	Not enough sales to make a valid judgment (Project came on-line in 2002)
Walla Walla	WA	No sales in the view shed since project completion
Iowa	WI	No electronic data - accessible in office on paper only
Carbon	WY	State law prohibits access to information

I. Data Acquired, but Insufficient for Analysis

County State Reason for Exclusion

Logan CO Not enough sales to make a valid judgment (Five Sales)

Years Reviewed: 1996 to 2002

Assessor comments: Assessor Ann Rogers-Ridnour said her office has seen no impact from the wind project, and that it was hard gauge because there are so few sales.

Worth IA Not enough sales to make a valid judgment (38 sales over seven years)

Years Reviewed: 1996 to 2002

Assessor comments: Assessor said the project was surrounded only by agricultural land, that it was hard to pinpoint home locations on farms if any because addresses are vague, and that they felt the wind projects have been welcomed.

Umatilla OR Not enough sales to make a valid judgment (28 sales)

Years Reviewed: 1995 to 2002

Assessor comments: Assessor Lee Butler said there were only 28 sales in view shed.

Howard TX Comparable not available at time of publication

Years Reviewed: 1996 to 2002

The exact location of the Big Spring wind farm in Howard County, TX, and thus definition of the view shed, was elusive. While site maps with individual turbine locations were obtained, they were hand drawn and not to scale. Interviews with county Assessors and on-site operations staff yielded conflicting descriptions of the exact location of the turbines. In the end, the wind farm location was fixed in an interview with one of the original site developers, Mark Haller of Zilkha Inc. According to Mr. Haller, the turbine towers reach out far away from the Big Spring, but the closest one is only 100 yards or so from the third tee of a golf course on the south side of town – close enough for golfers often take chip shots at it.

The view shed covers portions, but not all of, the three school districts in the county: Coahoma, Big Spring, and Forsan. Approximately 70 percent of Big Spring City, all of Coahoma City, and none of Forsan City are within the view shed. Because this project lacks the resources to identify every property by street address, the view shed is defined to include all of Big Spring City, which is equivalent to using a six-mile radius view shed instead of a five-mile radius view shed for this case only. The final view shed dataset contains 1,896 sales from 1996 to 2002.

Interviews with Howard County Assessors were conducted by phone to determine what percentage of residential properties in the view shed can see all or a portion of the wind turbines. In Chief Assessor Keith Toomire's opinion, 30 percent of Big Spring City properties can see the turbines. Mr. Haller added that due to the various plateaus surrounding Big Spring, there are portions of the town that cannot see the turbines.

The selection of an appropriate comparable for Big Spring is difficult because the area has experienced an economic downturn and loss of jobs for a number of years. According to Howard County Chief Assessor Keith Toomire, the two major employment categories in the Big Spring are agriculture and petroleum extraction. Due to a 10-year draught in the region, crop yields are severely reduced, with significant economic impacts for the city. Additionally, depletion of petroleum resources has led to the closing of wells and economic downturn in the local petroleum industry.

Because the view shed for Big Spring was defined very late in the process of producing this report, data for a comparable has not yet been obtained.

Upton TX Not enough sales to make a valid judgment (Seven sales)

Years Reviewed: 1996 to 2002

Assessor comments: Chief Appraiser Shari Stevens said no sales near southwest Mesa, and only seven sales near the King Mountain project.

II. Data Not Acquired

County	State	Reason for Exclusion

Weld CO **Not enough sales to make a valid judgment**

Years Reviewed: 1996 to 2002

Assessor comments: Office staff said there were very few people in the project area and didn't think anybody could see it.

Cerro Gordo IA **No electronic data - accessible in office on paper only**

Years Reviewed: 1996 to 2002

Assessor comments: Assessor said we were the third group to call them about the same question and that they've looked into every way they could to parse their data, and could find no proof that there was any impact on county property values.

Gray KS **State law prohibits access to information**

Years Reviewed: 1996 to 2002

Assessor comments: Assessor Jerry Dewey said area had only small populations and that most land was agricultural; therefore he said they have seen no impact, primarily because the land is assessed for productive use.

Pipestone MN **No electronic data - accessible in office on paper only – and not enough sales**

Years Reviewed: 1991 to 2002

Assessor comments: Interim Assessor "Farley" said he's not seen any impact on property values. Also, he added that there haven't been enough sales to make a judgment call, and all property surrounding the project is agricultural land which is valued on productive use (so unless the turbines were on the property itself, then the property value would not go up).

Lincoln MN **No electronic data - accessible in office on paper only**

Years Reviewed: 1991 to 2002

Assessor comments: Assessor "Bruce" (last name unavailable) said the project was a "non-issue" and has not seen any impact on values. Specifically, the projects were welcomed and some people tried to have the turbines built on their land.

Gilliam OR **No electronic data - accessible in office on paper only**

Years Reviewed: 1997 to 2002

Assessor comments: Assessor Pat Shaw said area around project had a population less than 700 all living dispersed among agricultural land. Also, he expressed no sense of impact on property values

Culberson TX **No electronic data - accessible in office on paper only**

Years Reviewed: 1992 to 2002

Assessor comments: Appraiser Sally Carrasco said they've been very happy with the wind farms. She added that because they have a terrible economy, she wasn't sure if they would even have a town were it not for the revenue from turbines that support the schools.

Pecos TX **No electronic data - accessible in office on paper only – and no sales in view shed**

Years Reviewed: 1997 to 2002

Assessor comments: Assessor Santa S. Acosta said there were no residences with a view, and that there are so few sales in general that the area wasn't due for re-appraisal until 2003.

Taylor TX No electronic data - accessible in office on paper only

Years Reviewed: 1997 to 2002

Assessor comments: Assessor Ralf Anders said no homes had a view.

Benton WA Not enough sales to make a valid judgment

(Project came on-line in 2002)

Years Reviewed: 1996 to 2002

Assessor comments: Office clerk "Harriet" said they only have the past three months of data in electronic form; everything else is in paper and a person must go to office to search records.

Walla Walla WA No sales in the view shed since project completion

Years Reviewed: 1996 to 2002

Assessor comments: Walla-Walla County Assessor Larry Shelley said there have been no sales since the wind project was built.

Iowa WI No electronic data - accessible in office on paper only

Years Reviewed: 1996 to 2002

Assessor comments: Assessor said only small village areas had views, but that the wind projects were welcomed. –Assessor specifically made a comment that a bowling alley has built a small tourist attraction around the project.

Carbon WY State law prohibits access to information

Years Reviewed: 1996 to 2002

Assessor comments: Assessor Darrell Stubbs said that although it is illegal to release individual property information, he has seen no impact on values. Specifically, he noted if any impact occurred, property values have risen because the population is so small that the infusion of a few jobs from the project in the area is enough to raise prices.

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Appendix 1. County Classification Descriptions

U.S. Department of Agriculture, Economic Research Service Rural-Urban Continuum Codes

Metro counties:	
0	Central counties of metro areas of 1 million population or more.
1	Fringe counties of metro areas of 1 million population or more.
2	Counties in metro areas of 250,000 to 1 million population.
3	Counties in metro areas of fewer than 250,000 population.
Nonmetro counties:	
4	Urban population of 20,000 or more, adjacent to a metro area.
5	Urban population of 20,000 or more, not adjacent to a metro area.
6	Urban population of 2,500 to 19,999, adjacent to a metro area.
7	Urban population of 2,500 to 19,999, not adjacent to a metro area.
8	Completely rural or less than 2,500 urban population, adjacent to a metro area.
9	Completely rural or less than 2,500 urban population, not adjacent to a metro area.

Note: New Rural-Urban Continuum Codes based on the 2000 Census are not expected to be available until 2003. The development of the updated codes requires journey-to-work commuting data from the long form of the 2000 Census and delineation of the new metropolitan area boundaries by the Office of Management and Budget. OMB's work is not scheduled to be completed until 2003. www.ers.usda.gov/briefing/rurality/RuralUrbCon/

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The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis

Ben Hoen, Ryan Wiser, Peter Cappers, Mark Thayer, and Gautam Sethi

Environmental Energy Technologies Division

December 2009

The work described in this report was funded by the Office of Energy Efficiency and Renewable Energy (Wind & Hydropower Technologies Program) of the U.S. Department of Energy under Contract No. DE-AC02-05CH1123.

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Principal Authors:

Ben Hoen, Ryan Wiser, Peter Cappers
Ernest Orlando Lawrence Berkeley National Laboratory

Mark Thayer
San Diego State University

Gautam Sethi
Bard College

1 Cyclotron Road, MS 90R4000
Berkeley CA 94720-8136

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Abstract

With wind energy expanding rapidly in the U.S. and abroad, and with an increasing number of communities considering wind power development nearby, there is an urgent need to empirically investigate common community concerns about wind project development. The concern that property values will be adversely affected by wind energy facilities is commonly put forth by stakeholders. Although this concern is not unreasonable, given property value impacts that have been found near high voltage transmission lines and other electric generation facilities, the impacts of wind energy facilities on residential property values had not previously been investigated thoroughly. The present research collected data on almost 7,500 sales of single-family homes situated within 10 miles of 24 existing wind facilities in nine different U.S. states. The conclusions of the study are drawn from eight different hedonic pricing models, as well as both repeat sales and sales volume models. The various analyses are strongly consistent in that none of the models uncovers conclusive evidence of the existence of any widespread property value impacts that might be present in communities surrounding wind energy facilities. Specifically, neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices. Although the analysis cannot dismiss the possibility that individual homes or small numbers of homes have been or could be negatively impacted, it finds that if these impacts do exist, they are either too small and/or too infrequent to result in any widespread, statistically observable impact.

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Acknowledgements

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Executive Summary

Overview

Wind power development in the United States has expanded dramatically in recent years. If that growth is to continue it will require an ever-increasing number of wind power projects to be sited, permitted, and constructed. Most permitting processes in the U.S. require some form of environmental impact assessment as well as public involvement in the siting process. Though public opinion surveys generally show that acceptance towards wind energy is high, a variety of concerns with wind power development are often expressed on the local level during the siting and permitting process. One such concern is the potential impact of wind energy projects on the property values of nearby residences.

Concerns about the possible impact of wind power facilities on residential property values can take many forms, but can be divided into the following non-mutually exclusive categories:

- Area Stigma: A concern that the general area surrounding a wind energy facility will appear more developed, which may adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines.
- Scenic Vista Stigma: A concern that a home may be devalued because of the view of a wind energy facility, and the potential impact of that view on an otherwise scenic vista.
- Nuisance Stigma: A concern that factors that may occur in close proximity to wind turbines, such as sound and shadow flicker, will have a unique adverse influence on home values.

Although concerns about the possible impact of wind energy facilities on the property values of nearby homes are reasonably well established, the available literature[1] that has sought to quantify the impacts of wind projects on residential property values has a number of shortcomings:

1) Many studies have relied on surveys of homeowners or real estate professionals, rather than trying to quantify real price impacts based on market data;
2) Most studies have relied on simple statistical techniques that have limitations and that can be dramatically influenced by small numbers of sales transactions or survey respondents;
3) Most studies have used small datasets that are concentrated in only one wind project study area, making it difficult to reliably identify impacts that might apply in a variety of areas;
4) Many studies have not reported measurements of the statistical significance of their results, making it difficult to determine if those results are meaningful;
5) Many studies have concentrated on an investigation of the existence of Area Stigma, and have ignored Scenic Vista and/or Nuisance Stigmas;
6) Only a few studies included field visits to homes to determine wind turbine visibility and collect other important information about the home (e.g., the quality of the scenic vista); and
7) Only two studies have been published in peer-reviewed academic journals.

[1] This literature is briefly reviewed in Section 2 of the full report, and includes: Jordal-Jorgensen (1996); Jerabek (2001); Grover (2002); Jerabek (2002); Sterzinger et al. (2003); Beck (2004); Haughton et al. (2004); Khatri (2004); DeLacy (2005); Poletti (2005); Goldman (2006); Hoen (2006); Firestone et al. (2007); Poletti (2007); Sims and Dent (2007); Bond (2008); McCann (2008); Sims et al. (2008); and Kielisch (2009).

This report builds on the previous literature that has investigated the potential impact of wind projects on residential property values by using a hedonic pricing model and by avoiding many of the shortcomings enumerated above. The hedonic pricing model is one of the most prominent and reliable methods for identifying the marginal impacts of different housing and community characteristics on residential property values (see side bar). This approach dates to the seminal work of Rosen (1974) and Freeman (1979), and much of the available literature that has investigated the impacts of potential disamenities on property values has relied on this method.[2]

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). 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, and 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 a home at a specified point in time), as would be done with an automated valuation model. Instead, the typical goal of a hedonic model is to estimate the marginal contribution of individual house or community characteristics to sales prices.

To seed the hedonic model with appropriate market data, this analysis collects information on a large quantity of residential home sales (i.e., transactions) (n = 7,459) from ten communities surrounding 24 existing wind power facilities spread across multiple parts of the U.S. (e.g., nine states). Homes included in this sample are located from 800 ft to over five miles from the nearest wind energy facility, and were sold at any point from before wind facility announcement to over four years after the construction of the nearby wind project. Each of the homes that sold was visited to determine the degree to which the wind facility was likely to have been visible at the time of sale and to collect other essential data.

To assess the potential impacts of all three of the property value stigmas described earlier, a base hedonic model is applied as well as seven alternative hedonic models each designed to investigate the reliability of the results and to explore other aspects of the data (see Table ES - 1 below). In addition, a repeat sales model is analyzed, and an investigation of possible impacts on sales volumes is

[2] Many of these studies are summarized in the following reviews: Kroll and Priestley (1992); McCann (1999); Bateman et al. (2001); Boyle and Kiel (2001); Jackson (2001); Simons and Saginor (2006); and Leonard et al. (2008). For further discussion of the hedonic model and its application to the quantification of environmental stigmas see Jackson (2005) and Simons (2006a).

conducted. Though some limitations to the analysis approach and available data are acknowledged, the resulting product is the most comprehensive and data-rich analysis to date in the U.S. or abroad on the impacts of wind projects on nearby property values.

Analysis Findings

Table ES - 1 describes the ten resulting statistical models that are employed to investigate the effects of wind facilities on residential sales prices, and the specific stigmas that those models investigate. Though all models test some combination of the three possible stigmas, they do so in different ways. For instance, the Base Model asks the question, "All else being equal, do homes near wind facilities sell for prices different than for homes located farther away?", while the All Sales Model asks, "All else being equal, do homes near wind facilities that sell after the construction of the wind facility sell for prices different from similar homes that sold before the announcement and construction of the facility?" Each model is therefore designed to not only test for the reliability of the overall results, but also to explore the myriad of potential effects from a variety of perspectives. Table ES-2 summarizes the results from these models.

Table ES - 1: Description of Statistical Models

Statistical Model	Description
Base Hedonic Model	Using only "post-construction" transactions (those that occurred after the wind facility was built), this model investigates all three stigmas in a straightforward manner
Alternative Hedonic Models	
View Stability	Using only post-construction transactions, this model investigates whether the Scenic Vista Stigma results from the Base Model are independent of the Nuisance and Area Stigma results
Distance Stability	Using only post-construction transactions, this model investigates whether the Nuisance and Area Stigma results from the Base Model are independent of the Scenic Vista Stigma results
Continuous Distance	Using only post-construction transactions, this model investigates Area and Nuisance Stigmas by applying a continuous distance parameter as opposed to the categorical variables for distance used in the previous models
All Sales	Using all transactions, this model investigates whether the results for the three stigmas change if transactions that occurred before the announcement and construction of the wind facility are included in the sample
Temporal Aspects	Using all transactions, this model further investigates Area and Nuisance Stigmas and how they change for homes that sold more than two years pre-announcement through the period more than four years post-construction
Orientation	Using only post-construction transactions, this model investigates the degree to which a home's orientation to the view of wind turbines affects sales prices
Overlap	Using only post-construction transactions, this model investigates the degree to which the overlap between the view of a wind facility and a home's primary scenic vista affects sales prices
Repeat Sales Model	Using paired transactions of homes that sold once pre-announcement and again post-construction, this model investigates the three stigmas, using as a reference transactions of homes located outside of five miles of the nearest wind turbine and that have no view of the turbines
Sales Volume Model	Using both pre-announcement and post-construction transactions, this model investigates whether the rate of home sales (not the price of those sales) is affected by the presence of nearby wind facilities

Table ES-2: Impact of Wind Projects on Property Values: Summary of Key Results

Statistical Model	Is there statistical evidence of: Area Stigma?	Scenic Vista Stigma?	Nuisance Stigma?	Section Reference
Base Model	No	No	No	*Section 4*
View Stability	Not tested	No	Not tested	*Section 5.1*
Distance Stability	No	Not tested	No	*Section 5.1*
Continuous Distance	No	No	No	*Section 5.2*
All Sales	No	No	Limited	*Section 5.3*
Temporal Aspects	No	No	No	*Section 5.4*
Orientation	No	No	No	*Section 5.5*
Overlap	No	Limited	No	*Section 5.6*
Repeat Sales	No	Limited	No	*Section 6*
Sales Volume	No	Not tested	No	*Section 7*

"No"…………………… *No statistical evidence of a negative impact*
"Yes"…………………. *Strong statistical evidence of a negative impact*
"Limited"……………. *Limited and inconsistent statistical evidence of a negative impact*
"Not tested"………… *This model did not test for this stigma*

Base Model Results

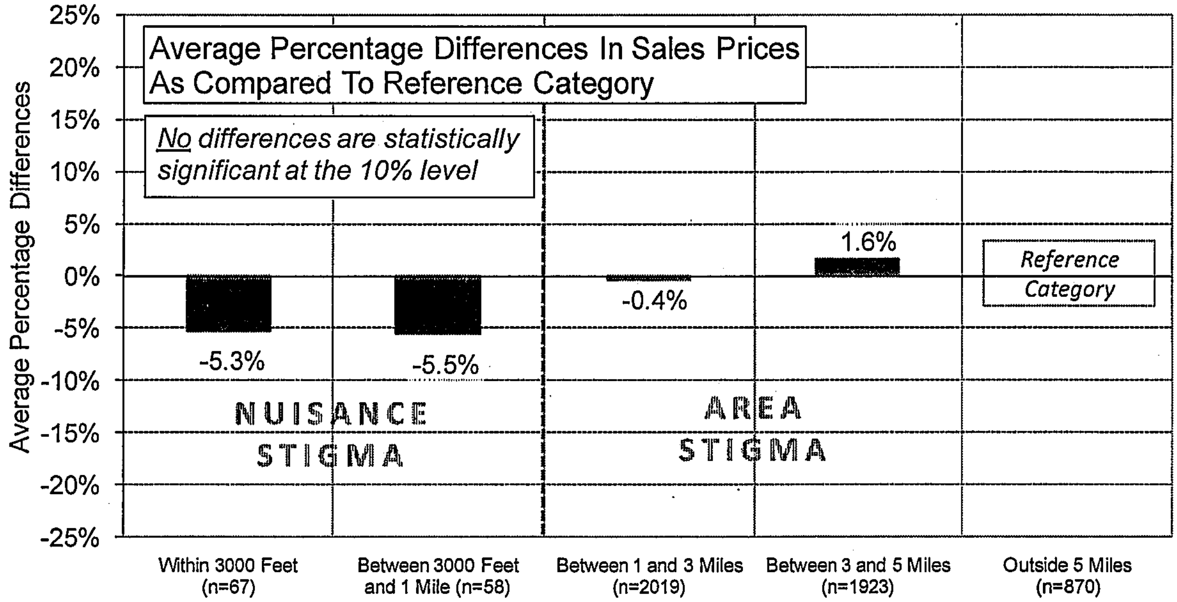
The Base Model serves as the primary model and allows all three stigmas to be explored. In sum, this model finds no persuasive evidence of any of the three potential stigmas: neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, and statistically significant effect on home sales prices.

- Area Stigma: To investigate Area Stigma, the model tests whether the sales prices of homes situated anywhere outside of one mile and inside of five miles of the nearest wind facility are measurably different from the sales price of those homes located outside of five miles. No statistically significant differences in sales prices between these homes are found (see Figure ES-1).
- Scenic Vista Stigma: For Scenic Vista Stigma, the model is first used to investigate whether the sales prices of homes with varying scenic vistas - absent the presence of the wind facility - are measurably different. The model results show dramatic and statistically significant differences in this instance (see Figure ES-2); not surprisingly, home buyers and sellers consider the scenic vista of a home when establishing the appropriate sales price. Nonetheless, when the model tests for whether homes with minor, moderate, substantial, or extreme views of wind turbines have measurably different sales prices, no statistically significant differences are apparent (see Figure ES-3).
- Nuisance Stigma: Finally, for Nuisance Stigma, the model is used to test whether the sales prices of homes situated inside of one mile of the nearest wind energy facility are measurably different from those homes located outside of five miles. Although sample size is somewhat limited in this case,[3] the model again finds no persuasive statistical evidence that wind

[3] 125 homes were located inside of one mile of the nearest wind facility and sold post-construction.

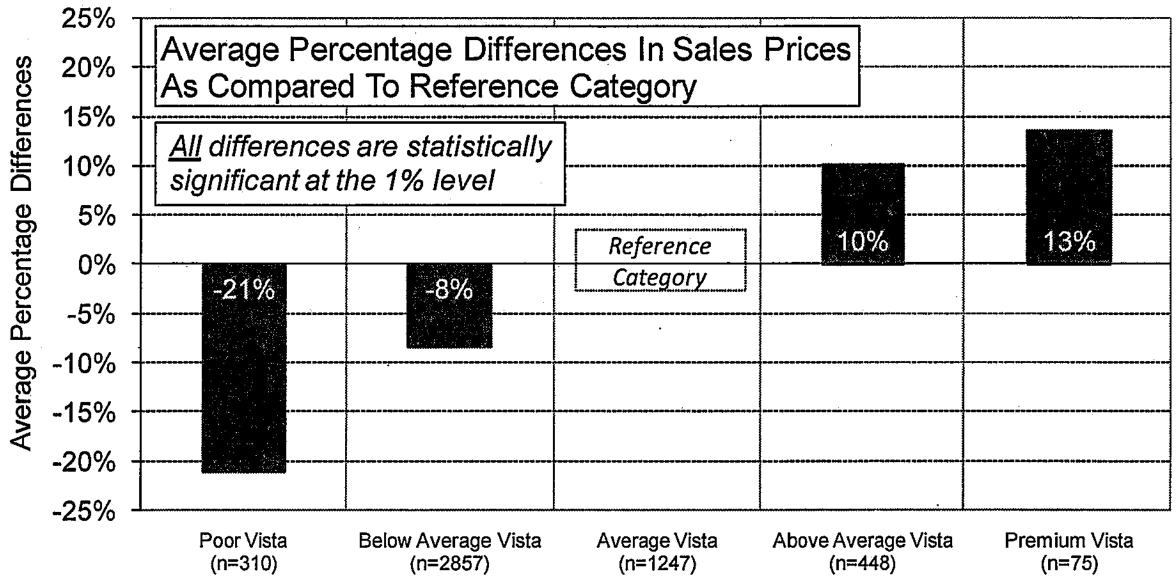
facilities measurably and broadly impact residential sales prices (see Figure ES-1 and later results).

Figure ES-1: Base Model Results: Area and Nuisance Stigma



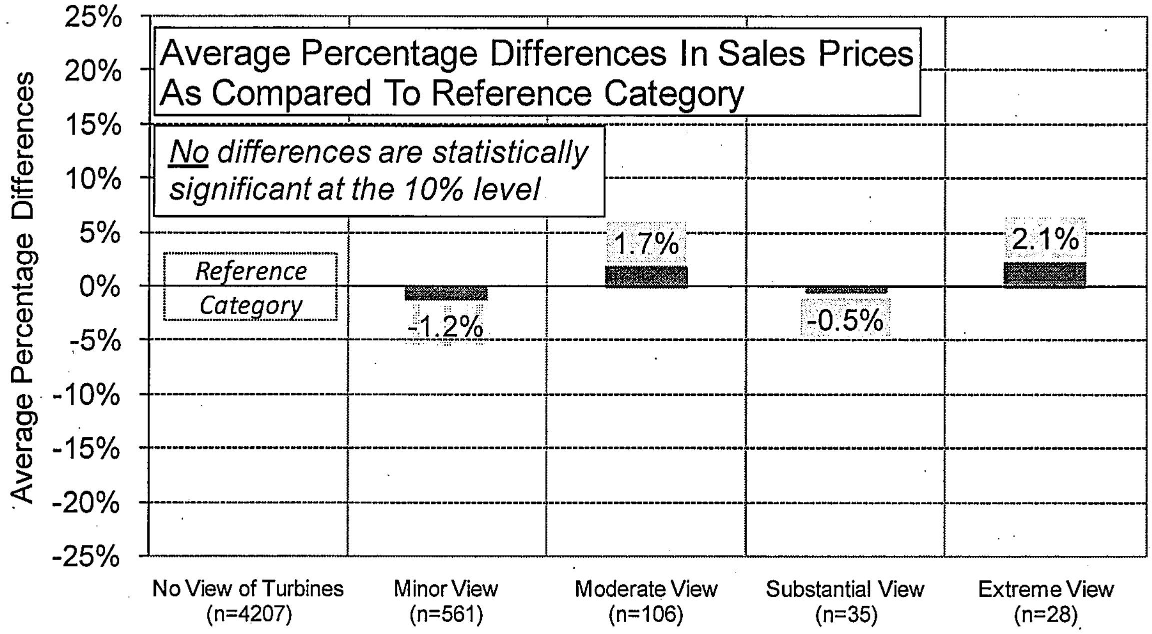
The reference category consists of transactions for homes situated more than five miles from the nearest turbine, and that occured after construction began on the wind facility

Figure ES-2: Base Model Results: Scenic Vista



The reference category consists of transactions for homes with an Average Vista, and that occured after construction began on the wind facility

Figure ES-3: Base Model Results: Scenic Vista Stigma



The reference category consists of transactions for homes without a view of the turbines, and that occured after construction began on the wind facility

The seven alternative hedonic models and the additional analysis contained in the Repeat Sales and Sales Volume Models (see Table ES-2) provide a fuller picture of the three stigmas and the robustness of the Base Model results.

Area Stigma: Other Model Results

Concentrating first on Area Stigma, the results from all of the models are similar: there is no statistical evidence of a widespread Area Stigma among the homes in this sample. Homes in the study areas analyzed here do not appear to be measurably stigmatized by the arrival of a wind facility, regardless of when those homes sold in the wind project development process and regardless of whether the homes are located one mile or five miles away from the nearest facility.

In the All Sales Model, for example, after adjusting for inflation,[4] homes that sold after wind facility construction and that had no view of the turbines are found to have transacted for higher prices - not lower - than those homes that sold prior to wind facility construction. Moreover, in the Temporal Aspects Model, homes that sold more than two years prior to the announcement of the wind facility and that were located more than five miles from where the turbines were eventually located are found to have transacted for lower prices - not higher - than homes situated closer to the turbines and that sold at any time after the announcement and construction of the wind facility (see Figure ES - 4). Further, in the Repeat Sales Model, homes located near the wind facilities that transacted more than once were found to have appreciated between those sales by an amount that was no different from that experienced by homes located in an area

[4] All sales prices in all models are adjusted for inflation, but because this model (and the Temporal Aspects Model) deals with time explicitly, it is mentioned specifically here.

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many miles away from the wind facilities. Finally, as shown in Table ES-2, none of the other models identified evidence of a broadly negative and statistically significant Area Stigma.

Scenic Vista Stigma: Other Model Results
With respect to Scenic Vista Stigma, the seven alternative hedonic models and the additional analysis contained in the Repeat Sales Model find little consistent evidence of a broadly negative and statistically significant impact. Although there are 730 residential transactions in the sample that involve homes that had views of a wind facility at the time of sale, 160 of which had relatively significant views (i.e., a rating higher than Minor), none of the various models finds strong statistical evidence that the view of a nearby wind facility impacts sales prices in a significant and consistent manner.

When concentrating only on the view of the wind facilities from a home (and not testing for Area and Nuisance Stigmas simultaneously), for example, the results from the View Stability Model are very similar to those derived from the Base Model, with no evidence of a Scenic Vista Stigma. Similarly, the All Sales Model finds that homes that sold after wind facility construction and that had a view of the facility transacted for prices that are statistically indistinguishable from those homes that sold at any time prior to wind facility construction. The Orientation Model, meanwhile, fails to detect any difference between the sales prices of homes that had either a front, back, or side orientation to the view of the wind facility. As shown in Table ES-2, the Continuous Distance and Temporal Aspects models also do not uncover any evidence of a broadly negative and statistically significant Scenic Vista Stigma.

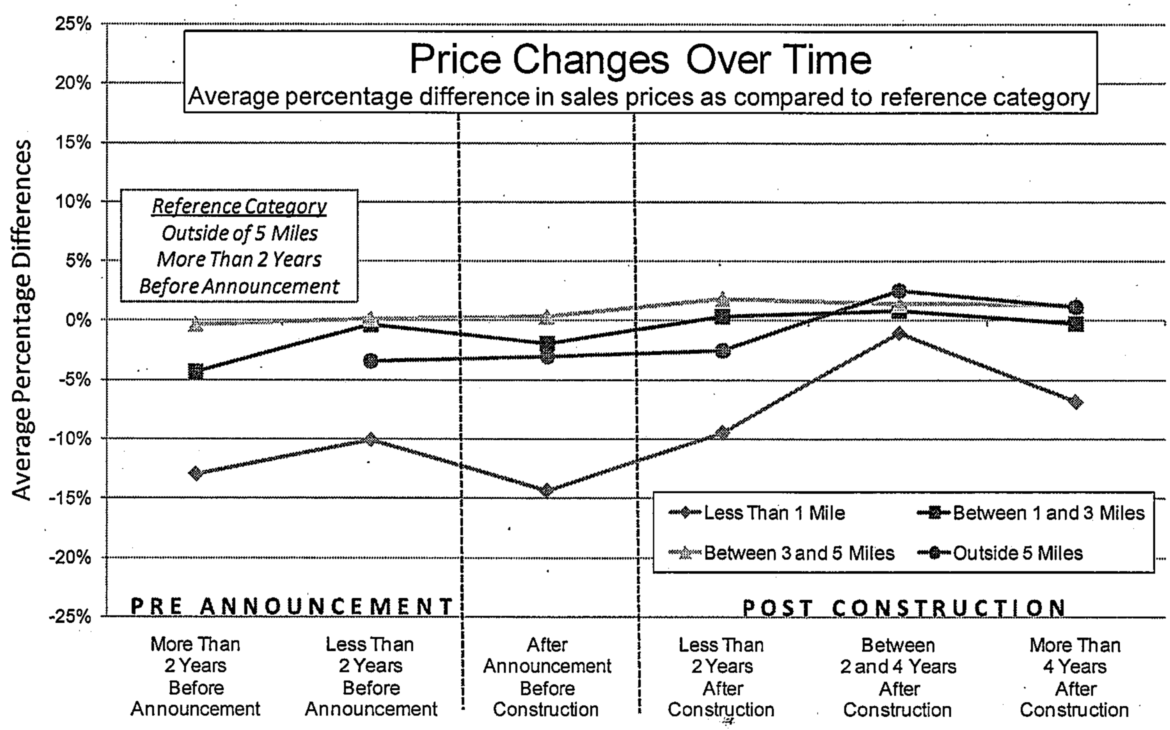
In the Repeat Sales Model, some limited evidence is found that a Scenic Vista Stigma may exist, but those effects are weak, fairly small, somewhat counter-intuitive, and are at odds with the results of other models. This finding is likely driven by the small number of sales pairs that are located within one mile of the wind turbines and that experience a dramatic view of those turbines. Finally, in the Overlap Model, where the degree to which a view of the wind facility overlaps the primary scenic vista from the home is accounted for, no statistically significant differences in sales prices are detected between homes with somewhat or strongly overlapping views when compared to those homes with wind turbine views that did not overlap the primary scenic vista. Though this model produces some weak evidence of a Scenic Vista Stigma among homes with Minor views of wind facilities, the same model finds that the sales prices of those homes with views that barely overlap the primary scenic vista are positively impacted by the presence of the wind facility. When these two results are combined, the overall impact is negligible, again demonstrating no persuasive evidence of a Scenic Vista Stigma.

Nuisance Stigma: Other Model Results
Results for Nuisance Stigma from the seven alternative hedonic models and the additional analysis contained in the Repeat Sales and Sales Volume Models support the Base Model results. Taken together, these models present a consistent set of results: homes in this sample that are within a mile of the nearest wind facility, where various nuisance effects have been posited, have not been broadly and measurably affected by the presence of those wind facilities. These results imply that Nuisance Stigma effects are either not present in this sample, or are too small and/or infrequent to be statistically distinguished.

In the Distance Stability Model, for example, when concentrating only on the distance from homes to the nearest wind turbine (and not testing for Scenic Vista Stigma simultaneously), the results are very similar to those derived from the Base Model, with no statistical evidence of a Nuisance Stigma. These results are corroborated by the Continuous Distance, Orientation, Overlap, and Repeat Sales Models, none of which find a statistically significant relationship between distance and either sales prices or appreciation rates. Relatedly, the Sales Volume analysis finds no evidence that homes located within one mile of the nearest wind turbine are sold any more or less frequently than homes located farther away from the wind facilities.

In the All Sales Model, a weakly significant difference is found between the sales prices of homes located between 3000 feet and one mile of the nearest wind facility and the homes that sold before the announcement of the wind facility. This effect, however, is largely explained by the results of the Temporal Aspects Model, shown in Figure ES - 4. The Temporal Aspects Model finds that homes located within one mile of where the wind turbines would eventually be located sold for depressed prices well before the wind facility was even announced or constructed. In all time periods following the commencement of wind facility construction, however, inflation-adjusted sales prices increased - not decreased - relative to pre-announcement levels, demonstrating no statistical evidence of a Nuisance Stigma. The results from the All Sales Model (and, for that matter, the negative, albeit statistically insignificant coefficients inside of one mile in the Base Model, see Figure ES-1) are therefore an indication of sales price levels that preceded wind facility announcement construction, and that are not sustained after construction.

Figure ES - 4: Temporal Aspects Model Results: Area and Nuisance Stigma



The reference category consists of transactions of homes situated more than five miles from where the nearest turbine would eventually be located and that occurred more than two years before announcement of the facility

Conclusions and Further Research Needs

Though each of the analysis techniques used in this report has strengths and weaknesses, the results as a whole are strongly consistent in that none of the models uncovers conclusive evidence of the presence of any of the three property value stigmas that might be present in communities surrounding wind power facilities. Therefore, based on the data sample and analysis presented here, no evidence is found that home prices surrounding wind facilities are consistently, measurably, and significantly affected by either the view of wind facilities or the distance of the home to those facilities. Although the analysis cannot dismiss the possibility that individual homes or small numbers of homes have been or could be negatively impacted, it finds that if these impacts do exist, they are either too small and/or too infrequent to result in any widespread, statistically observable impact. Moreover, to the degree that homes and wind facilities in this sample are similar to homes and facilities in other areas of the United States, the results presented here are expected to be transferable to other areas.

This work builds on the existing literature in a number of respects, but there remain a number of areas for further research. The primary goal of subsequent research should be to concentrate on those homes located closest to wind facilities, where the data sample herein was the most limited. Additional research of the nature reported in this paper could be pursued, but with a greater number of transactions, especially for homes particularly close to wind facilities. A more detailed analysis of sales volume impacts may also be fruitful, as would an assessment of the potential impact of wind facilities on the length of time homes are on the market in advance of an eventual sale. Finally, it would be useful to conduct a survey of those homeowners living close to existing wind facilities, and especially those residents who have bought and sold homes in proximity to wind facilities after facility construction, to assess their opinions on the impacts of wind project development on their home purchase and sales decisions.

1. Introduction

Wind power development has expanded dramatically in recent years (GWEC, 2009). Although the percent of electricity supplied to the U.S. and globally from wind power projects installed through 2008 remains relatively low (1.9% and 1.5%, respectively) (Wiser and Bolinger, 2009), there are expectations that those percentages will rise and that wind energy could contribute a significant percentage of future electricity supply (GWEC, 2008; Wiser and Hand, 2010). Most recently, President Obama, in his 2009 State of the Union address, called for a doubling of renewable energy in three years (by 2012), and in 2008 the U.S. Department of Energy produced a report that analyzed the feasibility of meeting 20% of U.S. electricity demand with wind energy by 2030 (US DOE, 2008).

To meet these goals, a significant amount of wind project development activity would be required. The average size of wind power projects built in the U.S. in 2007 and 2008 was approximately 100 MW (Wiser and Bolinger, 2009) and the total amount of capacity required to reach 20% wind electricity is roughly 300,000 MW (US DOE, 2008). Therefore, to achieve 20% wind electricity by 2030, a total of 3,000 wind facilities may need to be sited and permitted. Most permitting processes in the U.S. require some form of environmental impact assessment, and some form of public involvement in the siting process. Though surveys show that public acceptance is high in general for wind energy (e.g., Wolsink, 2000; Firestone and Kempton, 2006), a variety of concerns are often expressed on the local level that can impact the length and outcome of the siting and permitting process. These concerns range from the potential impacts of wind projects on wildlife habitat and mortality, radar and communications systems, ground transportation and historic and cultural resources, to aesthetic and property value concerns as well as potential nuisance and health impacts. As a result, a variety of siting and permitting guidelines (AWEA, 2008) and impact assessments (NAS, 2007) have been completed.

Surveys of local communities considering wind facilities have consistently ranked adverse impacts on aesthetics and property values in the top tier of concerns (e.g., BBC R&C, 2005; Firestone and Kempton, 2006). Developers of wind energy echo this assessment: they ranked aesthetics and property values as two of the top concerns (first and third respectively) for individuals or communities opposed to wind power development (Paul, 2006). Local residents have even brought suit against a developer over property values (Dale Rankin v. FPL, 2008), and some developers have responded to these concerns by offering "neighbor agreements" that compensate nearby homeowners for the potential impacts of wind projects.

The two concerns of aesthetics and property values are intrinsically linked. It is well established that a home's value will be increased if a high-quality scenic vista is enjoyed from the property (e.g., Seiler et al., 2001). Alternatively, it is reasonable to assume that if a home's scenic vista overlaps with a view of a disamenity, the home might be devalued, as has been found for high-voltage transmission lines (HVTL) (Kroll and Priestley, 1992; Des-Rosiers, 2002). Whether a view of wind turbines similarly impacts home values is a key topic of debate in local siting decisions. Aesthetics alone, however, is not the only pathway through which wind projects might impact residential property values. Distance to the nearest wind turbine, for example, might also have an impact if various nuisance effects are prominent, such as turbine noise,

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shadow flicker,[5] health or safety concerns, or other impacts, real or perceived. In this way, property values near wind turbines might be impacted in the same way as homes near roads might be devalued (Bateman et al., 2001). Additionally, there is evidence that proximity to a disamenity, even if that disamenity is not visible and is not so close as to have obvious nuisance effects, may still decrease a home's sales price, as has been found to be the case for landfills (Thayer et al., 1992).

Taken together, these general concerns about the possible impacts of wind projects on residential property values can be loosely categorized into three potential stigmas:

- Area Stigma: A concern that the general area surrounding a wind energy facility will appear more developed, which may adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines.
- Scenic Vista Stigma: A concern that a home may be devalued because of the view of a wind energy facility, and the potential impact of that view on an otherwise scenic vista.
- Nuisance Stigma: A concern that factors that may occur in close proximity to wind turbines, such as sound and shadow flicker, will have a unique adverse influence on home values.

These three potential stigmas are not mutually exclusive and could, in theory, be present in part or in combination for any single home. Consequently, all three potential impacts must be considered when analyzing the effects of wind facilities on residential sales prices.

Although concerns about the potential impact of wind projects on residential property values are often mentioned in siting cases, the state of the existing literature on this topic leaves much to be desired. To some extent, the growing body of research investigating this topic has come to opposing conclusions. The most recent and comprehensive of these studies have often concluded that no widespread impacts of wind projects on residential property values are apparent (Hoen, 2006; Sims and Dent, 2007; Sims et al., 2008). At the same time, pre-construction surveys of both homeowners and real estate experts have sometimes found an expectation of negative impacts (e.g. Haughton et al., 2004), and post-construction appraisals have sometimes come to similar conclusions (McCann, 2008; Kielisch, 2009). Given the state of the literature, it is not uncommon for local siting and permitting processes to involve contradicting testimony from experts, as occurred in 2004 when the Public Service Commission of Wisconsin heard opposing conclusions from two studies conducted by experienced home valuation experts (Poletti, 2005; Zarem, 2005).

This report contains the most comprehensive and data-rich analysis to date on the potential impacts of wind projects on nearby residential sales prices. Data from 7,459 residential transactions were collected from the surrounding communities of 24 individual wind projects in nine states and 14 counties in the United States.[6] Because of the large sample size, the diversity of wind projects included in the analysis, and the depth of information collected, a number of different analyses were possible. Specifically, this report relies heavily on a hedonic regression

[5] Shadow flicker occurs when the sun shines through the wind turbine blades when at a low angle to the horizon and shadows are cast on a window or interior wall of a residence (NAS, 2007).

[6] The majority of the analysis only includes homes that sold after wind facility construction began, totaling 4,937 transactions.

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model[7] and uses various forms of that model to investigate potential effects and to confirm the robustness of the resulting findings. To further investigate the robustness of the results, a repeat sales model[8] and a sales volume model[9] are also utilized. In sum, this work builds and improves on the previous literature, and provides an in-depth assessment of the question of whether residential property values in the United States have been affected, in a statistically measurable way, by views of and proximity to wind power facilities.

The remainder of this report is structured as follows. The next section discusses the hedonic model in general, its application to environmental disamenities research, and some potentially analogous results drawn from these studies. This is followed by a summary of the existing literature that has investigated the effects of wind energy on residential property values. The report then turns to the data used in the analysis, a discussion of the primary (or "base") hedonic model, and an analysis of the results from that statistical model. Following that, a set of alternative hedonic models are estimated, as well as a repeat sales model and sales volume model, to test for the robustness of the "base" model results and to explore other aspects of the data. Taking into account the full set of results presented earlier, the report then discusses the three stigmas that may lead to wind projects impacting residential property values, and summarizes how the analysis informs the existence and magnitude of these potential effects. The report ends with a brief conclusion, and a discussion of future research possibilities. A number of appendices follow the conclusion, and contain detailed information on each wind project study area, the data collection instrument and qualitative rating systems used in the field research, the investigation of the best "base" model, the hedonic model assumptions and related tests, and full results from all of the additional statistical models estimated in the report.

[7] The hedonic regression model, which was briefly described in a sidebar in the Executive Summary, is described in detail in Section 2.1.

[8] A repeat sales model uses, as its dataset, only those homes that have sold more than once. By comparing annual appreciation rates of homes that sold once before facility announcement, and again after construction, it can be tested, in an alternative fashion, if home values are affected by the distance to or view of nearby wind turbines.

[9] Sales volume can be defined as the percentage of homes that fit a certain criteria (e.g. single family, on less than 25 acres, zoned residential, assessed for more than $10,000) that actually did sell. By comparing sales volumes at various distances to wind facilities, before and after the facility was built, a further robustness test is possible.

2. Previous Research

Hedonic pricing models are frequently used to assess the marginal impacts of house and community characteristics on sales prices and by extension on property values in general. Because the hedonic model is the primary statistical method used in this report, this section begins by describing the model in more detail and providing some relevant examples of its use. The section then reviews the existing literature on the effects of wind energy facilities on surrounding property values, highlights the shortcomings of that literature, and outlines how the present research addresses those shortcomings.

2.1. Hedonic Models and Environmental Disamenities

A house can be thought of as a bundle of characteristics (e.g., number of square feet, number of bathrooms, number of fireplaces, and amount of acreage). When a price is agreed upon between a buyer and seller there is an implicit understanding that those characteristics have value. When data from a number of sales transactions are available, the individual marginal contribution to the sales price of each characteristic can be estimated with a hedonic regression model (Rosen, 1974; Freeman, 1979). This relationship takes the basic form:

Sales price = f(house structural characteristics, other factors)

where "house structural characteristics" might include, but are not limited to, the number of square feet of living area, bathrooms, and fireplaces, the presence of central AC and the condition of the home, and "other factors" might include, but are not limited to, home site characteristics (e.g., number of acres), neighborhood characteristics (e.g., school district), market conditions at the time of sale (e.g., prevailing mortgage interest rates), and surrounding environmental conditions (e.g., proximity to a disamenity or amenity).

The relationship between the sales price of homes and the house characteristics and other factors can take various forms. The most common functional form is the semi-log construction where the dependent variable is the natural log of the inflation adjusted sales price, and the independent variables are unadjusted (not transformed) home characteristics and other factors. The usefulness of this form of hedonic model is well established (Malpezzi, 2003; Sirmans et al., 2005b; Simons and Saginor, 2006) assuming that certain threshold assumptions are met.[10] The model is used commonly by academics, real estate assessors, appraisers, and realtors when large datasets are available on past residential sales transactions, and when estimates of the marginal impact of certain house characteristics and other factors on sales prices are desired.[11]

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[10] These assumptions, which are discussed in greater detail in Section 4.2 and Appendix G, include absence of outliers and/or influencers, presence of homoskedastic variances, absence of spatial and temporal autocorrelation, and absence of collinearity between the variables of interest and other independent variables.

[11] It should be emphasized that a hedonic model is not designed to appraise properties (i.e., to establish an estimate of the market value of a home at a specified point in time), as would be done with an automated valuation model (AVM). Rather, hedonic models are designed to estimate the marginal contribution of individual house or community characteristics to sales prices, which requires hedonic models to rely upon large data sets with a sizable number of explanatory variables. Appraisal models, on the other hand, are generally based on small, localized data sets (i.e., "comps") and a limited number of explanatory variables that pertain to nearby properties. Due to their higher level of accuracy through the use of significantly more information (e.g., diverse spatial, temporal, and

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A particularly useful application of the hedonic regression 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 (e.g., Mahan et al., 2000) or lake views (e.g., Seiler et al., 2001), and disamenities, such as proximity to and/or views of high-voltage transmission lines (HVTLs) (e.g. Des-Rosiers, 2002), fossil fuel power plants (Davis, 2008), roads (e.g. Bateman et al., 2001), cell phone towers (e.g. Bond and Wang, 2007), and landfills (e.g., Thayer et al., 1992; Ready and Abdalla, 2005).

There are a number of useful reviews that describe the application of hedonic models in these circumstances (Kroll and Priestley, 1992; Farber, 1998; McCann, 1999; Bateman et al., 2001; Boyle and Kiel, 2001; Jackson, 2001; Ready and Abdalla, 2005; Simons and Saginor, 2006; Simons, 2006b; Leonard et al., 2008).[12] The large number of studies covered in these reviews demonstrate that hedonic models are regularly used to investigate the interplay between home values and distance to potential disamenities, teasing out if and how sales prices are adversely affected depending on the distance of a typical home from a disamenity. For example, Carroll et al. (1996) use a hedonic model to estimate a devaluation of 16% for homes "close to" a chemical plant, with a 6.5% increase in sales price per mile away out to 2.5 miles, at which point effects fade entirely. Dale et al. (1999) find a maximum effect of -4% near a lead smelter, with sales prices increasing 2% for each mile away out to two miles, where effects again fade. Ready and Abdalla (2005) find maximum effects near landfills of -12.4%, which fade entirely outside 2,400 feet, and maximum effects near confined animal feeding operations of -6.4%, which fade entirely outside of 1,600 feet. Meanwhile, studies of other energy infrastructure, such as HVTLs, find maximum effects of -5.7% for homes adjacent to a HVTL tower, and an increase in prices of 0.018% per foot away from the tower out to 300 feet (Hamilton and Schwann, 1995), and maximum effects of -14% for homes within 50 feet of a HVTL, but no effect for similar homes at 150 feet (Des-Rosiers, 2002). Further, for fossil fuel power plants, Davis (2008) finds average adverse effects of between 3 and 5% inside of two miles but that those effects fade entirely outside of that distance range.

In addition to investigating how sales prices change with distance to a disamenity, hedonic models have been used to investigate how prices have changed over time. For instance, sales prices have sometimes been found to rebound after the removal of a disamenity, such as a lead smelter (Dale et al., 1999), or to fade over time, as with HVTLs (Kroll and Priestley, 1992) or spent fuel storage facilities (Clark and Allison, 1999). Finally, hedonic models have been used to estimate how views of a disamenity affect sales prices. Des-Rosiers (2002), for example, finds that homes adjacent to a power line and facing a HVTL tower sell for as much as 20% less than similar homes that are not facing a HVTL tower.

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characteristic information) and rigorous methodology, hedonic models can also be used as appraisal models. Automated valuation models cannot, however, be reliably used to measure marginal effects because they do not employ sufficient information to do so, and, more importantly, AVMs do not hold controlling characteristics constant, which could bias any resulting estimates of marginal effects.

[12] For further discussion of the hedonic model and its application to the quantification of environmental stigmas in comparison to other methods see Jackson (2005).

It is unclear how well the existing hedonic literature on other disamenities applies to wind turbines, but there are likely some similarities. For instance, in general, the existing literature seems to suggest that concerns about lasting health effects provide the largest diminution in sales prices, followed by concerns for one's enjoyment of the property, such as auditory and visual nuisances, and that all effects tend to fade with distance to the disamenity - as the perturbation becomes less annoying. This might indicate that property value effects from wind turbines are likely to be the most pronounced quite close to them, but fade quickly as their auditory and visual impacts fade. The existing hedonic literature also, in general, finds that effects fade with time as self-selecting buyers without prejudice towards the disamenity move into the area, or as the real or perceived risks of the disamenity are lessoned (Jackson, 2001). This implies that any stigmas related to wind turbines might also fade over time as local communities come to accept their presence.

2.2. Impacts of Wind Projects on Property Values

Turning to the literature that has investigated the potential property value effects from wind facilities directly, it deserves note that few studies have been academically peer-reviewed and published; in some cases, the work has been performed for a party on one side or the other of the permitting process (e.g., the wind developer or an opposition group). Nonetheless, at a minimum, a brief review of this existing literature will set the stage for and motivate the later discussion of the methods and results of the present work. The literature described below is summarized in Table 1. To frame this discussion, where possible, the three potential stigmas discussed earlier are used:

- Area Stigma: A concern that the general area surrounding a wind energy facility will appear more developed, which may adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines.
- Scenic Vista Stigma: A concern that a home may be devalued because of the view of a wind energy facility, and the potential impact of that view on an otherwise scenic vista.
- Nuisance Stigma: A concern that factors that may occur in close proximity to wind turbines, such as sound and shadow flicker, will have a unique adverse influence on home values.

In one of the most recent studies, Sims et al. (2008) used a hedonic model to investigate Scenic Vista Stigma using 199 residential transactions within ¼ of a mile of the 16-turbine Bears Down wind facility in Cornwall, UK. They found both large positive and smaller negative significant relationships between views of the turbines and sales prices depending on whether the view is seen from the front or rear of the home, respectively, but found no relationship between the number of wind turbines visible and sales prices. Previously, Sims and Dent (2007) used a hedonic model to investigate Nuisance and Scenic Vista Stigma with 919 transactions for homes within five miles of two wind facilities in the UK, finding only limited evidence of a relationship between proximity to and views of turbines and sales prices, which local real estate experts attributed to other causes. Hoen (2006) investigated Scenic Vista Stigma using a hedonic model to analyze 280 residential transactions occurring near a wind facility in Madison County, NY, and found no evidence that views of turbines significantly affects prices. Jordal-Jorgensen (1996) investigated Nuisance Stigma in Denmark, and found an adverse effect for homes located "close" to the turbines, but no statistical significance was reported.[13]

[13] A copy of this report could not be obtained and therefore its findings are reported based on other citations.

Using different statistical methods, Poletti (2005; 2007) used a *t*-Test to investigate Nuisance and Area Stigma by comparing the mean sales prices of 187 and 256 homes in Illinois and Wisconsin, respectively, located near wind facilities (target group) to those further away (control group).[14, 15] He split these target and control groups into respective smaller and more-homogenous sub-groups, such as large and small tracts, with and without homes, finding no statistical evidence that homes near the wind facilities sold for different prices than those farther away. Sterzinger et al. (2003) analyzed roughly 24,000 residential transactions, which were divided between those within five miles of a wind facility and those outside of five miles in an effort to assess Area Stigma. They compared residential appreciation rates over time, and found no apparent difference between those homes within and outside of five miles from a wind facility, but the statistical significance of this comparison was not reported.

Other authors have used smaller samples of residential transactions and a variety of simple statistical techniques, without reporting statistical significance, and have found a lack of evidence of effects from Nuisance Stigma (Jerabek, 2001; Jerabek, 2002; Beck, 2004) and Area Stigma (DeLacy, 2005; Goldman, 2006). These results, however, are somewhat contrary to what one appraiser has found. In his investigation of Nuisance Stigma around a wind facility in Lee County, IL, McCann (2008) found that two homes nearby a wind facility had lengthy selling periods that, he believes, also adversely affected transaction prices. Additionally, Kielisch (2009) investigated Nuisance Stigma by comparing twelve transactions of undeveloped land near two wind facilities in Wisconsin (Blue Sky Green Field and Forward) to undeveloped land transactions farther away. He found that land tracts near the wind facilities sold for dramatically lower prices ($/acre) than the comparable group, but the statistical significance of the comparison was not reported.

In addition to these revealed preference studies, a number of stated preference surveys (e.g., contingent valuation) and general opinion surveys have investigated the existence of potential effects.[16] A survey of <u>local residents</u>, conducted after the wind facilities were erected, found no evidence of Area Stigma (Goldman, 2006), while another found limited evidence of these stigmas (Bond, 2008).[17] Similarly, some surveys of <u>real estate experts</u> conducted after facility

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[14] A *t*-Test is used to compare two sample means by discerning if one is significantly different from the other.

[15] The 2007 study used the data contained in the 2005 study in combination with new data consisting of transactions that occurred in the interim period.

[16] Contingent valuation is a survey based technique to value non-market goods (e.g., an environmental disamenity) that asks respondents what their "willingness to pay" (or "willingness to accept") is to have, for instance, a disamenity removed from (or to have it remain in) their neighborhood. This technique is distinct from a general opinion survey, which might ask whether respondents believe property values have been impacted by an environmental disamenity and, if so, "by how much." Although there are important distinctions between the two techniques, with the contingent valuation method often preferred by economic practitioners, for simplicity no distinction is made here between these two approaches. Finally, another subset of the survey literature focuses on public acceptance (i.e., opinion). Though these public acceptance surveys sometimes cover possible impacts on property values, those impacts are not quantified in economic terms. As a result, public acceptance survey results are not reported here.

[17] Bond (2008) asked respondents to declare if the wind facility, which is located roughly 7 miles away, would effect what they would be willing to pay for their house and 75% said either they would pay the same or more for their house, while the remainder would pay less. When those latter respondents were asked to estimate the percentage difference in value, their estimates averaged roughly 5%.

construction have found no evidence of Area or Nuisance Stigmas (Grover, 2002; Goldman, 2006). These results, however, are contrary to the expectations for Area, Scenic Vista, and Nuisance Stigma effects predicted by local residents (Haughton et al., 2004; Firestone et al., 2007) and real estate experts (Haughton et al., 2004; Khatri, 2004; Kielisch, 2009) prior to construction found elsewhere.[18] The difference between predicted and actual effects might be attributable, at least in part, to the fear of the unknown. For instance, Wolsink (1989) found that public attitudes toward wind power, on average, are at their lowest for local residents during the wind project planning stage, but return almost to pre-announcement levels after the facilities are built. This result is echoed by Exeter-Enterprises-Ltd. (1993) and Palmer (1997), whose post-construction surveys found higher approval than those conducted pre-construction. Others, however, have found that perceptions do not always improve, attributing the lack of improvement to the perceived "success" or lack therefore of the project, with strong disapproval forming if turbines sit idle (Thayer and Freeman, 1987) or are perceived as a waste of taxpayer dollars (Devine-Wright, 2004).

When this literature is looked at as a whole, it appears as if wind projects have been predicted to negatively impact residential property values when pre-construction surveys are conducted, but that sizable, widespread, and statistically significant negative impacts have largely failed to materialize post-construction when actual transaction data become available for analysis. The studies that have investigated Area Stigma with market data have failed to uncover any pervasive effect. Of the studies focused on Scenic Vista and Nuisance Stigmas, only one is known to have found statistically significant adverse effects, yet the authors contend that those effects are likely driven by variables omitted from their analysis (Sims and Dent, 2007). Other studies that have relied on market data have sometimes found the possibility of negative effects, but the statistical significance of those results have rarely been reported.

Despite these findings, the existing literature leaves much to be desired. First, many studies have relied on surveys of homeowners or real estate professionals, rather than trying to quantify real price impacts based on market data. Second, a number of studies conducted rather simplified analyses of the underlying data, potentially not controlling for the many drivers of residential sales prices. Third, many of the studies have relied upon a very limited number of residential sales transactions, and therefore may not have had an adequate sample to statistically discern any property value effects, even if effects did exist. Fourth, and perhaps as a result, many of the studies did not conduct, or at least have not published, the statistical significance of their results. Fifth, when analyzed, there has been some emphasis on Area Stigma, and none of the studies have investigated all three possible stigmas simultaneously. Sixth, only a few of the studies (Hoen, 2006; Sims and Dent, 2007; Sims et al., 2008; Kielisch, 2009) conducted field visits to the homes to assess the quality of the scenic vista from the home, and the degree to which the wind facility might impact that scenic vista. Finally, with two exceptions (Sims and Dent, 2007; Sims et al., 2008), none of the studies have been academically peer-reviewed and published.

[18] It should be noted that the samples used by both Khatri and Kielisch contained a subset of respondents who did have some familiarity with valuing homes near wind facilities.

Table 1: Summary of Existing Literature on Impacts of Wind Projects on Property Values

Document Type Author(s)	Year	Number of Transactions or Respondents	Before or After Wind Facility Construction Commenced	Area Stigma	Scenic Vista Stigma	Nuisance Stigma
Homeowner Survey						
Haughton et al.	2004	501	Before	- *	- *	
Goldman	2006	50	After	none		
Firestone et al.	2007	504	Before	- *	- *	
Bond	2008	~300	After		- ?	- ?
Expert Survey						
Grover	2002	13	After	none		none
Haughton et al.	2004	45	Before	- *	- *	
Khatri	2004	405	Before‡	- ?		- ?
Goldman	2006	50	After	none		none
Kielisch	2009	57	Before‡			- ?
Transaction Analysis - Simple Statistics						
Jerabek	2001	25	After			none
Jerabek	2002	7	After			none
Sterzinger et al.	2003	24,000	After	none		
Beck	2004	2	After			none
Poletti	2005	187	After	none		none
DeLacy	2005	21	Before†	none		
Goldman	2006	4	After	none		
Poletti	2007	256	After	none		none
McCann	2008	2	After			- ?
Kielisch	2009	103	After			- ?
Transaction Analysis - Hedonic Model						
Jordal-Jorgensen	1996	?	After			- ?
Hoen	2006	280	After		none	
Sims & Dent	2007	919	After			- *
Sims et al.	2008	199	After		-/+ *	

" none " indicates the majority of the respondents do not believe properties have been affected (for surveys) or that no effect was detected at 10% significance level (for transaction analysis)

"- ?" indicates a negative effect without statistical significance provided

*"- *" indicates statistically significant negative effect at 10% significance level*

*"-/+ *" indicates positive and negative statistically significant effects at 10% significance level*

† Sales were collected after facility announcement but before construction

‡ Some respondents had experience with valuations near facilities while others did not

3. Data Overview

The methods applied in the present work are intended to overcome many of the limitations of the existing literature. First, a large amount of data is collected from residential transactions within 10 miles of 24 different wind projects in the U.S., allowing for a robust statistical analysis across a pooled dataset that includes a diverse group of wind project sites. Second, all three potential stigmas are investigated by exploring the potential impact of wind projects on home values based both on the distance to and view of the projects from the homes. Third, field visits are made to every home in the sample, allowing for a solid assessment of the scenic vista enjoyed by each home and the degree to which the wind facility can be seen from the home, and to collect other value-influencing data from the field (e.g., if the home is situated on a cul-de-sac). Finally, a number of hedonic regression models are applied to the resulting dataset, as are repeat sales and sales volume analyses, in order to assess the robustness of the results.

Testing for the three potential stigmas requires a significant sample of residential transactions within close proximity to existing wind facilities. Unfortunately for the study, most wind power projects are not located near densely populated areas. As a result, finding a single wind project site with enough transaction data to rigorously analyze was not possible. Instead, the approach was to collect data from multiple wind project sites, with the resulting data then pooled together to allow for robust statistical analyses.[19] The remainder of this section describes the site selection process that is used, and provides a brief overview of both the selected study areas and the data that were collected from these areas. Also provided is a description of how scenic vista, views of turbines, and distances from turbines were quantified for use in the hedonic analysis, and a summary of the field data collection effort. The section ends with a brief summary of the resulting dataset.

3.1. Site Selection

For the purpose of this study, an ideal wind project area would:

1) Have a large number of residential transactions both before and, more importantly, after wind facility construction, and especially in close proximity (e.g., within 2 miles) of the facility;
2) Have comprehensive data on home characteristics, sales prices, and locations that are readily available in electronic form; and
3) Be reasonably representative of the types of wind power projects being installed in the United States.

To identify appropriate sites that met these criteria, and that also provided a diversity of locations, the authors obtained from Energy Velocity, LLC a set of Geographic Information System (GIS) coordinates representing 241 wind projects in the U.S. that each had a total nameplate capacity greater than 0.6 megawatts (MW) and had gone online before 2006.[20] Also provided were facility capacity, number of turbines, and announcement, construction, and operational dates. These data were cross-checked with a similar dataset provided by the American Wind Energy Association (AWEA), which also included some turbine hub-height information.

[19] A thorough discussion of this "pooled" approach is contained in Section 4.2 and in Appendix F.

[20] Energy Velocity, LLC was owned at the time by Global Energy Decisions, which was later purchased by Ventyx. The dataset is available as Velocity Suite 2008 from Ventyx.

By using a variety of different GIS sorting techniques involving nearby towns with populations greater than, for example, 2,500 people, using census tract population densities, and having discussions with wind energy stakeholders, a prospective list of 56 possible study areas was generated, which were then ranked using two scales: "highly desirable" to "least desirable," and "feasible" to "potentially unfeasible."[21] Then, through an iterative process that combined calls to county officials to discuss the number of residential transactions and data availability, with investigations using mapping software to find the location of individual wind turbines, and, in some cases, preliminary visits, a list of 17 prospective study areas were chosen as both "highly desirable" and "feasible." Ultimately, three of these proved to be "unfeasible" because of data availability issues and four "undesirable" because the study area was considered not representative. This effort ultimately resulted in a final set of ten study areas that encompass a total of 24 distinct wind facilities (see Figure 1 and Table 2).[22] A full description of each study area is provided in Appendix A.

[21] "Desirability" was a combination of a number of factors: the wind facility having more than one turbine; the study area having greater than 350 sales within 5 miles and within 10 years, 250 of which transacted following construction of the facility; having some transaction data old enough to pre-date facility announcement; having data on the core home and site characteristics (e.g., square feet, acres); and, where possible, having a concentration of sales within 1 mile of the facility. "Feasibility" was also a combination of factors: having home characteristic and sales data in electronic form; having GIS shapefiles of the parcel locations; and being granted ready access to this information.

[22] The "unfeasible" study areas were Cerro Gordo County, IA, Bennington County, VT, and Atlantic County, NJ. Cerro Gordo County, IA contained multiple wind projects totaling 140 MW. Although the data at this site were available in electronic form, the county only agreed to share data in paper form, which would have created an enormous data entry burden. Because another site in the sample was considered similar to the Cerro Gordo site (IABV), Cerro Gordo County was dropped from the prospective sites. Bennington County, VT contained the 11 turbine Searsburg Wind Project (6 MW) but had no electronic records. Atlantic County, NJ contained the five turbine Jersey Atlantic Wind Farm (7.5 MW), but had data in paper records only and the county was unresponsive to inquiries regarding the study. The "undesirable" study areas were Plymouth County, MA, Wood County, OH, Cascade County, MT, and Riverside County, CA. Although the data in Plymouth County, MA were more than adequate, this small, on-land, yet coastal Hull Wind facility (2 turbines, 2.5 MW) was not considered to be particularly representative of wind development across the US. Wood County's four turbine Bowling Green facility (7 MW) met the appropriate data requirements, but ultimately it was decided that this facility was too small and remote to be representative. Cascade County's six turbine Horseshoe Bend Wind Park (9 MW) did not have enough transactions to justify study. Riverside, CA, where roughly 2500 turbines are located, had less-than-desired home characteristic data, had transactions that came more than 10 years after large scale development began, and despite having homes that were within 1 mile of the turbines, those homes typically had limited views because of high subdivision walls.

Figure 1: Map of Study Areas and Potential Study Areas

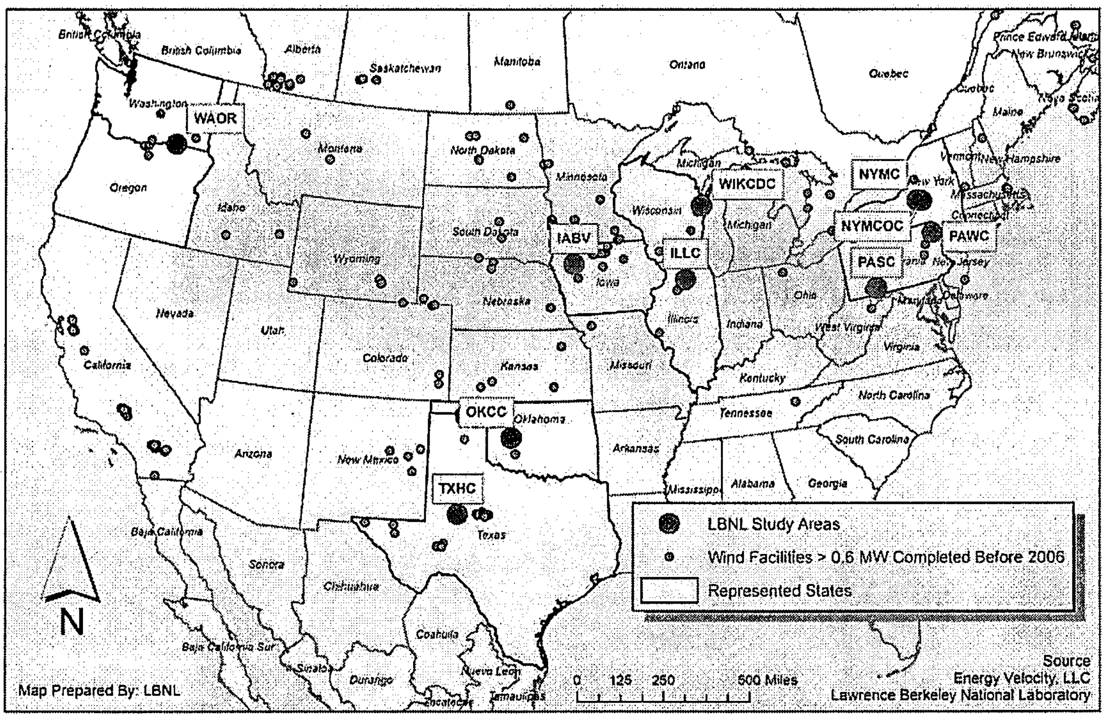

Table 2: Summary of Study Areas

Study Area Code	Study Area Counties, States	Facility Names	Number of Turbines	Number of MW	Max Hub Height (meters)	Max Hub Height (feet)
WAOR	Benton and Walla Walla Counties, WA and Umatilla County, OR	Vansycle Ridge, Stateline, Nine Canyon I & II, Combine Hills	582	429	60	197
TXHC	Howard County, TX	Big Spring I & II	46	34	80	262
OKCC	Custer County, OK	Weatherford I & II	98	147	80	262
IABV	Buena Vista County, IA	Storm Lake I & II, Waverly, Intrepid I & II	381	370	65	213
ILLC	Lee County, IL	Mendota Hills, GSG Wind	103	130	78	256
WIKCDC	Kewaunee and Door Counties, WI	Red River, Lincoln	31	20	65	213
PASC	Somerset County, PA	Green Mountain, Somerset, Meyersdale	34	49	80	262
PAWC	Wayne County, PA	Waymart	43	65	65	213
NYMCOC	Madison and Oneida Counties, NY	Madison	7	12	67	220
NYMC	Madison County, NY	Fenner	20	30	66	218
		TOTAL	**1345**	**1286**		

These 10 study areas and 24 projects are located in nine separate states, and include projects in the Pacific Northwest, upper Midwest, the Northeast, and the South Central region. The wind projects included in the sample total 1,286 MW, or roughly 13% of total U.S. wind power capacity installed at the time (the end of 2005). Turbine hub heights in the sample range from a minimum of 164 feet (50 meters) in the Washington/Oregon (WAOR) study area, to a maximum of 262 (80 meters) (TXHC, OKCC and PASC), with nine of the ten study areas having hub heights of at least 213 feet (65 meters). The sites include a diverse variety of land types, including combinations of ridgeline (WAOR, PASC, and PAWC), rolling hills (ILLC, WIKCDC, NYMCOC, and NYMC), mesa (TXHC), and windswept plains (OKCC, IABV).[23]

3.2. Data Collection

In general, for each study area, residential transaction data in as close proximity to the wind turbines as possible was sought, from both before and after wind facility construction. To balance the cost and quantity of data collection in each study area with the desire to cover as many study areas as possible, the research effort sought to collect data on 400 to 1,250 transactions in each study area.[24] In some instances, this meant including all residential transactions within ten miles of the wind turbines. In others, only transactions within five miles were included. In some extreme instances, when the number of transactions inside of five miles far exceeded the 1,250 limit, all transactions in close proximity to the wind turbines (e.g., inside three miles) were included in combination with a random sample of transactions outside of that distance band (e.g., between three and five miles).[25] The data selection processes for each Study Area are contained in Appendix A.

Three primary sets of data are used in the analysis: tabular data, GIS data, and field data, each of which is discussed below. Following that, this subsection highlights the two qualitative variables that are essential to this analysis and that therefore require special attention, scenic vista and views of turbines, and then discusses the field data collection process.

3.2.1. Tabular Data

Berkeley Lab obtained tabular transaction data from participating counties[26] containing 7,459 "valid"[27] transactions of single family residential homes, on less than 25 acres,[28] which were

[23] Some areas, such as PASC, had both a ridgeline and rolling hills on which wind facilities were located.

[24] This range was chosen to ensure that a minimum of data were present in each study area to allow for a robust analysis, and yet not too much so as to make data collection (e.g., the visiting of each home) inordinately time and resource consuming in any individual study area.

[25] An alternative method would have been to collect data on every sale that occurred. Although in most cases this would be preferred, in ours it would not have added one additional transaction within close proximity or with dramatic views of wind turbine, the focus of the study. Rather, it would have added an overwhelming majority of transactions of homes without views and at distances outside of three miles from the turbines, all of which would have come at considerably cost and, more importantly, would not likely have influenced the results significantly while perhaps necessitating a reduction in the total number of study areas that could be included in the sample.

[26] In some cases, the county officials, themselves, extracted data from their database, and in some cases a company engaged to manage a county's data provided the necessary information. In either case the provider is referred to as "county." Detailed descriptions of the providers are presented in Appendix A.

[27] Validity was determined by each individual county data provider. A sale that is considered "valid" for county purposes would normally meet the minimum requirements of being arm's length; being a transfer of all rights and warrants associated with the real estate; containing an insignificant amount of personal property so as not to affect the price; demonstrating that neither party in the sale acting under duress or coercion; not being the result of a liquidation of assets or any other auction, a mortgage foreclosure, a tax sale, or a quit claim; and being appropriate for use in calculating the sales price to assessed value ratios that are reported to the state. Due to the formal requirements associated with this calculation, "validity" is often defined by a state's Department of Revenue, as shown, for example, here: http://www.orps.state.ny.us/assessor/manuals/vol6/rfv/index.htm. In addition, though the

sold for a price of more than $10,000,[29] which occurred after January 1, 1996,[30] and which had fully populated "core" home characteristics. These core characteristics are: number of square feet of the living area (not including finished basement), acres of land, bathrooms, and fireplaces, the year the home was built,[31] if the home had exterior wallsthatwere stone, a central air conditioning unit, and/or a finished basement, and the exterior condition of the home. The 7,459 residential transactions in the sample consist of 6,194 homes (a number of the homes in the sample sold more than once in the selected study period). Because each transaction had a corresponding set of the core home characteristic data, they could all be pooled into a single model. In addition to the home characteristic data, each county provided, at a minimum, the home's physical address and sales price. The counties often also provided data on homes in the study area that did not sell in the study period.[32] Finally, market-specific quarterly housing inflation indexes were obtained from Freddie Mac, which allowed nominal sales prices to be adjusted to 1996 dollars.[33]

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sample originally contained 7,498 sales, 34 homes sold twice in a 6 month period and, after discussions with local officials, these transactions were considered likely to have been "invalid" despite the county coding them to the contrary. Additionally, five transactions produced standardized residuals that were more than six standard deviations away from the mean, indicating that these sales were abnormal and likely not valid. Both of these sets of transactions, totaling 39, were removed from the final dataset. Of the 39 sales, 32 sold following construction, 10 were concentrated in IABV and nine in TXHC with the others spread between seven of the remaining eight study areas. One of the homes was inside of one mile from the turbines at the time of sale, and two had views of the turbines (both of which were MINOR). The home that was located within one mile was surrounded by a number of other homes – at similar distances from the turbines - that transacted both before and after the wind facilities were built and were included in the sample. A more thorough discussion of the screening techniques used to ensure the appropriateness of the final data set are presented in detail in Appendix G under "Outliers/Influencers." Finally, it should be noted that the authors are aware of four instances in the study areas when homes were sold to wind developers. In two cases the developer did not resell the home; in the other two, the developer resold the home at a lower price than which it was purchased. But, because the sales were to a related party, these transactions were not considered "valid' and are therefore not included here. One might, however, reasonably expect that the property values of these homes were impacted by the presence of the wind turbines.

[28] Single family residences on more than 25 acres were considered to be likely candidates for alternative uses, such as agricultural and recreational, which could have an influence on sales price that was outside of the capabilities of the model to estimate. Because all records were for parcels that contained a residence, the model did not contain any "land-only" transactions. Further, none of the transactions provided for this research were for parcels on which a turbine was located.

[29] A sales price of $10,000 was considered the absolute minimum amount an improved parcel (one containing a residential structure) would sell for in any of the study areas and study periods. This provided an additional screen over and above the "valid" screen that the counties performed.

[30] This provided a maximum of 12 years of data. Some counties did not have accessible data back to 1996 but in all cases these countries had data on transactions that occurred before the wind facilities were erected.

[31] "Year Built" was used to construct a variable for the age of the home at the time of the sale.

[32] These data were used to calculate the "Sales Volume" percentages referred to in Section 7.

[33] Freddie Mac Conventional Mortgage Home Price Index: municipal statistical area (MSA) series data are available from the following site: http://www.freddiemac.com/finance/cmhpi/. Because most of the study areas do not fall within the MSAs, a collection of local experts was relied upon, including real estate agents, assessors, and appraisers, to decide which MSA most-closely matched that of the local market. In all cases the experts had consensus as to the best MSA to use. In one case (NYMCOC) the sample was split between two MSAs. These indexes are adjusted quarterly, and span the entire sample period. Therefore, during the housing boom, insofar as a boom occurred in the sample areas, the indexes increased in value. Subsequently when the market began falling, the index retracted.

3.2.2. GIS Data

GIS data on parcel location and shape were also required, and were obtained from the counties. The counties also often provided GIS layers for roads, water courses, water bodies, wind turbines (in some cases), house locations, and school district and township/town/village delineations. GIS data on census tract and school district delineations were obtained from the U.S. Census Bureau, if not provided by the county.[34] GIS data were obtained on water courses, water bodies, land elevations, and satellite imagery, as was necessary, from the U.S. Department of Agriculture.[35] Combined, these data allowed each home to be identified in the field, the construction of a GIS layer of wind turbine locations for each facility, and the calculation of the distance from each home to the nearest wind turbine.[36] Determining the distance from each home to the nearest wind turbine was a somewhat involved process, and is discussed in detail in Appendix B. Suffice it to say that each transaction had a unique distance ("DISTANCE")[37] that was determined as the distance between the home and nearest wind turbine at the time of sale, and that these distances are grouped into five categories: inside of 3000 feet (0.57 miles), between 3000 feet and one mile, between one and three miles, between three and five miles, and outside of five miles.[38] Finally, the GIS data were used to discern if the home was situated on a cul-de-sac and had water frontage, both of which were corroborated in the field.

3.2.3. Field Data

Additional data had to be collected through field visits to all homes in the sample. Two qualitative measures in particular – for scenic vista and for view of the wind turbines – are worth discussing in detail because each is essential to the analysis and each required some amount of professional judgment in its creation.

The impact or severity of the view of wind turbines ("VIEW") [39] may be related to some combination of the number of turbines that are visible, the amount of each turbine that is visible (e.g., just the tips of the blades or all of the blades and the tower), the distance to the nearest turbines, the direction that the turbines are arrayed in relation to the viewer (e.g., parallel or perpendicular), the contrast of the turbines to their background, and the degree to which the turbine arrays are harmoniously placed into the landscape (Gipe, 2002). Recent efforts have made some progress in developing quantitative measures of the aesthetic impacts of wind turbines (Torres-Sibillea et al., 2009),[40] but, at the time this project began, few measures had

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[34] These data were sourced from the U.S. Census Bureau's Cartographic Boundary Files Webpage: http://www.census.gov/geo/www/cob/bdy_files.html.

[35] These data were sourced from the USDA Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/GatewayHome.html.

[36] Although in some cases the county provided a GIS layer containing wind turbine points, often this was not available. A description of the turbine mapping process is provided in Appendix B.

[37] Distance measures are collectively and individually referred to as "DISTANCE" from this point forward.

[38] The minimum distance of "inside 3000 feet" was chosen because it was the closest cutoff that still provided an ample supply of data for analysis.

[39] View of turbines ratings are collectively and individually referred to as "VIEW" from this point forward.

[40] In addition to these possible field techniques, previous studies have attempted to use GIS to estimate wind turbine visibility using "line-of-sight" algorithms. For example, Hoen (2006) used these algorithms after adding ground cover to the underlying elevation layer. He found that the GIS method differed substantially from the data collected in the field. Seemingly, small inaccuracies in the underlying elevation model, errors in the software's algorithm, and the existence of ground cover not fully accounted for in the GIS, substantially biased GIS-based assessments of

been developed, and what had been developed was difficult to apply in the field (e.g., Bishop, 2002). As a result, the authors opted to develop an ordered qualitative VIEW rating system that consisted of placing the view of turbines into one of five possible categories: NO VIEW, MINOR, MODERATE, SUBSTANTIAL, and EXTREME. These ratings were developed to encompass considerations of distance, number of turbines visible, and viewing angle into one ordered categorical scale, and each rating is defined in Table 3:[41]

Table 3: Definition of VIEW Categories

NO VIEW	The turbines are not visible at all from this home.
MINOR VIEW	The turbines are visible, but the scope (viewing angle) is narrow, there are many obstructions, or the distance between the home and the facility is large.
MODERATE VIEW	The turbines are visible, but the scope is either narrow or medium, there might be some obstructions, and the distance between the home and the facility is most likely a few miles.
SUBSTANTIAL VIEW	The turbines are dramatically visible from the home. The turbines are likely visible in a wide scope and most likely the distance between the home and the facility is short.
EXTREME VIEW	This rating is reserved for sites that are unmistakably dominated by the presence of the wind facility. The turbines are dramatically visible from the home and there is a looming quality to their placement. The turbines are often visible in a wide scope or the distance to the facility is very small.

Photographic examples of each of the categories are contained in Appendix E.

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visibility. This was corroborated elsewhere by Maloy and Dean (2001) and Riggs and Dean (2007). As a result of these findings, it was determined that field collection of VIEW data was essential.

[41]In addition to the qualitative rating system that was ultimately used in this study, a variety of quantitative data were collected that might describe the nature of the view of wind turbines, including the total number of turbines visible, the distance of the home to the nearest wind turbine, and the view scope/viewing angle (i.e., the degree to which the turbines spread out in front of the home: narrow, medium, or wide). To explore the validity of the qualitative rating scale two tests were conducted. First, a pre-study survey was conducted by showing 10 different off-site respondents 15 randomly selected photographs from the field representing the various rated VIEW categories. The higher VIEW ratings were oversampled to create a roughly equal distribution among the categories. The respondents rated the views into one of the qualitative categories. The on-site / field collected ratings matched the off-site responses 65% of the time, with 97% of the rankings differing by no more than one category. Ninety-eight percent of the on-site-ranked MINOR VIEWs and 89% of the EXTREME VIEWs were similarly ranked by off-site respondents. The on-site rankings were less than the off-site rankings 97% of the time; it is assumed that this is because on-site ratings took into account a greater portion of the panorama than were captured in the photos, which translated into a lower ranking. Secondly, a post hoc Multinomial Logistic Regression model was created that used the qualitative on-site VIEW ratings as the dependent variable and the quantitative measures of distance to nearest turbine, number of turbines visible, and view scope as the independent variables. This model produced high Pseudo R^2 statistics (Cox and Snell 0.88, Nagelkerke 0.95, and McFadden 0.79) and predicted values that were highly correlated with the actual qualitative rating (Pearson's 0.88). Therefore, both tests corroborated the appropriateness of the simpler qualitative VIEW rankings used herein.

In addition to the qualitative VIEW measurements, a rating for the quality of the scenic vista ("VISTA")[42] from each home, absent the existence of the wind facilities, was also collected in the field. An assessment of the quality of the VISTA from each home was needed because VIEW and VISTA are expected to be correlated; for example, homes with a PREMIUM VISTA are more likely to have a wide viewing angle in which wind turbines might also be seen. Therefore, to accurately measure the impacts of the VIEW of wind turbines on property values a concurrent control for VISTA (independent of any views of turbines) is required. Drawing heavily on the landscape-quality rating system developed by Buhyoff et al. (1994) and to a lesser degree on the systems described by others (Daniel and Boster, 1976; USDA, 1995), an ordered VISTA rating system consisting of five categories was developed: POOR, BELOW AVERAGE, AVERAGE, ABOVE AVERAGE, and PREMIUM, with each rating defined in Table 4:[43]

Table 4: Definition of VISTA Categories

POOR VISTA	These vistas are often dominated by visually discordant man-made alterations (not considering turbines), or are uncomfortable spaces for people, lack interest, or have virtually no recreational potential.
BELOW AVERAGE VISTA	These scenic vistas contain visually discordant man-made alterations (not considering turbines) but are not dominated by them. They are not inviting spaces for people, but are not uncomfortable. They have little interest or mystery and have minor recreational potential.
AVERAGE VISTA	These scenic vistas include interesting views that can be enjoyed often only in a narrow scope. These vistas may contain some visually discordant man-made alterations (not considering turbines), are moderately comfortable spaces for people, have some interest, and have minor recreational potential.
ABOVE AVERAGE VISTA	These scenic vistas include interesting views that often can be enjoyed in a medium to wide scope. They might contain some man-made alterations (not considering turbines), yet still possess significant interest and mystery, are moderately balanced and have some potential for recreation.
PREMIUM VISTA	These scenic vistas would include "picture postcard" views that can be enjoyed in a wide scope. They are often free or largely free of any discordant man made alterations (not considering turbines), possess significant interest, memorable qualities, and mystery and are well balanced and likely have a high potential for recreation.

Photographic examples of each of the categories are contained in Appendix D.

[42] Scenic vista ratings are individually and collectively referred to as "VISTA" from this point forward.

[43] The appropriateness of these rankings were tested in two ways. First, a set of 34 pictures taken on-site and representing various categories of VISTA were shown to 10 off-site respondents who were asked to rank them using the same categories, and then explain why they rated them as such. Although the off-site ratings matched the on-site ratings only 51% of the time, 94% of on- and off-site rankings differed by no more than one category, with 17% of the off-site rankings below the on-site and 26% ranked above. The descriptions of why the rankings where chosen by the off-site respondents illuminated the fact that off-site ratings did not take into account a number of aspects that were not adequately captured in the photos, but that were apparent in the field. This finding was borne out by a second test that had five individuals visit seven homes in the field to rank their scenic vistas. When all respondents were on-site, they similarly ranked the vista 72% of the time, with a rankingthat differed by no more than one category occurring one hundred percent of the time.

In addition to the VIEW and VISTA ratings, it was assumed that the orientation of the home to the view of turbines (e.g., front, back, or side) ("ORIENTATION"), and the degree to which the view of the turbines overlapped the primary scenic vista (e.g., not at all, barely, somewhat or strongly) ("OVERLAP"), might influence residential property values. As such, information on ORIENTATION and OVERLAP were also collected in the field.

3.2.4. Field Data Collection

Field data collection was conducted on a house-by-house basis. Each of the 6,194 homes was visited by the same individual to remove bias among field ratings. Data collection was conducted in the fall of 2006, and the spring, summer, and fall of 2007 and 2008. Each house was photographed and, when appropriate, so too were views of turbines and the prominent scenic vista.[44] Data on VIEW were collected only for those homes that sold after at least one wind power facility had been erected in the study area. When multiple wind facilities, with different construction dates, were visible from a home, field ratings for VIEW were made by taking into account which turbines had been erected at the time of sale. Additionally, if the season at the time of sale differed from that of data collection and, for example, if leaves were off the trees for one but on for the other, an effort was made to modulate the VIEW rating accordingly if necessary.[45]

Both VIEW and VISTA field ratings were arrived at through a Q-Sort method (Pitt and Zube, 1979), which is used to distinguish relatively similar rankings. For views of turbines, the rater first determined if the ranking was MINOR or EXTREME. If neither of these two rankings was appropriate, then only a choice between MODERATE and SUBSTANTIAL was required. Similarly, for VISTA rankings, first POOR and PREMIUM were distinguished from the others; if neither applied then BELOW AVERAGE or ABOVE AVERAGE could be selected. If neither of those were appropriate the VISTA, by default, was considered AVERAGE. In all cases, if wind turbines were visible from the home, the VISTA rankings were made as if those turbines did not exist.

3.3. Data Summary

The final dataset consists of 7,459 valid and screened residential transactions occurring between January 2, 1996 and June 30, 2007. Those transactions are arrayed across time and the ten wind project study areas as shown in Table 5. The sample of valid residential transactions ranges from 412 in Lee County, Illinois (ILLC) to 1,311 in Howard County, Texas (TXHC).[46] Of the total 7,459 transactions, 4,937 occurred after construction commenced on the relevant wind facilities. More specifically, 23% of the transactions (n=1,755) took place before any wind facility was announced and 10% occurred after announcement but before construction commenced (n=767),

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[44] In many cases the prominent VISTA was homogenous across groups of home, for instance urban homes on the same road. In those cases a picture of the VISTA of one home was applied to all of the homes. All pictures were taken with a Canon EOS Rebel XTi Single Lens Reflex Camera with a 18-55mm lens. VIEW and VISTA pictures were taken with the lens set to 18mm, with the camera at head height, and with the center of the camera pointed at the center of the prominent VISTA or VIEW. Examples of the various VISTA and VIEW categories are contained in Appendices D and E respectively.

[45] This "modulation" occurred only for trees in the foreground, where, for instance, a single tree could obscure the view of turbines; this would not be the case for trees nearer the horizon.

[46] See description of "valid" in footnote 27 on page 13.

with the rest of the transactions occurring after construction commenced (66%, *n*=4,937).[47] Of that latter group, 17% (*n*=824, 11% of total) sold in the first year following the commencement of construction, 16% in the second year (*n*=811, 11% of total), and the remainder (67%) sold more than two years after construction commenced (*n*=3,302, 44% of total).

Table 5: Summary of Transactions across Study Areas and Development Periods

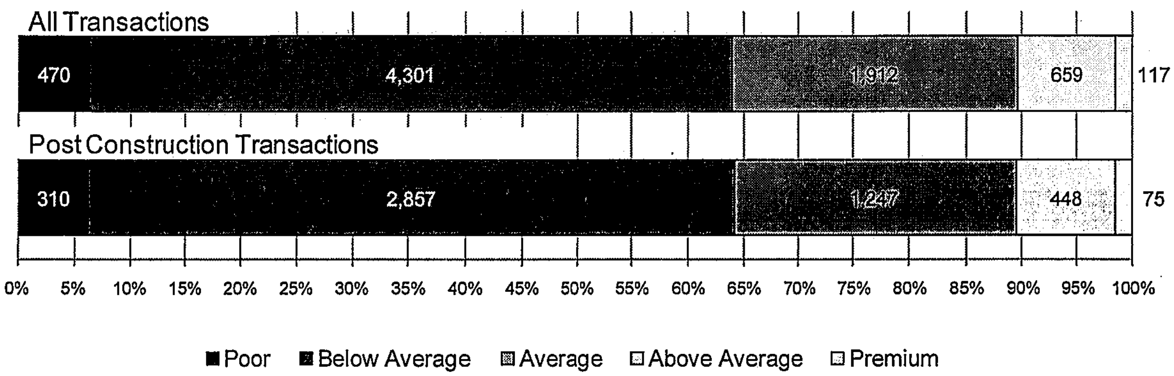
	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Benton/Walla Walla, WA & Umatilla, OR (WAOR)	226	45	76	59	384	**790**
Howard, TX (TXHC)	169	71	113	131	827	**1311**
Custer, OK (OKCC)	484	153	193	187	96	**1113**
Buena Vista, IA (IABV)	152	65	80	70	455	**822**
Lee, IL (ILLC)	115	84	62	71	80	**412**
Kewaunee/Door, WI (WIKCDC)	44	41	68	62	595	**810**
Somerset, PA (PASC)	175	28	46	60	185	**494**
Wayne, PA (PAWC)	223	106	64	71	87	**551**
Madison/Oneida, NY (MYMCOC)	108	9	48	30	268	**463**
Madison, NY (NYMC)	59	165	74	70	325	**693**
TOTAL	**1755**	**767**	**824**	**811**	**3302**	**7459**

A basic summary of the resulting dataset, including the many independent variables used in the hedonic models described later, is contained in Table 6 and Table 7. These tables present summary information for the full dataset (7,459 transactions) as well as the post-construction subset of that dataset (4,937 transactions); the latter is provided because much of the analysis that follows focuses on those homes that sold after wind facility construction. The mean nominal residential transaction price in the sample is $102,968, or $79,114 in 1996 dollars. The average house in the sample can be described as follows: it is 46 years old, has 1,620 square feet of finished living area above ground, is situated on 1.13 acres, has 1.74 bathrooms, and has a

[47] The announcement date (as well as construction and online dates) was provided by Energy Velocity with the GIS files as described in footnote 20 on page 10. The date corresponds to the first time the facility appears in the public record, which was often the permit application date. This constitutes the first well established date when the existing wind facility would have been likely known by the public, and therefore is appropriate to use for this analysis, but there remain a number of areas for potential bias in this date. First, the permit application date might be preceded by news reports of the impending application; alternatively, if the public record was not published online (that Energy Velocity used to establish their date), the "announcement" date – as used here - could, in fact, follow the permit application date. To address this, when possible, the authors had discussions with the developer of the facility. In most cases, the Energy Velocity dates were found to be accurate, and when they were not they were adjusted to reflect the dates provided by the developer. A second potential source of bias is the possibility that a different project was proposed but never built, but that influenced the residential market in the study area prior to the "announcement" date. Although this is likely rarer, we are aware of at least a few projects that fit that description in the study areas. A final source of bias might revolve around the likelihood that awareness of a project could occur even before the facility is formally announced. For example, a community member might know that a wind facility is being considered because they had been approached by the wind development company well ahead of a public announcement. In turn, they might have had private discussions regarding the facility with other members of the community. Taken together, it is appropriate to assume that there is some bias in the "announcement" date, and that awareness of the project might precede the date used in this analysis. How this bias might affect the results in this report is addressed further in Section 5.3 and footnote 74 on page 38.

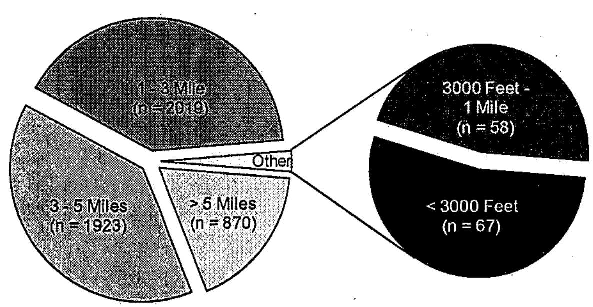
slightly better than average condition.[48] Within the full sample, 6% and 58% of homes had a poor or below average VISTA rating, respectively; 26% of homes received an average rating on this scale, with 9% above average and 2% experiencing premium vistas (see Figure 2).

Figure 2: Frequency of VISTA Ratings for All and Post-Construction Transactions



With respect to the variables of interest, among the post-construction subset of 4,937 transactions, the frequency of the DISTANCE categories is found to follow geometry with the smallest numbers of transactions occurring near the wind turbines and ever increasing numbers further away (see Figure 3). 67 transactions (1%) are situated inside of 3,000 feet (< 0.57 Miles), 58 (1%) are between 3,000 feet and one mile (0.57-1 mile), 2,019 (41%) occur outside of one mile but inside of three miles (1-3 miles), 1,923 (39%) occur between three and five miles (3-5 miles), and 870 (18%) occur outside of five miles (>5 miles).[49] In this same post-construction group, a total of 730 homes that sold (15%) have a view of the wind turbines (see Figure 4). A large majority of those homes have MINOR view ratings (n = 561, 11% of total), with 2% having MODERATE ratings (n=106) and the remaining transactions roughly split between SUBSTANTIAL and EXTREME ratings (n=35, 0.6%, and n=28, 0.5%, respectively). A full description of the variables of interest and how they are arrayed at the study area level is contained in Appendix A.

Figure 3: Frequency of DISTANCE Ratings for Post-Construction Transactions



[48] The variable for the condition of the home was not uniform across study areas because, in some cases, it took into account construction grade while in others it did not.

[49] These numbers and percentages are skewed slightly from the overall population of transactions because homes outside of three miles were often under-sampled to reduce field data collection burdens. Further, higher numbers of homes fall into each of the categories when the post-announcement-pre-construction transactions are included, as they are in some models. These additional transactions are described below in Table 7 under "All Sales."

Figure 4: Frequency of VIEW Ratings for Post-Construction Transactions

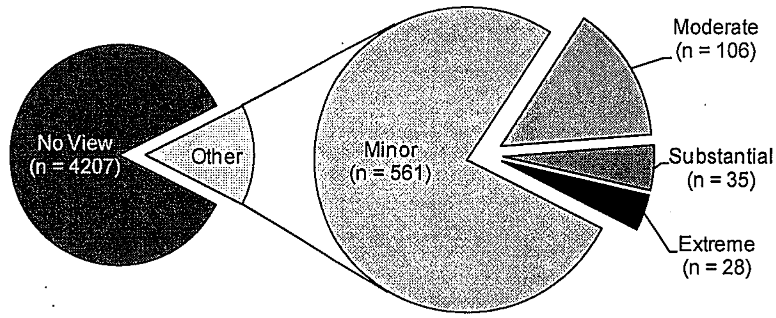


Table 6: Summary Statistics: All Sales and Post-Construction Sales

		All Sales			Post Construction Sales		
Variable Name	**Description**	**Freq. ***	**Mean**	**Std. Dev.**	**Freq. ***	**Mean**	**Std. Dev.**
SalePrice	The unadjusted sale price of the home (in US dollars)	7,459	102,968	64,293	4,937	110,166	69,422
SalePrice96	The sale price of the home adjusted to 1996 US dollars	7,459	79,114	47,257	4,937	80,156	48,906
LN_SalePrice96	The natural log transformation of the sale price of the home adjusted to 1996 US dollars	7,459	11.12	0.58	4,937	11.12	0.60
AgeatSale	The age of the home at the time of sale	7,459	46	37	4,937	47	36
AgeatSale_Sqrd	The age of the home at the time of sale squared	7,459	3,491	5,410	4,937	3,506	5,412
Sqft_1000	The number of square feet of above grade finished living area (in 1000s)	7,459	1.623	0.59	4,937	1.628	0.589
Acres	The number of Acres sold with the residence	7,459	1.13	2.42	4,937	1.10	2.40
Baths	The number of Bathrooms (Full Bath = 1, Half Bath = 0.5)	7,459	1.74	0.69	4,937	1.75	0.70
ExtWalls_Stone	If the home has exterior walls of stone, brick or stucco (Yes = 1, No = 0)	2,287	0.31	0.46	1,486	0.30	0.46
CentralAC	If the home has a Central AC unit (Yes = 1, No = 0)	3,785	0.51	0.50	2,575	0.52	0.50
Fireplace	The number of fireplace openings	2,708	0.39	0.55	1,834	0.40	0.55
Cul_De_Sac	If the home is situated on a cul-de-sac (Yes = 1, No = 0)	990	0.13	0.34	673	0.14	0.34
FinBsmt	If finished basement square feet is greater than 50% times first floor square feet (Yes = 1, No = 0)	1,472	0.20	0.40	992	0.20	0.40
Water_Front	If the home shares a property line with a body of water or river (Yes = 1, No = 0)	107	0.01	0.12	87	0.02	0.13
Cnd_Low	If the condition of the home is Poor (Yes = 1, No = 0)	101	0.01	0.12	69	0.01	0.12
Cnd_BAvg	If the condition of the home is Below Average (Yes = 1, No = 0)	519	0.07	0.25	359	0.07	0.26
Cnd_Avg	If the condition of the home is Average (Yes = 1, No = 0)	4,357	0.58	0.49	2,727	0.55	0.50
Cnd_AAvg	If the condition of the home is Above Average (Yes = 1, No = 0)	2,042	0.27	0.45	1,445	0.29	0.46
Cnd_High	If the condition of the home is High (Yes = 1, No = 0)	440	0.06	0.24	337	0.07	0.25
Vista_Poor	If the Scenic Vista from the home is Poor (Yes = 1, No = 0)	470	0.06	0.24	310	0.06	0.24
Vista_BAvg	If the Scenic Vista from the home is Below Average (Yes = 1, No = 0)	4,301	0.58	0.49	2,857	0.58	0.49
Vista_Avg	If the Scenic Vista from the home is Average (Yes = 1, No = 0)	1,912	0.26	0.44	1,247	0.25	0.44
Vista_AAvg	If the Scenic Vista from the home is Above Average (Yes = 1, No = 0)	659	0.09	0.28	448	0.09	0.29
Vista_Prem	If the Scenic Vista from the home is Premium (Yes = 1, No = 0)	117	0.02	0.12	75	0.02	0.12
SaleYear	The year the home was sold	7,459	2002	2.9	4,937	2004	2.3

** "Freq." applies to the number of cases the parameter's value is not zero*

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Table 7: Summary of Variables of Interest: All Sales and Post-Construction Sales

		All Sales			Post Construction Sales		
Variable Name	Description	Freq. *	Mean	Std. Dev.	Freq. *	Mean	Std. Dev.
View_None	If the home sold after construction began and had no view of the turbines (Yes = 1, No = 0)	4,207	0.56	0.50	4,207	0.85	0.36
View_Minor	If the home sold after construction began and had a Minor View of the turbines (Yes = 1, No = 0)	561	0.08	0.26	561	0.11	0.32
View_Mod	If the home sold after construction began and had a Moderate View of the turbines (Yes = 1, No = 0)	106	0.01	0.12	106	0.02	0.15
View_Sub	If the home sold after construction began and had a Substantial View of the turbines (Yes = 1, No = 0)	35	-	0.07	35	0.01	0.08
View_Extrm	If the home sold after construction began and had a Extreme View of the turbines (Yes = 1, No = 0)	28	-	0.06	28	0.01	0.08
DISTANCE †	Distance to nearest turbine if the home sold after facility "announcement", otherwise 0	5,705	2.53	2.59	4,895	3.57	1.68
Mile_Less_0.57 †	If the home sold after facility "announcement" and was within 0.57 miles (3000 feet) of the turbines (Yes = 1, No = 0)	80	0.01	0.09	67	0.01	0.12
Mile_0.57to1 †	If the home sold after facility "announcement" and was between 0.57 miles (3000 feet) and 1 mile of the turbines (Yes = 1, No = 0)	65	0.01	0.09	58	0.01	0.11
Mile_1to3 †	If the home sold after facility "announcement" and was between 1 and 3 miles of the turbines (Yes = 1, No = 0)	2,359	0.27	0.44	2,019	0.41	0.49
Mile_3to5 †	If the home sold after facility "announcement" and was between 3 and 5 miles of the turbines (Yes = 1, No = 0)	2,200	0.26	0.44	1,923	0.39	0.49
Mile_Gtr5 †	If the home sold after facility "announcement" and was outside 5 miles of the turbines (Yes = 1, No = 0)	1,000	0.12	0.32	870	0.18	0.38

** "Freq." applies to the number of cases the parameter's value is not zero*

† "All Sales" freq., mean and standard deviation DISTANCE and DISTANCE fixed effects variables (e.g., Mile_1to3) include transactions that occurred after facility "announcement" and before "construction" as well as those that occured post-construction

4. Base Hedonic Model

This section uses the primary hedonic model ("Base Model") to assess whether residential sales prices are affected, in a statistically measurable way, by views of and proximity to wind power facilities. In so doing, it simultaneously tests for the presence of the three potential property value stigmas associated with wind power facilities: Area, Scenic Vista, and Nuisance. This section begins with a discussion of the dataset that is used and the form of the model that is estimated, and then turns to the results of the analysis. Various alternative hedonic models are discussed and estimated in Section 5, with Sections 6 and 7 providing a discussion of and results from the repeat sales and sales volume models.

4.1. Dataset

The data used for the Base Model were described in Section 3.3. A key threshold question is whether or not to include the residential transactions that pre-date the relevant wind facility. Specifically, though the complete dataset consists of 7,459 residential transactions, a number of these transactions ($n = 2,522$) occurred before the wind facility was constructed. Should these homes which, at the time of sale, would not have had any view of or distance to the wind facility, be included? Two approaches could be applied to address this issue. First, pre-construction transactions could be included in the hedonic model either as part of the reference category within which no wind-project property value impacts are assumed to exist, or instead by specifically identifying these pre-construction transactions through an indicator variable. Second, and alternatively, pre-construction transactions could simply be excluded from the analysis altogether.

For the purpose of the Base Model, the latter approach is used, therefore relying on only the post-construction subset of 4,937 residential transactions. This approach, as compared to the others, results in somewhat more intuitive findings because all homes have a distance greater than zero and have a possibility of some view of the turbines. More importantly, this approach minimizes the chance of inaccuracies that may otherwise exist due to inflation adjustment concerns or outdated home characteristics information.[50] Nonetheless, to test for the implications of this choice of datasets, alternative hedonic models that use the full dataset were estimated, and are discussed in detail in Sections 5.3 and 5.4.

[50] Home characteristics were obtained as of the last property assessment. The timing of that assessment relative to the timing of the home sale transaction dictates how representative the assessed home characteristics are of the subject home when it was sold. For example, if a home sold early in the study period but subsequently had significant improvements made that are reflected in the current assessment data used in the analysis, the model would assign value to these home characteristics at the time of sale when, in fact, those characteristics were inaccurate. Additionally, the inflation adjustment index used in this analysis to translate home values to real 1996 dollars came from the nearest or more appropriate municipal statistical area (MSA). Many of the wind projects in the analysis are located in relatively rural parts of the country, and the housing market in the nearest metropolitan area could be different than the market surrounding wind projects. Although these areas have – in many instances – recently begun to attract home buyers willing to commute back to the metropolitan areas on which the index is based, the older index adjustments are likely less accurate than the more recent adjustments. Using a subset of the data for the majority of the analyses that removes the older, pre-construction, homes minimizes both of these biases.

4.2. Model Form

A standard semi-log functional form is used for the hedonic models (as was discussed in Section 2.1), where the dependent variable (sales price in inflation-adjusted 1996 dollars) is transformed to its natural log form and the independent variables (e.g., square feet and acres) are not transformed. Using this form to examine the effect that views of, and distance to, wind facilities have on sales prices, the following basic model is estimated:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 VIEW + \sum_d \beta_5 DISTANCE + \varepsilon \qquad (1)$$

where

P represents the inflation-adjusted sales price,

N is the spatially weighted neighbors' predicted sales price,

S is the vector of *s* Study Area fixed effects variables (e.g., WAOR, OKCC, etc.),

X is a vector of *k* home and site characteristics (e.g., acres, square feet, number of bathrooms, condition of the home, age of home, VISTA, etc.),

VIEW is a vector of *v* categorical view of turbine variables (e.g., MINOR, MODERATE, etc.),

DISTANCE is a vector of *d* categorical distance to turbine variables (e.g., less than 3000 feet, between one and three miles, etc.),

β_0 is the constant or intercept across the full sample,

β_1 is a parameter estimate for the spatially weighted neighbor's predicted sales price,

β_2 is a vector of *s* parameter estimates for the study area fixed effects as compared to homes sold in the Washington/Oregon (WAOR) study area,

β_3 is a vector of *k* parameter estimates for the home and site characteristics,

β_4 is a vector of *v* parameter estimates for the VIEW variables as compared to homes sold with no view of the turbines,

β_5 is a vector of *d* parameter estimates for the DISTANCE variables as compared to homes sold situated outside of five miles, and

ε is a random disturbance term.

As such, this model, and all subsequent hedonic models, has four primary groups of parameters: variables of interest, spatial adjustments, study-area fixed effects, and home and site characteristics.

The variables of interest, VIEW and DISTANCE, are the focus of this study, and allow the investigation of the presence of Area, Scenic Vista, and Nuisance Stigmas. These variables were defined in Section 3, and are summarized in Table 8. Both VIEW and DISTANCE appear in the model together because a home's value may be affected in part by the magnitude of the view of the wind turbines, and in part by the distance from the home to those turbines, and both variables appear in the Base Model as ordered categorical values. The coefficients associated with these two vectors of variables (β_4 and β_5) represent the marginal impact of views of, and distances to, wind turbines on sales prices, as compared to a "reference" category of residential transactions, and should be ordered monotonically from low to high.[51] This form of variable was used to

[51] "Reference category" refers to the subset of the sample to which other observations are compared, and is pertinent when using categorical or "fixed effect" variables.

impose the least structure on the underlying data.[52] For the purpose of the Base Model, the reference category for the DISTANCE variables are those transactions of homes that were situated outside of five miles from the nearest wind turbine. The reference category for the VIEW variables are those transactions of homes that did not have a view of the wind facility upon sale. Among the post-construction sample of homes, these reference homes are considered the least likely to be affected by the presence of the wind facilities.[53]

Table 8: List of Variables of Interest Included in the Base Model

Variable Name	Description	Type	Expected Sign
View_None	If the home sold after construction began and had no view of the turbines (Yes = 1, No = 0)	Reference	n/a
View_Minor	If the home sold after construction began and had a Minor View of the turbines (Yes = 1, No = 0)	OC	-
View_Mod	If the home sold after construction began and had a Moderate View of the turbines (Yes = 1, No = 0)	OC	-
View_Sub	If the home sold after construction began and had a Substantial View of the turbines (Yes = 1, No = 0)	OC	-
View_Extrm	If the home sold after construction began and had an Extreme View of the turbines (Yes = 1, No = 0)	OC	-
Mile_Less_0.57	If the home sold after facility "construction" and was within 0.57 miles (3000 feet) of the turbines (Yes = 1, No = 0)	OC	-
Mile_0.57to1	If the home sold after facility "construction" and was between 0.57 miles (3000 feet) and 1 mile of the turbines (Yes = 1, No = 0)	OC	-
Mile_1to3	If the home sold after facility "construction" and was between 1 and 3 miles of the turbines (Yes = 1, No = 0)	OC	-
Mile_3to5	If the home sold after facility "construction" and was between 3 and 5 miles of the turbines (Yes = 1, No = 0)	OC	-
Mile_Gtr5	If the home sold after facility "construction" and was outside 5 miles of the turbines (Yes = 1, No = 0)	Reference	n/a

"OC" Ordered Categorical (1 = yes, 0 = no) values are interpreted in relation to the reference categorical case and are expected to have a monotonic order from low to high.

The three stigmas are investigated though these VIEW and DISTANCE variables. Scenic Vista Stigma is investigated through the VIEW variables. Area and Nuisance Stigmas, on the other hand, are investigated through the DISTANCE variables. To distinguish between Area and

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[52] In place of the ordered categorical DISTANCE variables, practitioners often rely on a continuous DISTANCE form (e.g., Sims et al., 2008). Similar to ordered categorical variables, continuous variables have a natural ordering, either ascending or descending, but, unlike categorical variables, these "continuous" values are on a scale. Therefore, given any two of its values X_1 and X_2 and a specific functional form, the ratio "X_1/X_2" and the distance "X_1 - X_2" have a fixed meaning. Examples of continuous variables other than DISTANCE that are commonly used include the number of square feet of living area (in 1000s) in a home (SQFT_1000) or the acres in the parcel (ACRES). A continuous functional form of this nature "imposes structure" because practitioners must decide how price is related to the underlying variables through the selection of a specific functional relationship between the two. For instance, in the case of DISTANCE, is there a linear relationship (which would imply a similar marginal difference between two distances both near and far from the turbines), does it decay slowly as distance grows, or does it fade completely at some fixed distance? Because of the lack of literature in this area, no *a priori* expectations for which functional form is the best were established, and therefore unstructured categorical variables are used in the Base Model. Nonetheless, a continuous DISTANCE form is explored in Section 5.2.

[53] It is worth noting that these reference homes are situated in both rural and urban locales and therefore are not uniquely affected by influences from either setting. This further reinforces their worthiness as a reference category.

Nuisance Stigma, it is assumed that Nuisance effects are concentrated within one mile of the nearest wind turbine, while Area effects will be considered for those transactions outside of one mile. Any property value effects discovered outside of one mile and based on the DISTANCE variables are therefore assumed to indicate the presence of Area Stigma, while impacts within a mile may reflect the combination of Nuisance and Area Stigma.

The second set of variables in the Base Model - spatial adjustments - correct for the assumed presence of spatial autocorrelation in the error term (ε). It is well known that the sales price of a home can be systematically influenced by the sales prices of those homes that have sold nearby. Both the seller and the buyer use information from comparable surrounding sales to inform them of the appropriate transaction price, and nearby homes often experience similar amenities and disamenities. This lack of independence of home sale prices could bias hedonic regression results and, to help correct for this bias, a spatially (i.e., distance) weighted neighbors' sales price (N) is included in the model. Empirically, the neighbors' price has been found to be a strong (and sometimes even the strongest) predictor of home values (Leonard and Murdoch, forthcoming), and the coefficient β_1 is expected to be positive, indicating a positive correlation between the neighbors' and subject home's sales price. A more-detailed discussion of the importance of this variable, and how it was created, is contained in Appendix G.

The third group of variables in the Base Model - study area fixed effects - control for study area influences and the differences between them. The vector's parameters β_2 represent the marginal impact of being in any one of the study areas, as compared to a reference category. In this case, the reference category is the Washington/Oregon (WAOR) study area.[54] The estimated coefficients for this group of variables represent the combined effects of school districts, tax rates, crime, and other locational influences across an entire study area. Although this approach greatly simplifies the estimation of the model, because of the myriad of influences captured by these study-area fixed effects variables, interpreting the coefficient can be difficult. In general, though, the coefficients simply represent the mean difference in sales prices between the study areas and the reference study area (WAOR). These coefficients are expected to be strongly influential, indicating significant differences in sales prices across study areas.

The fourth group of variables in the Base Model are the core home and site characteristics (X), and include a range of continuous ("C"),[55] discrete ("D"),[56] binary ("B"),[57] and ordered categorical ("OC") variables. The specific home and site variables included in the Base Model are listed in Table 9 along with the direction of expected influence.[58] Variables included are age

[54] Because there is no intent to focus on the coefficients of the study area fixed effect variables, the reference case is arbitrary. Further, the results for the other variables in the model are completely independent of this choice.

[55] See discussion in footnote 52 on previous page.

[56] Discrete variables, similar to continuous variables, are ordered and the distance between the values, such as X_1 and X_2, have meaning, but for these variables, there are only a relatively small number of discrete values that the variable can take, for example, the number of bathrooms in a home (BATHROOMS).

[57] Binary variables have only two conditions: "on" or "off" (i.e., "1" or "0" respectively). Examples are whether the home has central air conditioning ("CENTRAL_AC") or if the home is situated on a cul-de-sac ("CUL_DE_SAC"). The coefficients for these variables are interpreted in relation to when the condition is "off."

[58] For those variables with a "+" sign it is expected that as the variable increases in value (or is valued at "1" as would be the case for fixed effects variables) the price of the home will increase, and the converse is true for the variables with a "-" sign. The expected signs of the variables all follow conventional wisdom (as discussed in

of the home, home and lot size, number of bathrooms and fireplaces, the condition of the home, the quality of the scenic vista from the home, if the home has central AC, a stone exterior, and/or a finished basement, and whether the home is located in a cul-de-sac and/or on a water way.[59]

Table 9: List of Home and Site Characteristics Included in the Base Model

Variable Name	Description	Type	Expected Sign
AgeatSale	The age of the home at the time of sale in years	C	-
AgeatSale_Sqrd	The age of the home at the time of sale squared	C	+
Sqft_1000	The number of square feet of above grade finished living area (in 1000s)	C	+
Acres	The number of Acres sold with the residence	C	+
Baths	The number of Bathrooms (Full Bath = 1, Half Bath = 0.5)	D	+
ExtWalls_Stone	If the home has exterior walls of stone, brick or stucco (Yes = 1, No = 0)	B	+
CentralAC	If the home has a Central AC unit (Yes = 1, No = 0)	B	+
Fireplace	The number of fireplace openings	D	+
Cul_De_Sac	If the home is situated on a cul-de-sac (Yes = 1, No = 0)	B	+
FinBsmt	If finished basement sqft > 50% times first floor sqft (Yes = 1, No = 0)	B	+
Water_Front	If the home shares a property line with a body of water or river (Yes = 1, No = 0)	B	+
Cnd_Low	If the condition of the home is Poor (Yes = 1, No = 0)	OC	-
Cnd_BAvg	If the condition of the home is Below Average (Yes = 1, No = 0)	OC	-
Cnd_Avg	If the condition of the home is Average (Yes = 1, No = 0)	Reference	n/a
Cnd_AAvg	If the condition of the home is Above Average (Yes = 1, No = 0)	OC	+
Cnd_High	If the condition of the home is High (Yes = 1, No = 0)	OC	+
Vista_Poor	If the Scenic Vista from the home is Poor (Yes = 1, No = 0)	OC	-
Vista_BAvg	If the Scenic Vista from the home is Below Average (Yes = 1, No = 0)	OC	-
Vista_Avg	If the Scenic Vista from the home is Average (Yes = 1, No = 0)	Reference	n/a
Vista_AAvg	If the Scenic Vista from the home is Above Average (Yes = 1, No = 0)	OC	+
Vista_Prem	If the Scenic Vista from the home is Premium (Yes = 1, No = 0)	OC	+

"C" Continuous, "D" Discrete, and "B" Binary (1 = yes, 0 = no) values are interpreted in relation to "No"
"OC" Ordered Categorical (1 = yes, 0 = no) values are interpreted in relation to the reference categorical case and are expected to have a monotonic order from low to high.

Sirmans et al., 2005a), save AgeatSale and AgeatSale_Sqrd, which are expected to be negative and positive, respectively. The magnitude of the coefficient of AgeatSale is expected to be larger than that of AgeatSale_Sqrd indicating an initial drop in value as a home increases in age, and then an increase in value as the home becomes considerably older and more "historic."

[59] Some characteristics, such as whether the home had a deck, a pool, or is located on a public sewer, are not available consistently across the dataset and therefore are not incorporated into the model. Other characteristics, such as the number of bedrooms, the number of stories, or if the home had a garage, are available but are omitted from the final model because they are highly correlated with characteristics already included in the model and therefore do not add significantly to the model's explanatory power. More importantly, and as discussed in Appendix G, when their inclusion or exclusion are tested, the results are stable with those derived from the Base Model.

It should be emphasized that in the Base Hedonic Model - equation (1) - and in all subsequent models presented in Section 5, all variables of interest, spatial adjustments, and home and site characteristics are pooled, and therefore their estimates represent the average across all study areas. Ideally, one would have enough data to estimate a model at the study area level - a fully unrestricted model - rather than pooled across all areas. This fully unrestricted model form, along with 15 other model forms (with some variables restricted and others not), are discussed in detail in Appendix F. In total, these 16 different models were estimated to explore which model was the most parsimonious (had the fewest parameters), performed the best (e.g., had the highest adjusted R^2 and the lowest Schwarz information criterion[60]), and had the most stable coefficients and standard errors. The basic pooled model described by equation (1) is found to fit that description, and that model is therefore chosen as the Base Model to which others are compared. By making this choice the effort concentrates on identifying the presence of potential property value impacts across all of the study areas in the sample as opposed to any single study area.[61]

Finally, to assure that the model produces the best linear unbiased parameter estimates, the underlying assumptions of Ordinary Least Squares (OLS) regression techniques must be verified:

1) Homoskedastic error term;
2) Absence of temporal serial correlation;
3) Reasonably limited multicollinearity; and
4) Appropriate controls for outliers and influencers.[62]

These assumptions, and the specific approaches that are used to address them, are discussed in detail in Appendix G.

4.3. Analysis of Results

Table 10 (on page 32) presents the results of the Base Model (equation 1).[63] The model performs well, with an adjusted R^2 of 0.77.[64] The spatial adjustment coefficient (β_1) of 0.29 (*p* value 0.00) indicates that a 10% increase in the spatially weighted neighbor's price increases the subject home's value by an average of 2.9%. The study-area fixed effects (β_2) variables are all significant at the one percent level, demonstrating important differences in home valuations

[60] The Schwarz information criterion measures relative parsimony between similar models (Schwarz, 1978).

[61] Because effects might vary between study areas, and the models estimate an average across all study areas, the full range of effects in individual study areas will go undetermined. That notwithstanding, there is no reason to suspect that effects will be completely "washed out." For that to occur, an effect in one study area would have to be positive while in another area it would have to be negative, and there is no reason to suspect that sales prices would increase because of the turbines in one community while decreasing in other communities.

[62] The absence of spatial autocorrelation is often included in the group of assumptions, but because it was discussed above (and in Appendix G), and is addressed directly by the variable (N_i) included in the model, it is not included in this list.

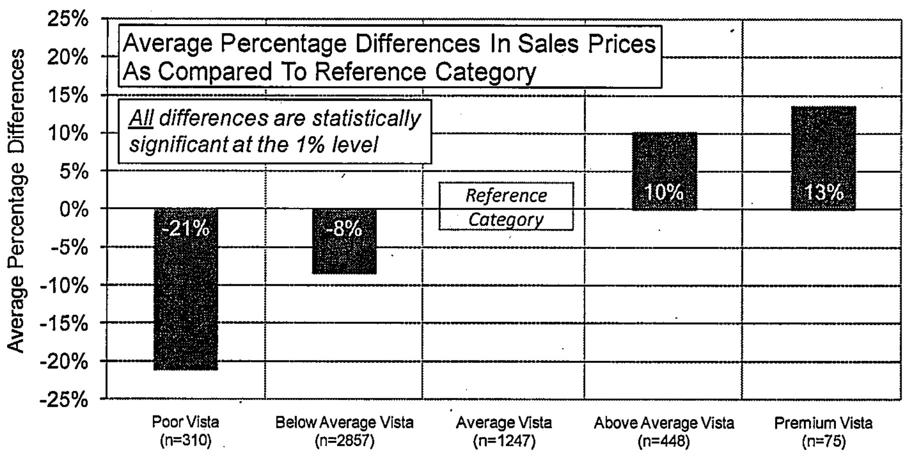
[63] This model and all subsequent models were estimated using the PROC REG procedure of SAS Version 9.2 TS1M0, which produces White's corrected standard errors.

[64] The appropriateness of the R^2 of 0.77 for this research is validated by the extensive hedonic literature that precedes it (see e.g., Kroll and Priestley, 1992; Boyle and Kiel, 2001; Simons, 2006b).

between the reference study area (WAOR) and the other nine study areas.[65] The sign and magnitudes of the home and site characteristics are all appropriate given the *a priori* expectations, and all are statistically significant at the one percent level.[66]

Of particular interest are the coefficient estimates for scenic vista (VISTA) as shown in Figure 5. Homes with a POOR vista rating are found, on average, to sell for 21% less (*p* value 0.00) than homes with an AVERAGE rating, while BELOW AVERAGE homes sell for 8% less (*p* value 0.00). Conversely, homes with an ABOVE AVERAGE vista are found to sell for 10% more (*p* value 0.00) than homes with an AVERAGE vista, while PREMIUM vista homes sell for 13% more than AVERAGE homes (*p* value 0.00). Based on these results, it is evident that home buyers and sellers capitalize the quality of the scenic vista in sales prices.[67]

Figure 5: Results from the Base Model for VISTA



The reference category consists of transactions for homes with an Average Vista, and that occurred after construction began on the wind facility

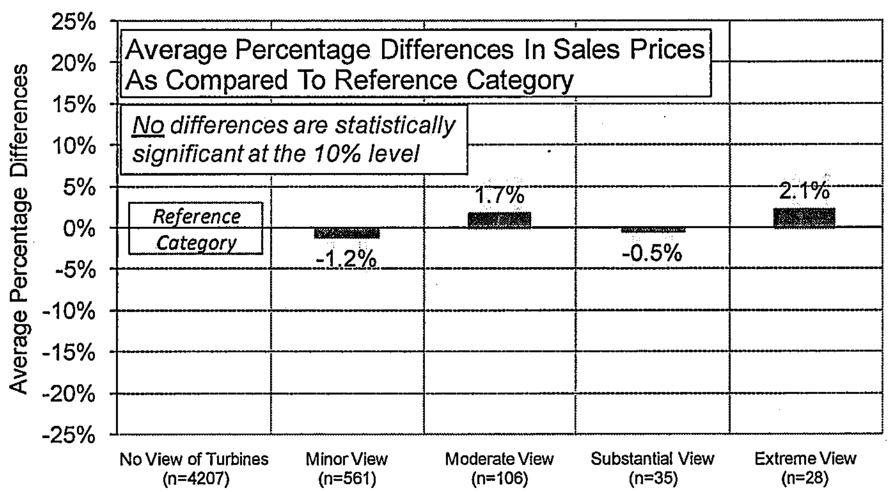
65 The reference category WAOR study area has the highest mean and median house values in the sample (as shown in Appendix A) so the negative coefficients for all the study area fixed effect variables are appropriate.

66 To benchmark the results against those of other practitioners the research by Sirmans et al. (2005a; 2005b) was consulted. They conducted a meta-analysis of 64 hedonic studies carried out in multiple locations in the U.S. during multiple time periods, and investigated the coefficients of ten commonly used characteristics, seven of which were included in the model. The similarities between their mean coefficients (i.e., the average across all 64 studies) and those estimated in the present Base Model are striking. The analysis presented here estimates the effect of square feet (in 1000s) on log of sales price at 0.28 and Sirmans et al. provide an estimate of 0.34, while ACRES was similarly estimated (0.02 to 0.03, Base Model and Sirmans et al., respectively). Further, AGEATSALE (age at the time of sale) (-0.006 to -0.009), BATHROOMS (0.09 to 0.09), CENTRALAC (0.09 to 0.08), and FIREPLACE (0.11 to 0.09) all similarly compare. As a group, the Base Model estimates differ from Sirmans et al. estimates in all cases by no more than a third of the Sirmans et al. mean estimate's standard deviation. This, taken with the relatively high adjusted R^2 of the Base Model, demonstrates the appropriateness of the model's specification.

67 To benchmark these results they are compared to the few studies that have investigated the contribution of inland scenic vistas to sales prices. Benson et al. (2000) find that a mountain vista increases sales price by 8%, while Bourassa et al. (2004) find that wide inland vistas increase sales price by 7.6%. These both compare favorably to the 10% and 14% above average and premium rated VISTA estimates. Comparable studies for below average and poor VISTA were not found and therefore no benchmarking of those coefficients is conducted. Finally, it should again be noted that a home's scenic vista, as discussed in Section 3.2.3, was ranked without taking the presence of the wind turbines into consideration, even if those turbines were visible at the time of home sale.

Despite this finding for scenic vista, however, no statistically significant relationship is found between views of wind turbines and sales prices.[68] The coefficients for the VIEW parameters (β_4) are all relatively small, none are statistically significant, and they are not monotonically ordered (see Figure 6). Homes with EXTREME or SUBSTANTIAL view ratings, for which the Base Model is expected to find the largest differences, sell for, on average, 2.1% more (*p* value 0.80) and 0.5% less (*p* value 0.94) than NO VIEW homes that sold in the same post-construction period. Similarly, homes with MODERATE or MINOR view ratings sell, on average, for 1.7% more (*p* value 0.58) and 1.2% less (*p* value 0.40) than NO VIEW homes, respectively. None of these coefficients are sizable, and none are statistically different from zero. These results indicate that, among this sample at least, a statistically significant relationship between views of wind turbines and residential property values is not evident. In other words, there is an absence of evidence of a Scenic Vista Stigma in the Base Model.

Figure 6: Results from the Base Model for VIEW



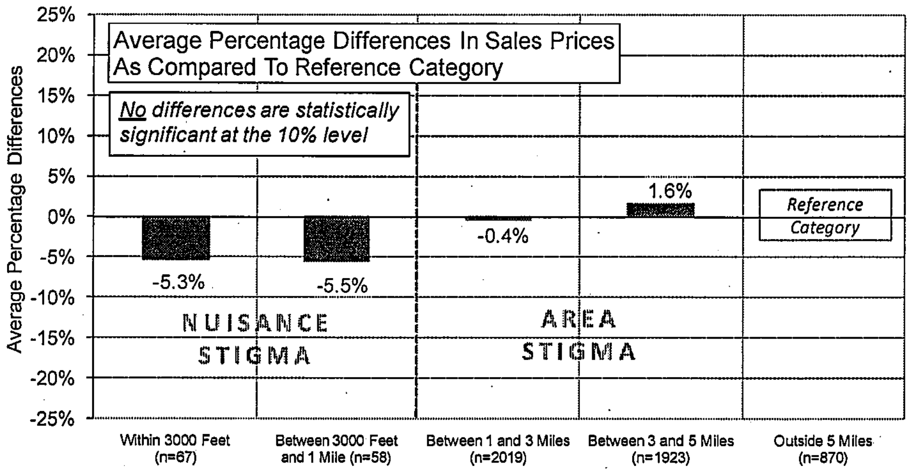
The reference category consists of transactions for homes without a view of the turbines, and that occured after construction began on the wind facility

The coefficients for the DISTANCE parameters (β_5) are also all relatively small and none are statistically significant (see Figure 7). Homes that are situated within 3000 feet (0.57 miles) of the nearest wind turbine, at the time of sale, are found to sell for 5.3% less (*p* value 0.40), on average, than homes outside of 5 miles that sold in the same "post-construction" period. Meanwhile, homes between 3000 feet and 1 mile sold for 5.5% less (*p* value 0.30), on average, than homes more than 5 miles away. Homes that are within 1 to 3 miles of the nearest turbine, as compared to homes outside of 5 miles, sold for essentially the same, on average (coefficient = 0.004, *p* value 0.80), while homes between 3 and 5 miles sold for 1.6% more (*p* value 0.23).

[68] A significance level of 10% is used throughout this report, which corresponds to a *p*-value at or above 0.10. Although this is more liberal than the often used 5% (*p*-value at or above 0.05), it was chosen to give more opportunities for effects that might be fairly weak to be considered significant.

00002706

Figure 7: Results from the Base Model for DISTANCE



The reference category consists of transactions for homes situated more than five miles from the nearest turbine, and that occured after construction began on the wind facility

Looking at these results as a whole, a somewhat monotonic order from low to high is found as homes are situated further away from wind facilities, but all of the coefficients are relatively small and none are statistically different from zero. This suggests that, for homes in the sample at least, there is a lack of statistical evidence that the distance from a home to the nearest wind turbine impacts sales prices, and this is true regardless of the distance band.[69] As such, an absence of evidence of an Area or Nuisance Stigma is found in the Base Model. That notwithstanding, the -5% coefficients for homes that sold within one mile of the nearest wind turbine require further scrutiny. Even though the differences are not found to be statistically significant, they might point to effects that exist but are too small for the model to deem statistically significant due to the relatively small number of homes in the sample within 1 mile of the nearest turbine. Alternatively, these homes may simply have been devalued even before the wind facility was erected, and that devaluation may have carried over into the post construction period (the period investigated by the Base Model). To explore these possibilities, transactions that occurred well before the announcement of the wind facility to well after construction are investigated in the Temporal Aspects Model in the following "Alternative Models" section.

[69] It is worth noting that the number of cases in each of these categories (e.g., $n = 67$ for homes inside of 3000 feet and $n = 58$ between 3000 feet and one mile) are small, but are similar to the numbers of cases for other variables in the same model (e.g., LOW CONDITION, $n = 69$; PREMIUM VISTA, $n = 75$), the estimates of which were found to be significant above the 1% level.

Table 10: Results from the Base Model

	Coef.	SE	p Value	*n*
Intercept	7.62	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.33	0.04	0.00	87
Cnd Low	-0.45	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.14	0.01	0.00	1,445
Cnd High	0.23	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.03	0.00	1,071
OKCC	-0.44	0.02	0.00	476
IABV	-0.24	0.02	0.00	605
ILLC	-0.09	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.31	0.03	0.00	291
PAWC	-0.07	0.03	0.01	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
Post Con NoView	Omitted	Omitted	Omitted	4,207
View Minor	-0.01	0.01	0.40	561
View Mod	0.02	0.03	0.58	106
View Sub	-0.01	0.07	0.94	35
View Extrm	0.02	0.09	0.80	28
Mile Less 0 57	-0.05	0.06	0.40	67
Mile 0 57to1	-0.05	0.05	0.30	58
Mile 1to3	0.00	0.02	0.80	2,019
Mile 3to5	0.02	0.01	0.23	1,923
Mile Gtr5	Omitted	Omitted	Omitted	870

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	1
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	37
F Statistic	442.8
Adjusted R Squared	0.77

5. Alternative Hedonic Models

The Base Hedonic Model presented in Section 4 found that residential property values have, on average, not been measurably affected by the presence of nearby wind facilities. To test the robustness of this result and to test for other possible impacts from nearby wind projects, the report now turns to a number of other hedonic models. These Alternative Models were created to investigate different approaches to exploring the impact of the variables of interest (#1 and #2, below) and to assess the presence of impacts that are not otherwise fully captured by the Base Model (#3 through #6, below).

1) **View and Distance Stability Models:** Using only post-construction transactions (the same as the Base Model) these models investigate whether the Scenic Vista Stigma (as measured with VIEW) results are independent of the Nuisance and Area Stigma results (as measured by DISTANCE) and vice versa.[70]
2) **Continuous Distance Model:** Using only post-construction transactions, this model investigates Area and Nuisance Stigmas by applying a continuous distance parameter as opposed to the categorical variables for distance used in the previous models.
3) **All Sales Model:** Using all transactions, this model investigates whether the results for the three stigmas change if transactions that occurred before the announcement and construction of the wind facility are included in the sample.
4) **Temporal Aspects Model:** Using all transactions, this model further investigates Area and Nuisance Stigmas and how they change for homes that sold more than two years pre-announcement through the period more than four years post-construction.
5) **Home Orientation Model:** Using only post-construction transactions, this model investigates the degree to which a home's orientation to the view of wind turbines affects sales prices.
6) **View and Vista Overlap Model:** Using only post-construction transactions, this model investigates the degree to which the overlap between the view of a wind facility and a home's primary scenic vista affects sales prices.

Each of these models is described in more depth in the pages that follow. Results are shown for the variables of interest only; full results are contained in Appendix H.

5.1. View and Distance Stability Models

The Base Model (equation 1) presented in Section 4 includes both DISTANCE and VIEW variables because a home's value might be affected in part by the magnitude of the view of a nearby wind facility and in part by the distance from the home to that facility. These two variables may be related, however, in-so-far as homes that are located closer to a wind facility are likely to have a more-dominating view of that facility. To explore the degree to which these two sets of variables are independent of each other (i.e. not collinear) and to further test the robustness of the Base Model results two alternative hedonic models are run, each of which includes only one of the sets of parameters (DISTANCE or VIEW). Coefficients from these models are then compared to the Base Model results.

[70] Recall that the qualitative VIEW variable incorporated the visible distance to the nearest wind facility.

5.1.1. Dataset and Model Form

The same dataset is used as in the Base Model, focusing again on post-construction transactions ($n = 4,937$). To investigate DISTANCE effects alone the following model is estimated:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_d \beta_5 DISTANCE + \varepsilon \qquad (2)$$

where

P represents the inflation-adjusted sales price,
N is the spatially weighted neighbors' predicted sales price,
S is the vector of s Study Area fixed effects variables (e.g., WAOR, OKCC, etc.),
X is a vector of k home and site characteristics (e.g., acres, square feet, number of bathrooms, condition of the home, age of home, VISTA, etc.),
DISTANCE is a vector of d categorical distance variables (e.g., less than 3000 feet, between one and three miles, etc.),
β_0 is the constant or intercept across the full sample,
β_1 is a parameter estimate for the spatially weighted neighbor's predicted sales price,
β_2 is a vector of s parameter estimates for the study area fixed effects as compared to transactions of homes in the WAOR study area,
β_3 is a vector of k parameter estimates for the home and site characteristics,
β_5 is a vector of d parameter estimates for the DISTANCE variables as compared to transactions of homes situated outside of five miles, and
ε is a random disturbance term.

The parameters of primary interest are β_5, which represent the marginal differences between home values at various distances from the wind turbines as compared to the reference category of homes outside of five miles. These coefficients can then be compared to the same coefficients estimated from the Base Model.

Alternatively, to investigate the VIEW effects alone, the following model is estimated:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 VIEW + \varepsilon \qquad (3)$$

where

VIEW is a vector of v categorical view variables (e.g., MINOR, MODERATE, etc.),
β_4 is a vector of v parameter estimates for the VIEW variables, and
all other components are as defined in equation (2).

The parameters of primary interest in this model are β_4, which represent the marginal differences between home values for homes with varying views of wind turbines at the time of sale as compared to the reference category of homes without a view of those turbines. Again, these coefficients can then be compared to the same coefficients estimated from the Base Model.

Our expectation for both of the models described here is that the results will not be dramatically different from the Base Model, given the distribution of VIEW values across the DISTANCE values, and vice versa, as shown in Table 11. Except for EXTREME view, which is concentrated inside of 3000 feet, all view ratings are adequately distributed among the distance categories.

Table 11: Frequency Crosstab of VIEW and DISTANCE Parameters

	Inside 3000 Feet	Between 3000 Feet and 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles	Outside 5 Miles	Total
No View	6	12	1653	1695	841	4207
Minor View	14	24	294	202	27	561
Moderate View	8	13	62	21	2	106
Substantial View	11	9	10	5	0	35
Extreme View	28	0	0	0	0	28
TOTAL	67	58	2019	1923	870	4937

5.1.2. Analysis of Results

Summarized results for the variables of interest from the Base Model and the two Alternative Stability Models are presented in Table 12. (For brevity, the full set of results for the models is not shown in Table 12, but is instead included in Appendix H.) The adjusted R^2 for the View and Distance Stability Models is the same as for the Base Model, 0.77. All study area, spatial adjustment, and home and site characteristics are significant at or above the one percent level and are similar in magnitude to the estimates presented earlier for the Base Model.

The DISTANCE and VIEW coefficients, β_5 and β_4, are stable, changing no more than 3%, with most (7 out of 8) not experiencing a change greater than 1%. In all cases, changes to coefficient estimates for the variables of interest are considerably less than the standard errors. Based on these results, there is confidence that the correlation between the VIEW and DISTANCE variables is not responsible for the findings and that these two variables are adequately independent to be included in the same hedonic model regression. As importantly, no evidence of Area, Scenic Vista, or Nuisance Stigma is found in the sample, as none of the VIEW or DISTANCE variables are found to be statistically different from zero.

Table 12: Results from Distance and View Stability Models

		Base Model			Distance Stability			View Stability		
Variables of Interest	*n*	Coef	SE	p Value	Coef	SE	p Value	Coef	SE	p Value
No View	4207	Omitted	Omitted	Omitted				Omitted	Omitted	Omitted
Minor View	561	-0.01	0.01	0.39				-0.02	0.01	0.24
Moderate View	106	0.02	0.03	0.57				0.00	0.03	0.90
Substantial View	35	-0.01	0.07	0.92				-0.04	0.06	0.45
Extreme View	28	0.02	0.09	0.77				-0.03	0.06	0.58
Inside 3000 Feet	67	-0.05	0.06	0.31	-0.04	0.04	0.25			
Between 3000 Feet and 1 Mile	58	-0.05	0.05	0.20	-0.06	0.05	0.17			
Between 1 and 3 Miles	2019	0.00	0.02	0.80	-0.01	0.02	0.71			
Between 3 and 5 Miles	1923	0.02	0.01	0.26	0.01	0.01	0.30			
Outside 5 Miles	870	Omitted	Omitted	Omitted	Omitted	Omitted	Omitted			

"Omitted" = reference category for fixed effects variables. "n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	1	2	3
Dependent Variable	LN_SalePrice96	LN_SalePrice96	LN_SalePrice96
Number of Cases	4937	4937	4937
Number of Predictors (k)	37	33	33
F Statistic	442.8	496.7	495.9
Adjusted R Squared	0.77	0.77	0.77

5.2. Continuous Distance Model

The potential impact of wind facilities on residential property values based on Area and Nuisance effects was explored with the Base Model by using five ordered categorical DISTANCE variables. This approach was used in order to impose the least restriction on the functional relationship between distance and property values (as discussed in footnote 52 on page 25). The literature on environmental disamenities, however, more commonly uses a continuous distance form (e.g., Sims et al., 2008), which imposes more structure on this relationship. To be consistent with the literature and to test if a more rigid structural relationship might uncover an effect that is not otherwise apparent with the five distance categories used in the Base Model, a hedonic model that relies upon a continuous distance variable is presented here. One important benefit of this model is that a larger amount of data (e.g., $n = 4{,}937$) is used to estimate the continuous DISTANCE coefficient then was used to estimate any of the individual categorical estimates in the Base Model (e.g., $n = 67$ inside 3000 feet, $n = 2019$ between one and three miles). The Continuous Distance Model therefore provides an important robustness test to the Base Model results.

5.2.1. Dataset and Model Form

A number of different functional forms can be used for a continuous DISTANCE variable, including linear, inverse, cubic, quadratic, and logarithmic. Of the forms that are considered, an inverse function seemed most appropriate.[71] Inverse functions are used when it is assumed that any effect is most pronounced near the disamenity and that those effects fade asymptotically as distance increases. This form has been used previously in the literature (e.g., Leonard et al., 2008) to explore the impact of disamenities on home values, and is calculated as follows:

$$\text{InvDISTANCE} = 1/\text{DISTANCE} \tag{4}$$

where
DISTANCE is the distances to the nearest turbine from each home as calculated at the time of sale for homes that sold in the post-construction period.

For the purpose of the Continuous Distance Model, the same dataset is used as in the Base Model, focusing again on post-construction transactions ($n = 4{,}937$). InvDISTANCE has a maximum of 6.67 (corresponding to homes that were 0.15 miles, or roughly 800 feet, from the nearest wind turbine), a minimum of 0.09 (corresponding to a distance of roughly 11 miles), and a mean of 0.38 (corresponding to a distance of 2.6 miles). This function was then introduced into the hedonic model in place of the DISTANCE categorical variables as follows:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \beta_5 \text{InvDISTANCE} + \varepsilon \tag{5}$$

where
InvDISTANCE_i is the inverse of the distance to the nearest turbine,
β_5 is a parameter estimate for the inverse of the distance to the nearest turbine, and

[71] The other distance functions (e.g., linear, quadratic, cubic & logarithmic) were also tested. Additionally, two-part functions with interactions between continuous forms (e.g., linear) and categorical (e.g., less than one mile) were investigated. Results from these models are briefly discussed below in footnote 72.

all other components are as defined in equation (1).

The coefficient of interest in this model is β_5, which, if effects exist, would be expected to be negative, indicating an adverse effect from proximity to the wind turbines.

5.2.2. Analysis of Results

Results for the variables of interest in the Continuous Distance Model and the Base Model are shown in Table 13. (For brevity, the full set of results for the model is not shown in Table 13, but is instead included in Appendix H.) The model performs well with an adjusted R^2 of 0.77. All study area, spatial adjustment, and home and site characteristics are significant at the one percent level. The coefficients for VIEW are similar to those found in the Base Model, demonstrating stability in results, and none are statistically significant. These results support the previous findings of a lack of evidence of a Scenic Vista Stigma.

Our focus variable InvDISTANCE produces a coefficient (β_5) that is slightly negative at -1%, but that is not statistically different from zero (*p* value 0.41), implying again that there is no statistical evidence of a Nuisance Stigma effect nor an Area Stigma effect and confirming the results obtained in the Base Model.[72]

Table 13: Results from Continuous Distance Model

	Base Model				Continuous Distance			
Variables of Interest	**Coef**	**SE**	**p Value**	***n***	**Coef**	**SE**	**p Value**	***n***
No View	Omitted	Omitted	Omitted	4,207	Omitted	Omitted	Omitted	4,207
Minor View	-0.01	0.01	0.39	561	-0.01	0.01	0.32	561
Moderate View	0.02	0.03	0.57	106	0.01	0.03	0.77	106
Substantial View	-0.01	0.07	0.92	35	-0.02	0.07	0.64	35
Extreme View	0.02	0.09	0.77	28	0.01	0.10	0.85	28
Inside 3000 Feet	-0.05	0.06	0.31	67				
Between 3000 Feet and 1 Mile	-0.05	0.05	0.20	58				
Between 1 and 3 Miles	0.00	0.02	0.80	2,019				
Between 3 and 5 Miles	0.02	0.01	0.26	1,923				
Outside 5 Miles	Omitted	Omitted	Omitted	870				
InvDISTANCE					-0.01	0.02	0.41	4,937

"Omitted" = reference category for fixed effects variables. "n" = number of cases in category when category = "1"

Model Information

	Base Model	Continuous Distance
Model Equation Number	1	5
Dependent Variable	LN_SalePrice96	LN_SalePrice96
Number of Cases	4937	4937
Number of Predictors (k)	37	34
F Statistic	442.8	481.3
Adjusted R Squared	0.77	0.77

5.3. All Sales Model

The Base Model presented earlier relied on only those transactions that occurred after the construction of the relevant wind facility. This approach, however, leaves open two key questions. First, it is possible that the property values of all of the post-construction homes in the

[72] As mentioned in footnote 71 on page 36, a number of alternative forms of the continuous distance function were also explored, including two-part functions, with no change in the results presented here. In all cases the resulting continuous distance function was not statistically significant.

sample have been affected by the presence of a wind facility, and therefore that the reference homes in the Base Model (i.e., those homes outside of five miles with no view of a wind turbine) are an inappropriate comparison group because they too have been impacted.[73] Using only those homes that sold before the announcement of the wind facility (pre-announcement) as the reference group would, arguably, make for a better comparison because the sales price of those homes are not plausibly impacted by the presence of the wind facility.[74] Second, the Base Model does not consider homes that sold in the post-announcement but pre-construction period, and previous research suggests that property value effects might be very strong during this period, during which an assessment of actual impacts is not possible and buyers and sellers may take a more-protective and conservative stance (Wolsink, 1989). This subsection therefore presents the results of a hedonic model that uses the full set of transactions in the dataset, pre- and post-construction.

5.3.1. Dataset and Model Form

Unlike the Base Model, in this instance the full set of 7,459 residential transactions is included. The following model is then estimated:

$$\ln(\mathrm{P}) = \beta_0 + \beta_1\mathrm{N} + \sum_{s}\beta_2\mathrm{S} + \sum_{k}\beta_3\mathrm{X} + \sum_{v}\beta_4\mathrm{VIEW} + \sum_{d}\beta_5\mathrm{DISTANCE} + \varepsilon \quad (6)$$

where

VIEW is a vector of v categorical view variables (e.g., NONE, MINOR, MODERATE, etc.),
DISTANCE is a vector of d categorical distance variables (e.g., less than 3000 feet, between one and three miles, outside of five mile, etc.),
β_4 is a vector of v parameter estimates for the VIEW variables as compared to pre-construction transactions,
β_5 is a vector of d parameter estimates for the DISTANCE variables as compared to pre-announcement transactions, and
all other components are as defined in equation (1).

It is important to emphasize that the VIEW and DISTANCE parameters in equation (6) have different reference categories than they do in the Base Model - equation (1). In the Base Model, DISTANCE and VIEW are estimated in the post-construction period in reference to homes that sold outside of five miles and with no view of the turbines respectively.[75] In the All Sales Model, on the other hand, the coefficients for VIEW (β_4) are estimated in reference to all pre-construction transactions (spanning the pre-announcement and post-announcement-pre-construction periods) and the coefficients for DISTANCE (β_5) are estimated in reference to all pre-announcement transactions. In making a distinction between the reference categories for VIEW and DISTANCE, it is assumed that awareness of the view of turbines and awareness of

[73] This might be the case if there is an Area Stigma that includes the reference homes.

[74] As discussed in footnote 47 on page 19, it is conceivable that awareness might occur prior to the "announcement" date used for this analysis. If true, this bias is likely to be sporadic in nature and less of an issue in this model, when all pre-announcement transactions are pooled (e.g., both transactions near and far away from where the turbines were eventually located) than in models presented later (e.g., temporal aspects model). Nonetheless, if present, this bias may weakly draw down the pre-announcement reference category.

[75] See Section 4.1 and also footnote 51 on page 24 for more information on why the post-construction dataset and five-mile-no-view homes reference category are used in the Base Model.

the distance from them might not occur at the same point in the development process. Specifically, it is assumed that VIEW effects largely occur after the turbines are erected, in the post-construction period, but that DISTANCE effects might occur in the post-announcement-pre-construction timeframe. For example, after a wind facility is announced, it is not atypical for a map of the expected locations of the turbines to be circulated in the community, allowing home buyers and sellers to assess the distance of the planned facility from homes. Because of this assumed difference in when awareness begins for VIEW and DISTANCE, the DISTANCE variable is populated for transactions occurring in the post-announcement-pre-construction period as well as the post-construction period (see Table 14 below), but the VIEW variable is populated only for transactions in the post-construction period – as they were in the Base Model.[76]

Table 14: Frequency Summary for DISTANCE in All Sales Model

	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Post-Construction	67	58	2019	1923	870	4937
Post-Announcement-Pre-Construction	13	7	340	277	130	767
TOTAL	80	65	2359	2200	1000	5704

One beneficial consequence of the differences in reference categories for the VIEW and DISTANCE variables in this model, as opposed to the Base Model, is that this model can accommodate all of the possible VIEW and DISTANCE categories, including NO VIEW transactions and transactions of homes outside of five miles. Because of the inclusion of these VIEW and DISTANCE categories, the tests to investigate Area, Scenic Vista, and Nuisance Stigmas are slightly different in this model than in the Base Model. For Area Stigma, for example, how homes with no view of the turbines fared can now be tested; if they are adversely affected by the presence of the wind facility, then this would imply a pervasive Area Stigma impact. For Scenic Vista Stigma, the VIEW coefficients (MINOR, MODERATE, etc.) can be compared (using a *t*-Test) to the NO VIEW results; if they are significantly different, a Scenic Vista Stigma would be an obvious culprit. Finally, for Nuisance Stigma, the DISTANCE coefficients inside of one mile can be compared (using a *t*-Test) to those outside of five miles; if there is a significant difference between these two categories of homes, then homes are likely affected by their proximity to the wind facility.

5.3.2. Analysis of Results

Results for the variables of interest for this hedonic model are summarized in Table 15, and Base Model results are shown for comparison purposes. (For brevity, the full set of results for the model is not shown in Table 15, but is instead included in Appendix H.) The adjusted R^2 for the model is 0.75, down slightly from 0.77 for the Base Model, and indicating that this model has slightly more difficulty (i.e. less explanatory power) modeling transactions that occurred pre-

[76] It is conceivable that VIEW effects could occur before the turbines are constructed. In some cases, for example, developers will simulate what the project will look like after construction during the post-announcement but pre-construction timeframe. In these situations, home buyers and sellers might adjust home values accordingly based on the expected views of turbines. It is assumed, however, that such adjustments are likely to be reasonably rare, and VIEW effects are therefore estimated using only post-construction sales.

construction.[77] All study area, spatial adjustment, and home and site characteristics are significant at or above the one percent level and are similar in sign and magnitude to the estimates derived from the post-construction Base Model.

The VIEW coefficients (β_4) are clearly affected by the change in reference category. All of the VIEW parameter estimates are higher than the Base Model estimates for the same categories. Of particular interest is the NO VIEW coefficient, which represents the values of homes without a view of the turbines and that sold in the post-construction period, as compared to the mean value of homes that sold in the pre-construction period, all else being equal. These homes, on average, are estimated to sell for 2% (p value 0.08) more than similar pre-construction homes. If an Area Stigma existed, a negative coefficient for these NO VIEW homes would be expected. Instead, a positive and statistically significant coefficient is found.[78] It is outside the ability of this study to determine whether the increase is directly related to the wind turbines, or whether some other factor is impacting these results, but in either instance, no evidence of a pervasive Area Stigma associated with the presence of the wind facilities is found.

To test for the possibility of Scenic Vista Stigma, the coefficients for MINOR, MODERATE, SUBSTANTIAL, and EXTREME views can be compared to the NO VIEW coefficient using a simple t-Test. Table 16 presents these results. As shown, no significant difference is found for any of the VIEW coefficients when compared to NO VIEW transactions. This reinforces the findings earlier that, within the sample at least, there is no evidence of a Scenic Vista Stigma.

The DISTANCE parameter estimates (β_5) are also found to be affected by the change in reference category, and all are lower than the Base Model estimates for the same categories. This result likely indicates that the inflation-adjusted mean value of homes in the pre-announcement period is slightly higher, on average, than for those homes sold outside of five miles in the post-construction period. This difference could be attributed to the inaccuracy of the inflation index, a pervasive effect from the wind turbines, or to some other cause. Because the coefficients are not systematically statistically significant, however, this result is not pursued further. What is of interest, however, is the negative 8% estimate for homes located between 3000 feet and one mile of the nearest wind turbine (p value 0.03). To correctly interpret this result, and to compare it to the Base Model, one needs to discern if this coefficient is significantly different from the estimate for homes located outside of five miles, using a t-Test.

The results of this t-Test are shown in Table 17. The coefficient differences are found to be somewhat monotonically ordered. Moving from homes within 3000 feet (-0.06, p value 0.22), and between 3000 feet and one mile (-0.08, p value 0.04), to between one and three miles (0.00, p value 0.93) and between three and five miles (0.01, p value 0.32) the DISTANCE coefficients are found to generally increase. Nonetheless, none of these coefficients are statistically significant except one, homes that sold between 3000 feet and one mile. The latter finding suggests the possibility of Nuisance Stigma. It is somewhat unclear why an effect would be found in this model, however, when one was not evident in the Base Model. The most likely

[77] This slight change in performance is likely due to the inaccuracies of home and site characteristics and the inflation adjustment for homes that sold in the early part of the study period. This is discussed in more detail in footnote 50 on page 23.

[78] For more on the significance level used for this report, see footnote 68 on page 30.

explanation is that the additional homes that are included in this model, specifically those homes that sold post-announcement but pre-construction, are driving the results. A thorough investigation of these "temporal" issues is provided in the next subsection.

In summation, no evidence is found of an Area or Scenic Vista Stigma in this alternative hedonic model, but some limited not-conclusive evidence of a Nuisance Stigma is detected. To further explore the reliability of this latter result, the analysis now turns to the Temporal Aspects Model.

Table 15: Results from All Sales Model

	Base Model				All Sales			
Variables of Interest	**Coef**	**SE**	**p Value**	***n***	**Coef**	**SE**	**p Value**	***n***
Pre-Construction Sales	n/a	n/a	n/a	n/a	Omitted	Omitted	Omitted	2,522
No View	Omitted	Omitted	Omitted	4,207	0.02	0.01	0.08	4,207
Minor View	-0.01	0.01	0.39	561	0.00	0.02	0.77	561
Moderate View	0.02	0.03	0.57	106	0.03	0.03	0.41	106
Substantial View	-0.01	0.07	0.92	35	0.03	0.07	0.53	35
Extreme View	0.02	0.09	0.77	28	0.06	0.08	0.38	28
Inside 3000 Feet	-0.05	0.06	0.31	67	-0.06	0.05	0.18	80
Between 3000 Feet and 1 Mile	-0.05	0.05	0.20	58	-0.08	0.05	0.03	65
Between 1 and 3 Miles	0.00	0.02	0.80	2,019	0.00	0.01	0.80	2,359
Between 3 and 5 Miles	0.02	0.01	0.26	1,923	0.01	0.01	0.59	2,200
Outside 5 Miles	Omitted	Omitted	Omitted	870	0.00	0.02	0.78	1,000
Pre-Announcement Sales	n/a	n/a	n/a	n/a	Omitted	Omitted	Omitted	1,755

"Omitted" = reference category for fixed effects variables. "n" = number of cases in category when category = "1"

Model Information

	Base Model	All Sales
Model Equation Number	1	6
Dependent Variable	LN_SalePrice96	LN_SalePrice96
Number of Cases	4937	7459
Number of Predictors (k)	37	39
F Statistic	442.8	579.9
Adjusted R Squared	0.77	0.75

Table 16: Results from Equality Test of VIEW Coefficients in the All Sales Model

	No View	**Minor View**	**Moderate View**	**Substantial View**	**Extreme View**
n	4,207	561	106	35	28
Coefficient	0.02	0.00	0.03	0.03	0.06
Coefficient Difference *	Reference	-0.02	0.00	0.01	0.04
Variance	0.0001	0.0003	0.0009	0.0030	0.0050
Covariance	n/a	0.00011	0.00010	0.00009	0.00008
Df	n/a	7419	7419	7419	7419
***t*-Test**	n/a	-1.20	0.17	0.23	0.58
Significance	n/a	0.23	0.87	0.82	0.57

** Differences are rounded to the nearest second decimal place.*
"n" = number of cases in category when category = "1"

Table 17: Results from Equality Test of DISTANCE Coefficients in the All Sales Model

	Inside 3000 Feet	Between 3000 Feet and 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles	Outside 5 Miles
n	80	65	2,359	2,200	1,000
Coefficient	-0.06	-0.08	0.00	0.01	0.00
Coefficient Difference *	-0.05	-0.08	0.00	0.01	Reference
Variance	0.0019	0.0015	0.0002	0.0002	0.0003
Covariance	0.00010	0.00013	0.00013	0.00015	n/a
Df	7419	7419	7419	7419	n/a
t Test	-1.23	-2.06	0.09	1.00	n/a
Significance	0.22	0.04	0.93	0.32	n/a

** Differences are rounded to the nearest second decimal place.*
"n" = number of cases in category when category = "1"

5.4. Temporal Aspects Model

Based on the results of the All Sales Model, a more thorough investigation of how Nuisance and Area Stigma effects might change throughout the wind project development period is warranted. As discussed previously, there is some evidence that property value impacts may be particularly strong after the announcement of a disamenity, but then may fade with time as the community adjusts to the presence of that disamenity (e.g., Wolsink, 1989). The Temporal Aspects Model presented here allows for an investigation of how the different periods of the wind project development process affect estimates for the impact of DISTANCE on sales prices.

5.4.1. Dataset and Model Form

Here the full set of 7,459 residential transactions is used, allowing an exploration of potential property value impacts (focusing on the DISTANCE variable) throughout time, including in the pre-construction period. The following model is then estimated:

$$\ln(\mathrm{P}) = \beta_0 + \beta_1 \mathrm{N} + \sum_{s} \beta_2 \mathrm{S} + \sum_{k} \beta_3 \mathrm{X} + \sum_{v} \beta_4 \mathrm{VIEW} + \sum_{y} \beta_5 (\mathrm{DISTANCE} \cdot \mathrm{PERIOD}) + \varepsilon \quad (7)$$

where

DISTANCE is a vector of categorical distance variables (e.g., less than one mile, between one and three miles, etc.),

PERIOD is a vector of categorical development period variables (e.g., after announcement and before construction, etc.),

β_5 is a vector of *y* parameter estimates for each DISTANCE and PERIOD category as compared to the transactions more than two years before announcement and outside of five miles, and all other components are as defined in equation (1).

The PERIOD variable contains six different options:

1) More than two years before announcement;
2) Less than two years before announcement;
3) After announcement but before construction;
4) Less than two years after construction;
5) Between two and four years after construction; and

00002718

6) More than four years after construction.

In contrast to the Base Model, the two DISTANCE categories inside of one mile are collapsed into a single "less than one mile" group. This approach increases the number of transactions in each crossed subcategory of data, and therefore enhances the stability of the parameter estimates and decreases the size of the standard errors, thus providing an increased opportunity to discover statistically significant effects. Therefore, in this model the DISTANCE variable contains four different options:

1) Less than one mile;
2) Between one and three miles;
3) Between three and five miles; and
4) Outside of five miles.[79]

The number of transactions in each of the DISTANCE and PERIOD categories is presented in Table 18.

The coefficients of interest are β_5, which represent the vector of marginal differences between homes sold at various distances from the wind facility (DISTANCE) during various periods of the development process (PERIOD) as compared to the reference group. The reference group in this model consists of transactions that occurred more than two years before the facility was announced for homes that were situated more than five miles from where the turbines were ultimately constructed. It is assumed that the value of these homes would not be affected by the future presence of the wind facility. The VIEW parameters, although included in the model, are not interacted with PERIOD and therefore are treated as controlling variables.[80]

Although the comparisons of these categorical variables between different DISTANCE and PERIOD categories is be interesting, it is the comparison of coefficients within each PERIOD and DISTANCE category that is the focus of this section. Such comparisons, for example, allow one to compare how the average value of homes inside of one mile that sold two years before announcement compare to the average value of homes inside of one mile that sold in the post-announcement-pre-construction period. For this comparison, a *t*-Test similar to that in the All Sales Model is used.

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[79] For homes that sold in the pre-construction time frame, no turbines yet existed, and therefore DISTANCE is created using a proxy: the Euclidian distance to where the turbines were eventually constructed. This approach introduces some bias when there is more than one facility in the study area. Conceivably, a home that sold in the post-announcement-pre-construction period of one wind facility could also be assigned to the pre-announcement period of another facility in the same area. For this type of sale, it is not entirely clear which PERIOD and DISTANCE is most appropriate, but every effort was made to apply the sale to the wind facility that was most likely to have an impact. In most cases this meant choosing the closest facility, but in some cases, when development periods were separated by many years, simply the earliest facility was chosen. In general, any bias created by these judgments is expected to be minimal because, in the large majority of cases, the development process in each study area was more-or-less continuous and focused in a specific area rather then being spread widely apart.

[80] As discussed earlier, the VIEW variable was considered most relevant for the post-construction period, so delineations based on development periods that extended into the pre-construction phase were unnecessary. It is conceivable, however, that VIEW effects vary in periods following construction, such as in the first two years or after that. Although this is an interesting question, the numbers of cases for the SUBSTANTIAL and EXTREME ratings – even if combined – when divided into the temporal periods were too small to be fruitful for analysis.

Table 18: Frequency Crosstab of DISTANCE and PERIOD

	More Than 2 Years Before Announcement	Less Than 2 Years Before Announcement	After Announcement Before Construction	Less Than 2 Years After Construction	Between 2 and 4 Years After Construction	More Than 4 Years After Construction	Total
Less Than 1 Mile	38	40	20	39	45	43	225
Between 1 and 3 Miles	283	592	340	806	502	709	3,232
Between 3 and 5 Miles	157	380	277	572	594	757	2,737
Outside of 5 Miles	132	133	130	218	227	425	1,265
TOTAL	610	1,145	767	1,635	1,368	1,934	7,459

5.4.2. Analysis of Results

Results for the variables of interest for this hedonic model are presented in Table 19; as with previous models, the full set of results is contained in Appendix H. Similar to the All Sales Model discussed in the previous section, the adjusted R^2 for the model is 0.75, down slightly from 0.77 for the Base Model, and indicating that this model has slightly more difficulty (i.e., less explanatory power) modeling transactions that occurred before wind facility construction. All study area, spatial adjustment, and home and site characteristics are significant at or above the one percent level, are of the appropriate sign, and are similar in magnitude to the estimates derived from the post-construction Base Model.

All of the DISTANCE / PERIOD interaction coefficients for distances outside of one mile are relatively small ($-0.04 < \beta_5 < 0.02$) and none are statistically significant. This implies that there are no statistically significant differences in property values between the reference category homes – homes sold more than two years before announcement that were situated outside of five miles from where turbines were eventually erected – and any of the categories of homes that sold outside of one mile at any other period in the wind project development process. These comparisons demonstrate, arguably more directly than any other model presented in this report that Area Stigma effects likely do not exist in the sample.

The possible presence of a Nuisance Stigma is somewhat harder to discern. For homes that sold inside of one mile of the nearest wind turbine, in three of the six periods there are statistically significant negative differences between average property values when compared to the reference category. Transactions completed more than two years before facility announcement are estimated to be valued at 13% less (*p* value 0.02) than the reference category, transactions less than two years before announcement are 10% lower (*p* value 0.06), and transactions after announcement but before construction are 14% lower (*p* value 0.04). For other periods, however, these marginal differences are considerably smaller and are not statistically different from the reference category. Sales prices in the first two years after construction are, on average, 9% less (*p* value 0.15), those occurring between three and four years following construction are, on average, 1% less (*p* value 0.86), and those occurring more than four years after construction are, on average, 7% less (*p* value 0.37).

Table 19: Results from Temporal Aspects Model

Variables of Interest		Temporal Aspects Coef	SE	p Value	*n*
Inside 1 Mile	More Than 2 Years Before Announcement	-0.13	0.06	0.02	38
	Less Than 2 Years Before Announcement	-0.10	0.05	0.06	40
	After Announcement Before Construction	-0.14	0.06	0.04	21
	2 Years After Construction	-0.09	0.07	0.11	39
	Between 2 and 4 Years After Construction	-0.01	0.06	0.85	44
	More Than 4 Years After Construction	-0.07	0.08	0.22	42
Between 1-3 Miles	More Than 2 Years Before Announcement	-0.04	0.03	0.18	283
	Less Than 2 Years Before Announcement	0.00	0.03	0.91	592
	After Announcement Before Construction	-0.02	0.03	0.54	342
	2 Years After Construction	0.00	0.03	0.90	807
	Between 2 and 4 Years After Construction	0.01	0.03	0.78	503
	More Than 4 Years After Construction	0.00	0.03	0.93	710
Between 3-5 Miles	More Than 2 Years Before Announcement	0.00	0.04	0.92	157
	Less Than 2 Years Before Announcement	0.00	0.03	0.97	380
	After Announcement Before Construction	0.00	0.03	0.93	299
	2 Years After Construction	0.02	0.03	0.55	574
	Between 2 and 4 Years After Construction	0.01	0.03	0.65	594
	More Than 4 Years After Construction	0.01	0.03	0.67	758
Outside 5 Miles	More Than 2 Years Before Announcement	Omitted	Omitted	Omitted	132
	Less Than 2 Years Before Announcement	-0.03	0.04	0.33	133
	After Announcement Before Construction	-0.03	0.03	0.39	105
	2 Years After Construction	-0.03	0.03	0.44	215
	Between 2 and 4 Years After Construction	0.03	0.03	0.44	227
	More Than 4 Years After Construction	0.01	0.03	0.73	424

"Omitted" = reference category for fixed effects variables.
"n" indicates number of cases in category when category = "1"

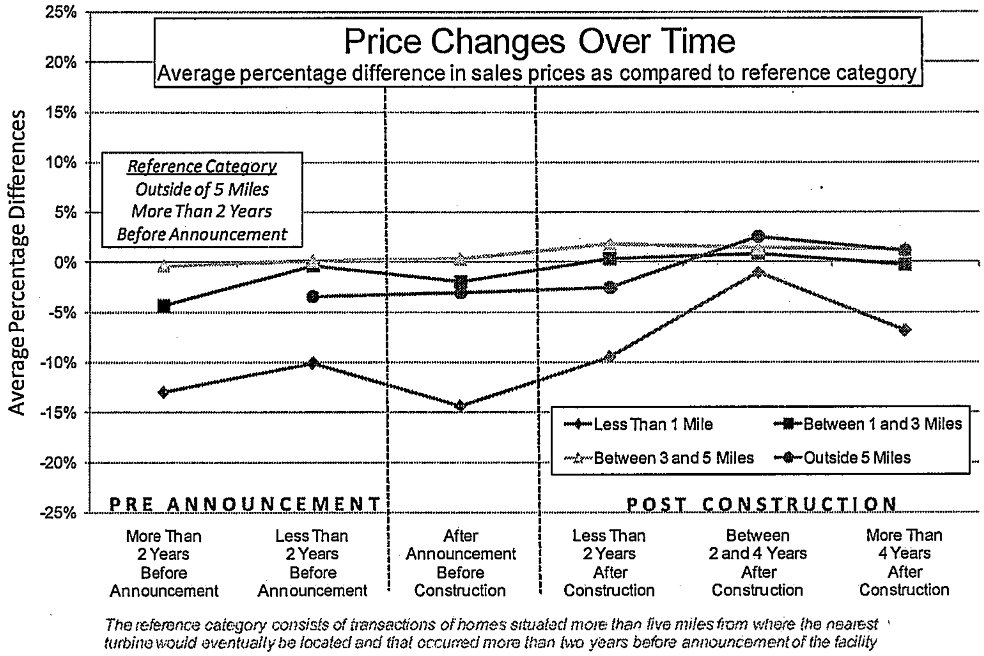
Model Information

Model Equation Number	7
Dependent Variable	LN_SalePrice96
Number of Cases	7459
Number of Predictors (k)	56
F Statistic	404.5
Adjusted R Squared	0.75

What these results suggest (as shown in Figure 8) is that homes inside of one mile in the sample, on average, were depressed in value (in relation to the reference category) before and after the announcement of the wind facility and up to the point that construction began, but that those values rebounded somewhat after construction commenced.[81] This conclusion also likely explains why a significant and negative effect for homes that sold between 3000 feet and one mile is found in the All Sales Model presented in Section 5.3: homes within this distance range that sold prior to facility construction were depressed in value and most likely drove the results for homes that sold after announcement. Regardless, these results are not suggestive of a pervasive Nuisance Stigma.

[81] As discussed in footnotes 47 (on page 19) and 74 (on page 38), the "announcement date" often refers to the first time the proposed facility appeared in the press. "Awareness" of the project in the community may precede this date, however, and therefore transactions occurring in the period "less than two years before announcement" could conceivably have been influenced by the prospective wind project, but it is considerably less likely that those in the period more than two years before announcement would have been influenced.

Figure 8: Results from the Temporal Aspects Model



To explore Nuisance Stigma further, the analysis again turns to the *t*-Test and compares the coefficients for transactions that occurred more than two years before wind facility announcement (during which time the future wind facility is not expected to have any impact on sales prices) to the estimates for the DISTANCE coefficients in the periods that follow. These results are shown in Table 20. Focusing on those transactions inside of one mile, it is found that all coefficients are greater in magnitude than the reference category except during the post-announcement-pre-construction period (which is 1% less and is not statistically significant; *p* value 0.90), indicating, on average, that home values are increasing or staying stable from the pre-announcement reference period onward. These increases, however, are not statistically significant except in the period of two to four years after construction (0.12, *p* value 0.08). With respect to Nuisance Stigma, the more important result is that, relative to homes that sold well before the wind facility was announced, no statistically significant adverse effect is found in any period within a one mile radius of the wind facility. Therefore, the -5% (albeit not statistically significant) average difference that is found in the Base Model, and the -8% (statistically significant) result that is found in the All Sales Model (for homes between 3000 feet and one mile) appear to both be a reflection of depressed home prices that preceded the construction of the relevant wind facilities. If construction of the wind facilities were downwardly influencing the sales prices of these homes, as might be deduced from the Base or All Sales Models alone, a diminution in the inflation adjusted price would be seen as compared to pre-announcement levels. Instead, an increase is seen. As such, no persuasive evidence of a Nuisance Stigma is evident among this sample of transactions.[82]

[82] It should be noted that the numbers of study areas represented for homes situated inside of one mile but in the periods "more than two years before announcement" and "more than four years after construction" are fewer ($n = 5$) than in the other temporal categories ($n = 8$). Further, the "more than two years before announcement – inside of one mile" category is dominated by transactions from one study area (OKCC). For these reasons, there is less

Turning to the coefficient differences for distances greater than one mile in Table 20, again, no statistical evidence of significant adverse impacts on home values is uncovered. Where statistically significant differences are identified, the coefficients are <u>greater</u> than the reference category. These findings corroborate the earlier Area Stigma results, and re-affirm the lack of evidence for such an effect among the sample of residential transactions included in this analysis.

Table 20: Results from Equality Test of Temporal Aspects Model Coefficients

	More Than 2 Years Before Announcement	Less Than 2 Years Before Announcement	After Announcement Before Construction	Less Than 2 Years After Construction	Between 2 and 4 Years After Construction	More Than 4 Years After Construction
Less Than 1 Mile	Reference	0.03 (0.45)	-0.01 (-0.13)	0.04 (0.56)	0.12 (1.74)*	0.06 (0.88)
Between 1 and 3 Miles	Reference	0.04 (1.92)*	0.02 (0.86)	0.05 (2.47)**	0.05 (2.27)**	0.04 (1.82)*
Between 3 and 5 Miles	Reference	0.01 (0.37)	0.01 (0.34)	0.02 (0.77)	0.02 (0.78)	0.02 (0.79)
Outside of 5 Miles †	Reference	-0.04 (-0.86)	-0.03 (-0.91)	-0.03 (-0.77)	0.03 (0.81)	0.01 (0.36)

*Numbers in parenthesis are t-Test statistics. Significance = *** 1% level, ** 5% level, * 10% level, <blank> below the 10% level.*

† For homes outside of 5 miles, the coefficient differences are equal to the coefficients in the Temporal Aspects Model, and therefore the t-values were produced via the OLS.

5.5. Orientation Model

All of the hedonic models presented to this point use a VIEW variable that effectively assumes that the impact of a view of wind turbines on property values will not vary based on the orientation of the home to that view; the impact will be the same whether the view is seen from the side of the home or from the back or front. Other literature, however, has found that the impact of wind projects on property values may be orientation-dependent (Sims et al., 2008). To investigate this possibility further a parameter for orientation is included in the model.

5.5.1. Dataset and Model Form

The same dataset is used as in the Base Model, focusing on post-construction transactions (n = 4,937). To investigate whether the orientation of a home to the turbines (ORIENTATION) has a marginal impact on residential property values, over and above that of the VIEW impacts alone, the following hedonic model is estimated:[83]

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confidence in these two estimates (-13% and -7% respectively) than for the estimates for other temporal periods inside of one mile. Based on additional sensitivity analysis not included here, it is believed that if they are biased, both of these estimates are likely biased downward. Further, as discussed in footnote 47 on page 19, there is a potential for bias in the "announcement" date in that awareness of a project may precede the date that a project enters the public record (i.e., the "announcement" date used for this analysis). Taken together, these two issues might imply that the curve shown in Figure 8 for "less than one mile" transactions, instead of having a flat and then increasing shape, may have a more of an inverse parabolic (e.g., "U") shape. This would imply that a relative minimum in sales prices is reached in the period after awareness began of the facility but before construction commenced, and then, following construction, prices recovered to levels similar to those prior to announcement (and awareness). These results would be consistent with previous studies (e.g., Wolsink, 1989; Devine-Wright, 2004) but cannot be confirmed without the presence of more data. Further research on this issue is warranted. In either case, such results would not change the conclusion here of an absence of evidence of a pervasive Nuisance Stigma in the post-construction period.

[83] The various possible orientations of the home to the view of turbines will be, individually and collectively, referred to as "ORIENTATION" in this report.

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 VIEW + \sum_d \beta_5 DISTANCE + \sum_o \beta_6 ORIENTATION + \varepsilon \quad (8)$$

where
ORIENTATION is a vector of *o* ORIENTATION variables (e.g., SIDE, FRONT, and BACK),
β_6 is a vector of *o* parameter estimates for ORIENTATION variables, and
all other components are as defined in equation (1).[84]

The ORIENTATION categories include FRONT, BACK, and SIDE, and are defined as follows:

- SIDE: The orientation of the home to the view of the turbines is from the side.
- FRONT: The orientation of the home to the view of the turbines is from the front.
- BACK: The orientation of the home to the view of the turbines is from the back.

The orientation of the home to the view of the wind facilities was determined in the course of the field visits to each home. If more than one orientation to the turbines best described the home (e.g., back and side, or front, back, and side) they were coded as such (e.g., turbines visible from back and side: SIDE = 1; BACK = 1; FRONT = 0).[85]

Not surprisingly, ORIENTATION is related to VIEW. Table 21 and Table 22 provide frequency and percentage crosstabs of ORIENTATION and VIEW. As shown, those homes with more dramatic views of the turbines generally have more ORIENTATION ratings applied to them. For instance, 25 out of 28 EXTREME VIEW homes have all three ORIENTATION ratings (i.e., FRONT, BACK, and SIDE). Virtually all of the MINOR VIEW homes, on the other hand, have only one ORIENTATION. Further, MINOR VIEW homes have roughly evenly spread orientations to the turbines across the various possible categories of FRONT, BACK, and SIDE. Conversely, a majority of the MODERATE and SUBSTANTIAL VIEW ratings coincide with an ORIENTATION from the back of the house.[86]

[84] Ideally, one would enter ORIENTATION in the model through an interaction with VIEW. There are two ways that could be accomplished: either with the construction of multiple fixed effects ("dummy") variables, which capture each sub-category of VIEW and ORIENTATION, or through a semi-continuous interaction variable, which would be created by multiplying the ordered categorical variable VIEW by an ordered categorical variable ORIENTATION. Both interaction scenarios are problematic, the former because it requires increasingly small subsets of data, which create unstable coefficient estimates, and the latter because there are no *a priori* expectations for the ordering of an ordered categorical ORIENTATION variable and therefore none could be created and used for the interaction. As a result, no interaction between the two variables is reported here.

[85] An "Angle" orientation was also possible, which was defined as being between Front and Side or Back and Side. An Angle orientation was also possible in combination with Back or Front (e.g., Back-Angle or Front-Angle). In this latter case, the orientation was coded as one of the two prominent orientations (e.g., Back or Front). An Angle orientation, not in combination with Front or Back, was coded as Side.

[86] The prevalence of BACK orientations for MODERATE and SUBSTANTIAL VIEW homes may be because BACK views might more-frequently be kept without obstruction, relative to SIDE views.

Table 21: Frequency Crosstab of VIEW and ORIENTATION

		VIEW				
		Minor	Moderate	Substantial	Extreme	Total
ORIENTATION	Front	217	33	17	27	**294**
	Back	164	67	24	25	**280**
	Side	194	17	15	27	**253**
	Total	561	106	35	28	730

Note: Total of ORIENTATION does not sum to 730 because multiple orientations are possible for each VIEW.

Table 22: Percentage Crosstab of VIEW and ORIENTATION

		VIEW				
		Minor	Moderate	Substantial	Extreme	Total
ORIENTATION	Front	39%	31%	49%	96%	**40%**
	Back	29%	63%	69%	89%	**38%**
	Side	35%	16%	43%	96%	**35%**

Note: Percentages are calculated as a portion of the total for each VIEW ratings (e.g., 24 of the 35 SUBSTANTIAL rated homes have a BACK ORIENTATION = 69%). Columns do not sum to 100% because multiple orientations are possible for each VIEW.

The parameter estimates of interest in this hedonic model are those for ORIENTATION (β_6) and VIEW (β_4). β_6 represent the marginal impact on home value, over and above that of VIEW alone, of having a particular orientation to the turbines. In the Base Model the VIEW coefficients effectively absorb the effects of ORIENTATION, but in this model they are estimated separately. Because a home's surrounding environment is typically viewed from the front or back of the house, one would expect that, to the extent that wind facility VIEW impacts property values, that impact would be especially severe for homes that have FRONT or BACK orientations to those turbines. If this were the case, the coefficients for these categories would be negative, while the coefficient for SIDE would be to be close to zero indicating little to no incremental impact from a SIDE ORIENTATION.

5.5.2. Analysis of Results

Results for the variables of interest for this hedonic model are shown in Table 23; as with previous models, the full set of results is contained in Appendix H. The model performs well with an adjusted R^2 of 0.77. All study area, spatial adjustment, and home and site characteristics are significant at or above the one percent level, are of the appropriate sign, and are similar in magnitude to the estimates derived from the post-construction Base Model. The coefficients for DISTANCE and VIEW are stable, in sign and magnitude, when compared to the Base Model results, and none of the marginal effects are statistically significant.

The coefficients for the variables of interest (β_6) do not meet the *a priori* expectations. The estimated effect for SIDE ORIENTATION, instead of being close to zero, is -3% (*p* value 0.36), while BACK and FRONT, instead of being negative and larger, are estimated at 3% (*p* value 0.37) and -1% (*p* value 0.72), respectively. None of these variables are found to be even marginally statistically significant, however, and based on these results, it is concluded that there is no evidence that a home's orientation to a wind facility affects property values in a measurable way. Further, as with previous models, no statistical evidence of a Scenic Vista Stigma is found among this sample of sales transactions.

Table 23: Results from Orientation Model

	Base Model				Orientation Model			
Variables of Interest	**Coef**	**SE**	**p Value**	***n***	**Coef**	**SE**	**p Value**	***n***
No View	Omitted	Omitted	Omitted	4207	Omitted	Omitted	Omitted	4207
Minor View	-0.01	0.01	0.39	561	-0.01	0.06	0.88	561
Moderate View	0.02	0.03	0.57	106	0.00	0.06	0.96	106
Substantial View	-0.01	0.07	0.92	35	-0.01	0.09	0.85	35
Extreme View	0.02	0.09	0.77	28	0.02	0.17	0.84	28
Inside 3000 Feet	-0.05	0.06	0.31	67	-0.04	0.07	0.46	67
Between 3000 Feet and 1 Mile	-0.05	0.05	0.20	58	-0.05	0.05	0.26	58
Between 1 and 3 Miles	0.00	0.02	0.80	2019	0.00	0.02	0.83	2019
Between 3 and 5 Miles	0.02	0.01	0.26	1923	0.02	0.01	0.26	1923
Outside 5 Miles	Omitted	Omitted	Omitted	870	Omitted	Omitted	Omitted	870
Front Orientation					-0.01	0.06	0.72	294
Back Orientation					0.03	0.06	0.37	280
Side Orientation					-0.03	0.06	0.36	253

"Omitted" = reference category for fixed effects variables. "n" = number of cases in category when category = "1"

Model Information

	Base Model	Orientation Model
Model Equation Number	1	8
Dependent Variable	LN_SalePrice96	LN_SalePrice96
Number of Cases	4937	4937
Number of Predictors (k)	37	40
F Statistic	442.8	410.0
Adjusted R Squared	0.77	0.77

5.6. Overlap Model

The Orientation Model, presented above, investigated, to some degree, how the potential effects of wind turbines might be impacted by how a home is oriented to the surrounding environment. In so doing, this model began to peel back the relationship between VIEW and VISTA, but stopped short of looking at the relationship directly. It would be quite useful, though, to understand the explicit relationship between the VISTA and VIEW variables. In particular, one might expect that views of wind turbines would have a particularly significant impact on residential property values when those views strongly overlap ("OVERLAP") the prominent scenic vista from a home. To investigate this possibility directly, and, in general, the relationship between VIEW and VISTA, a parameter for OVERLAP is included in the model.

5.6.1. Dataset and Model Form

Data on the degree to which the view of wind turbines overlaps with the prominent scenic vista from the home (OVERLAP) were collected in the course of the field visits to each home.[87] The categories for OVERLAP included NONE, BARELY, SOMEWHAT, and STRONGLY, and are described in Table 24: [88]

Table 24: Definition of OVERLAP Categories

OVERLAP - NONE	The scenic vista does not contain any view of the turbines.
OVERLAP - BARELY	A small portion (~ 0 - 20%) of the scenic vista is overlapped by the view of turbines, and might contain a view of a few turbines, only a few of which can be seen entirely.
OVERLAP - SOMEWHAT	A moderate portion (~20-50%) of the scenic vista contains turbines, and likely contains a view of more than one turbine, some of which are likely to be seen entirely.
OVERLAP - STRONGLY	A large portion (~50-100%) of the scenic vista contains a view of turbines, many of which likely can be seen entirely.

A crosstab describing the OVERLAP designations and the VIEW categories is shown in Table 25. As would be expected, the more dramatic views of wind turbines, where the turbines occupy more of the panorama, are coincident with the OVERLAP categories of SOMEWHAT or STRONGLY. Nonetheless, STRONGLY are common for all VIEW categories. Similarly, SOMEWHAT is well distributed across the MINOR and MODERATE rated views, while BARELY is concentrated in the MINOR rated views.

The same dataset is used as in the Base Model, focusing on post-construction transactions (n = 4,937). To investigate whether the overlap of VIEW and VISTA has a marginal impact on residential property values, over and above that of the VIEW and VISTA impacts alone, the following hedonic model is estimated:[89]

$$\ln(\mathrm{P}) = \beta_0 + \beta_1\mathrm{N} + \sum_{s}\beta_2\mathrm{S} + \sum_{k}\beta_3\mathrm{X} + \sum_{v}\beta_4\mathrm{VIEW} + \sum_{d}\beta_5\mathrm{DISTANCE} + \sum_{t}\beta_6\mathrm{VISTA} + \sum_{p}\beta_7\mathrm{OVERLAP} + \varepsilon \quad (9)$$

where
VIEW is a vector of v categorical view variables (e.g., MINOR, MODERATE, etc.),
VISTA is a vector of t categorical scenic vista variables (e.g., POOR, BELOW-AVERAGE, etc.),
OVERLAP is a vector of p categorical overlap variables (e.g., BARELY, SOMEWHAT, etc.),

[87] Scenic vista was rated while taking into account the entire panorama surrounding a home. But, for each home, there usually was a prominent direction that offered a preferred scenic vista. Often, but not always, the home was orientated to enjoy that prominent scenic vista. Overlap is defined as the degree to which the view of the wind facility overlaps with this prominent scenic vista.

[88] "...can be seen entirely" refers to being able to see a turbine from the top of the sweep of its blade tips to below the nacelle of the turbine where the sweep of the tips intersects the tower.

[89] Although VISTA appears in all models, and is usually included in the vector of home and site characteristics represented by X, it is shown separately here so that it can be discussed directly in the text that follows.

β_4 is a vector of *v* parameter estimates for VIEW fixed effects variables as compared to transactions of homes without a view of the turbines,
β_6 is a vector of *t* parameter estimates for VISTA fixed effect variables as compared to transactions of homes with an AVERAGE scenic vista,
β_7 is a vector of *o* parameter estimates for OVERLAP fixed effect variables as compared to transactions of homes where the view of the turbines had no overlap with the scenic vista, and all other components are as defined in equation (1).

The variables of interest in this model are VIEW, VISTA and OVERLAP, and the coefficients β_4, β_6, and β_7 are therefore the primary focus. Theory would predict that the VISTA coefficients in this model would be roughly similar to those derived in the Base Model, but that the VIEW coefficients may be somewhat more positive as the OVERLAP variables explain a portion of any negative impact that wind projects have on residential sales prices. In that instance, the OVERLAP coefficients would be negative, indicating a decrease in sales price when compared to those homes that experience no overlap between the view of wind turbines and the primary scenic vista.

Table 25: Frequency Crosstab of OVERLAP and VIEW

		VIEW					
		None	Minor	Moderate	Substantial	Extreme	Total
OVERLAP	None	4,207	317	3	0	0	**4,527**
	Barely	0	139	10	1	0	**150**
	Somewhat	0	81	42	7	2	**132**
	Strongly	0	24	51	27	26	**128**
	Total	**4,207**	**561**	**106**	**35**	**28**	**4,937**

5.6.2. Analysis of Results

Results for the variables of interest for this hedonic model are shown in Table 26; as with previous models, the full set of results is contained in Appendix H. The model performs well with an adjusted R^2 of 0.77. All study area, spatial adjustment, and home and site characteristics are significant at or above the one percent level, are of the appropriate sign, and are similar in magnitude to the estimates derived from the post-construction Base Model.

As expected from theory, the VISTA parameters are stable across models with no change in coefficient sign, magnitude, or significance. Counter to expectations, however, the VIEW coefficients, on average, decrease in value. MINOR VIEW is now estimated to adversely affect a home's sale price by 3% (*p* value 0.10) and is weakly significant, but none of the other VIEW categories are found to be statistically significant. Oddly, the OVERLAP rating of BARELY is found to significantly <u>increase</u> home values by 5% (*p* value 0.08), while none of the other OVERLAP ratings are found to have a statistically significant impact.

Taken at face value, these results are counterintuitive. For instance, absent any overlap of view with the scenic vista (NONE), a home with a MINOR view sells for 3% less than a home with no view of the turbines. If, alternatively, a home with a MINOR view BARELY overlaps the prominent scenic vista, it not only enjoys a 2% <u>increase</u> in value over a home with NO VIEW of the turbines but a 5% <u>increase</u> in value over homes with views of the turbines that do not overlap with the scenic vista. In other words, the sales price increases when views of turbines overlap the prominent scenic vista, at least in the BARELY category. A more likely explanation for these results are that the relatively high correlation (0.68) between the VIEW and OVERLAP parameters is spuriously driving one set of parameters up and the other down. More importantly, when the parameters are combined, they offer a similar result as was found in the Base Model. Therefore, it seems that the degree to which the view of turbines overlaps the scenic vista has a negligible effect on sales prices among the sample of sales transactions analyzed here.[90]

Despite these somewhat peculiar results, other than MINOR, none of the VIEW categories are found to have statistically significant impacts, even after accounting for the degree to which those views overlap the scenic vista. Similarly, none of the OVERLAP variables are simultaneously negative and statistically significant. This implies, once again, that a Scenic Vista Stigma is unlikely to be present in the sample. Additionally, none of the DISTANCE coefficients are statistically significant, and those coefficients remain largely unchanged from the Base Model, reaffirming previous results in which no significant evidence of either an Area or a Nuisance Stigma was found.

[90] An alternative approach to this model was also considered, one that includes an interaction term between VIEW and VISTA. For this model it is assumed that homes with higher rated scenic vistas might have higher rated views of turbines, and that these views of turbines would decrease the values of the scenic vista. To construct the interaction, VISTA, which can be between one and five (e.g., POOR=1,...PREMIUM=5), was multiplied by VIEW, which can be between zero and four (e.g. NO VIEW=0, MINOR=1,...EXTREME=4). The resulting interaction (VIEW*VISTA) therefore was between zero and sixteen (there were no PREMIUM VISTA homes with an EXTREME VIEW), with zero representing homes without a view of the turbines, one representing homes with a POOR VISTA and a MINOR VIEW, and sixteen representing homes with either a PREMIUM VISTA and a SUBSTANTIAL VIEW or an ABOVE AVERAGE VISTA and an EXTREME VIEW. The interaction term, when included in the model, was relatively small (-0.013) and weakly significant (*p* value 0.10 – not White's corrected). The VISTA estimates were unchanged and the VIEW parameters were considerably larger and positive. For instance, EXTREME was 2% in the Base Model and 16% in this "interaction" model. Similarly, SUBSTANTIAL was -1% in the Base Model and 13% in this model. Therefore, although the interaction term is negative and weakly significant, the resulting VIEW estimates, to which it would need to be added, fully offset this negative effect. These results support the idea that the degree to which a VIEW overlaps VISTA has a likely negligible effect on sales prices, while also confirming that there is a high correlation between the interaction term and VIEW variables.

Table 26: Results from Overlap Model

Variables of Interest	Base Model				Overlap Model			
	Coef	SE	p Value	*n*	Coef	SE	p Value	*n*
No View	Omitted	Omitted	Omitted	4,207	Omitted	Omitted	Omitted	4,207
Minor View	-0.01	0.01	0.39	561	-0.03	0.02	0.10	561
Moderate View	0.02	0.03	0.57	106	-0.02	0.04	0.65	106
Substantial View	-0.01	0.07	0.92	35	-0.05	0.09	0.43	35
Extreme View	0.02	0.09	0.77	28	-0.03	0.10	0.73	28
Inside 3000 Feet	-0.05	0.06	0.31	67	-0.05	0.06	0.32	67
Between 3000 Feet and 1 Mile	-0.05	0.05	0.20	58	-0.05	0.05	0.27	58
Between 1 and 3 Miles	0.00	0.02	0.80	2,019	0.00	0.02	0.82	2,019
Between 3 and 5 Miles	0.02	0.01	0.26	1,923	0.02	0.01	0.26	1,923
Outside 5 Miles	Omitted	Omitted	Omitted	870	Omitted	Omitted	Omitted	870
Poor Vista	-0.21	0.02	0.00	310	-0.21	0.02	0.00	310
Below Average Vista	-0.08	0.01	0.00	2,857	-0.08	0.01	0.00	2,857
Average Vista	Omitted	Omitted	Omitted	1,247	Omitted	Omitted	Omitted	1,247
Above Average Vista	0.10	0.02	0.00	448	0.10	0.02	0.00	448
Premium Vista	0.13	0.04	0.00	75	0.13	0.04	0.00	75
View Does Not Overlap Vista					Omitted	Omitted	Omitted	320
View Barely Overlaps Vista					0.05	0.03	0.08	150
View Somewhat Overlaps Vista					0.01	0.03	0.66	132
View Strongly Overlaps Vista					0.05	0.05	0.23	128

"Omitted" = reference category for fixed effects variables. "n" = number of cases in category when category = "1"

Model Information

	Base Model	Overlap Model
Model Equation Number	1	9
Dependent Variable	LN_SalePrice96	LN_SalePrice96
Number of Cases	4937	4937
Number of Predictors (k)	37	40
F Statistic	442.8	409.7
Adjusted R Squared	0.77	0.77

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6. Repeat Sales Analysis

In general, the Base and Alternative Hedonic Models presented in previous sections come to the same basic conclusion: wind power facilities in this sample have no demonstrable, widespread, sizable, and statistically significant affect on residential property values. These hedonic models contain 29 or more controlling variables (e.g., house and site characteristics) to account for differences in home values across the sample. Although these models perform well and explain nearly 80% of the variation in sales prices among homes in the sample, it is always possible that variables not included in (i.e., "omitted from") the hedonic models could be correlated with the variables of interest, therefore biasing the results.

A common method used to control for omitted variable bias in the home assessment literature is to estimate a repeat sales model (Palmquist, 1982). This technique focuses on just those homes that have sold on more than one occasion, preferably once before and once after the introduction of a possible disamenity, and investigates whether the price appreciation between these transactions is affected by the presence of that disamenity. In this section a repeat sales analysis is applied to the dataset, investigating in a different way the presence of the three possible property value stigmas associated with wind facilities, and therefore providing an important cross-check to the hedonic model results. The section begins with a brief discussion of the general form of the Repeat Sales Model and a summary of the literature that has employed this approach to investigate environmental disamenities. The dataset and model used in the analysis is then described, followed by a summary of the results from that analysis.

6.1. Repeat Sales Models and Environmental Disamenities Literature

Repeat sales models use the annual sales-price appreciation rates of homes as the dependent variable. Because house, home site, and neighborhood characteristics are relatively stable over time for any individual home, many of those characteristics need not be included in the repeat sales model, thereby increasing the degrees of freedom and allowing sample size requirements to be significantly lower and coefficient estimates to be more efficient (Crone and Voith, 1992). A repeat sales analysis is not necessarily preferred over a traditional hedonic model, but is rather an alternative analysis approach that can be used to test the robustness of the earlier results (for further discussion see Jackson, 2003). The repeat sales model takes the basic form:

Annual Appreciation Rate (AAR) = *f* (TYPE OF HOUSE, OTHER FACTORS)

where
TYPE OF HOUSE provides an indication of the segment of the market in which the house is situated (e.g., high end vs. low end), and
OTHER FACTORS include, but are not limited to, changes to the environment (e.g., proximity to a disamenity).

The dependent variable is the adjusted annual appreciation rate and is defined as follows:

$$AAR = \exp\left[\frac{\ln(P_1/P_2)}{t_1 - t_2}\right] - 1 \qquad (10)$$

where

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P_1 is the adjusted sales price at the first sale (in 1996 dollars),
P_2 is the adjusted sales price at the second sale (in 1996 dollars),
t_1 is the date of the first sale,
t_2 is the date of the second sale, and
$(t_1 - t_2)$ is determined by calculating the number of days that separate the sale dates and dividing by 365.

As with the hedonic regression model, the usefulness of the repeat sales model is well established in the literature when investigating possible disamenities. For example, a repeat sales analysis was used to estimate spatial and temporal sales price effects from incinerators by Kiel and McClain (1995), who found that appreciation rates, on average, are not sensitive to distance from the facility during the construction phase but are during the operation phase. Similarly, McCluskey and Rausser (2003) used a repeat sales model to investigate effects surrounding a hazardous waste site. They found that appreciation rates are not sensitive to the home's distance from the disamenity before that disamenity is identified by the EPA as hazardous, but that home values are impacted by distance after the EPA's identification is made.

6.2. Dataset

The 7,459 residential sales transactions in the dataset contain a total of 1,253 transactions that involve homes that sold on more than one occasion (i.e., a "pair" of sales of the same home). For the purposes of this analysis, however, the key sample consists of homes that sold once before the announcement of the wind facility, and that subsequently sold again after the construction of that facility. Therefore any homes that sold twice in either the pre-announcement or post-construction periods were not used in the repeat sales sample.[91] These were excluded because either they occurred before the effect would be present (for pre-announcement pairs) or after (for post-announcement pairs). This left a total of 368 pairs for the analysis, which was subsequently reduced to 354 usable pairs.[92]

The mean AAR for the sample is 1.0% per year, with a low of -10.5% and a high of 13.4%. Table 27 summarizes some of the characteristics of the homes used in the repeat sales model. The average house in the sample has 1,580 square feet of above-ground finished living area, sits on a parcel of 0.67 acres, and originally sold for $70,483 (real 1996 dollars). When it sold a second time, the average home in the sample was located 2.96 miles from the nearest wind turbine (14 homes were within one mile, 199 between one and three miles, 116 between three and five miles, and 25 outside of five miles). Of the 354 homes, 14% ($n = 49$) had some view of the facility (35 were rated MINOR, five MODERATE, and nine either SUBSTANTIAL or EXTREME). Because of the restriction to those homes that experienced repeat sales, the sample is relatively small for those homes in close proximity to and with dramatic views of wind facilities.

91 752 pairs occurred after construction began, whereas 133 pairs occurred before announcement.

92 Of the 368 pairs, 14 were found to have an AAR that was either significantly above or below the mean for the sample (mean +/- 2 standard deviations). These pairs were considered highly likely to be associated with homes that were either renovated or left to deteriorate between sales, and therefore were removed from the repeat sales model dataset. Only two of these 14 homes had views of the wind turbines, both of which were MINOR. All 14 of the homes were situated either between one and three miles from the nearest turbine ($n = 8$) or between three and five miles away ($n = 6$).

Table 27: List of Variables Included in the Repeat Sales Model

Variable Name	Description	Type	Sign	Freq.	Mean	Std. Dev.	Min.	Max.
SalePrice96_Pre	The Sale Price (adjusted for inflation into 1996 dollars) of the home as of the first time it had sold	C	+	354	$ 70,483	$ 37,798	$ 13,411	$ 291,499
SalePrice96_Pre_Sqr	SalePrice96_Pre Squared (shown in millions)	C	–	354	$ 6,393	$ 8,258	$ 180	$ 84,972
Acres	Number of Acres that sold with the residence	C	+	354	0.67	1.34	0.07	10.96
Sqft_1000	Number of square feet of finished above ground living area (in 1000s)	C	+	354	1.58	0.56	0.59	4.06
No View	If the home had no view of the turbines when it sold for the second time (Yes = 1, No = 0)	Omitted	n/a	305	0.86	0.35	0	1
Minor View	If the home had a Minor View of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	35	0.10	0.30	0	1
Moderate View	If the home had a Moderate View of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	5	0.01	0.12	0	1
Substantial/Extreme View	If the home had a Substantial or Extreme View of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	9	0.03	0.12	0	1
Less than 1 Mile	If the home was within 1 mile (5280 feet) of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	14	0.02	0.13	0	1
Between 1 and 3 Miles	If the home was between 1 and 3 miles of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	199	0.56	0.50	0	1
Between 3 and 5 Miles	If the home was between 3 and 5 miles of the turbines when it sold for the second time (Yes = 1, No = 0)	OC	–	116	0.33	0.47	0	1
Outside 5 Miles	If the home was outside 5 miles of the turbines when it sold for the second time (Yes = 1, No = 0)	Omitted	n/a	25	0.07	0.26	0	1

"C" Continuous, "OC" Ordered Categorical (1 = yes, 0 = no) values are interpreted in relation to the "Omitted" category. This table does not include the study area fixed effects variables that are included in the model (e.g., WAOR, TXHC, NYMC). The reference case for these variables is the WAOR study area.

6.3. Model Form

To investigate the presence of Area, Scenic Vista, and Nuisance Stigmas, the adjusted annual appreciation rate (AAR) is calculated for the 354 sales pairs in the manner described in equation (10), using inflation adjusted sales prices. The following model is then estimated:

$$\text{AAR} = \beta_0 + \sum_s \beta_1 \text{S} + \sum_k \beta_2 \text{X} + \sum_v \beta_3 \text{VIEW} + \sum_d \beta_4 \text{DISTANCE} + \varepsilon \qquad (11)$$

where
AAR represents the inflation-adjusted Annual Appreciation Rate for repeat sales,
S is the vector of *s* Study Area fixed effects variables (e.g., WAOR, OKCC, etc.),
X is a vector of *k* home, site and sale characteristics (e.g., acres, square feet, original sales price),
VIEW is a vector of *v* categorical view variables (e.g., MINOR, MODERATE, etc.),
DISTANCE is a vector of *d* categorical distance variables (e.g., less than one mile, between one and three miles, etc.),
β_0 is the constant or intercept across the full sample,
β_1 is a vector of *s* parameter estimates for the study area fixed effects as compared to sales that occurred in the WAOR study area,
β_2 is a vector of *k* parameter estimates for the home, site, and sale characteristics,
β_3 is a vector of *v* parameter estimates for the VIEW variables as compared to transactions of homes with no view of the turbines,
β_4 is a vector of *d* parameter estimates for the DISTANCE variables as compared to transactions of homes outside of five miles, and
ε is a random disturbance term.

Effectively, this model seeks to identify reasons that AARs vary among those sales pairs in the sample. Reasons for such differences in AARs might include variations in home and site characteristics, the study area in which the sale occurs, or the degree to which the home is in proximity to or has a dramatic view of a wind facility. As such, the model as shown by equation (11) has three primary groups of parameters: variables of interest; home, site, and sale characteristics; and study area fixed effects.

The variables of interest are VIEW and DISTANCE, and the coefficients β_3 and β_4 are therefore the primary focus of this analysis. Because of the small numbers of homes in the sample situated inside of 3000 feet and between 3000 feet and one mile, they are collapsed into a single category (inside one mile). For the same reason, homes with SUBSTANTIAL or EXTREME VIEWS are collapsed into a single category (SUBSTANTIAL/EXTREME). In this model, therefore, the influence on appreciation rates of the following variables of interest is estimated: MINOR, MODERATE, and SUBSTANTIAL/EXTREME VIEWS, and less than one mile, between one and three mile, and between three and five mile DISTANCES. For the VIEW fixed-effects variables, the reference category is NO VIEW; for DISTANCE, it is homes outside of five miles. As with previous models, if effects exist, it is expected that all of the coefficients would be negative and monotonically ordered.

The number of home, site, and sale characteristics included in a repeat sales model is typically substantially lower than in a hedonic model. This is to be expected because, as discussed earlier, the repeat sales model explores variations in AARs for sales pairs from individual homes, and home and site characteristics are relatively stable over time for any individual home. Nonetheless, various characteristics have been found by others (e.g., Kiel and McClain, 1995; McCluskey and Rausser, 2003) to affect appreciation rates. For the purposes of the Repeat Sales Model, these include the number of square feet of living space (SQFT_1000), the number of acres (ACRES), the inflation-adjusted price of the home at the first sale (SalePrice96_Pre), and that sales price squared (SalePrice96_Pre_Sqr). Of those characteristics, the SQFT_1000 and ACRES coefficients are expected to be positive indicating that, all else being equal, an increase in living area and lot size increases the relative appreciation rate. Conversely, it is expected that the combined estimated effect of the initial sales prices (SalePrice96_Pre and SalePrice96_Pre_Sqr) will trend downward, implying that as the initial sales price of the house increases the appreciation rate decreases. These expectations are in line with the previous literature (Kiel and McClain, 1995; McCluskey and Rausser, 2003).

Finally, the study-area fixed effects variables (β_1) are included in this model to account for differences in inflation adjusted appreciation rates that may exist across study areas (e.g., WAOR, TXHC, NYMC). The WAOR study area is the reference category, and all study-area coefficients therefore represent the marginal change in AARs compared to WAOR (the intercept represents the marginal change in AAR for WAOR by itself). These study area parameters provide a unique look into Area Stigma effects. Recall that the appreciation rates used in this model are adjusted for inflation by using an inflation index from the nearby municipal statistical area (MSA). These MSAs are sometimes quite far away (as much as 20 miles) and therefore would be unaffected by the wind facility. As such, any variation in the study area parameters (and the intercept) would be the result of local influences not otherwise captured in the inflation

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adjustment, and represent another test for Area Stigma; if effects exist, it is expected that the β_0 and β_1 coefficients will be negative.

As with the hedonic models presented earlier, the assumptions of homoskedasticity, absence of spatial autocorrelation, reasonably little multicollinearity, and appropriate controls for outliers are addressed as described in the associated footnote and in Appendix G.[93]

6.4. Analysis of Results

The results from the Repeat Sales Model are presented in Table 28. The model performs relatively poorly overall, with an Adjusted R^2 of just 0.19 (and an *F*-test statistic of 5.2). Other similar analyses in the literature have produced higher performance statistics but have done so with samples that are considerably larger or more homogenous than ours.[94] The low R^2 found here should not be cause for undue concern, however, given the relatively small sample spread across ten different study areas. Moreover, many of the home and site characteristics are found to be statistically significant, and of the appropriate sign. The coefficient for the adjusted initial sales price (SalePrice96_Pre), for example, is statistically significant, small, and negative (-0.000001, *p* value 0.00), while the coefficient for the adjusted initial sales price squared (SalePrice96_Pre_Sqr) is also statistically significant and considerably smaller (<0.000000, *p* value 0.00). These results imply, consistent with the prior literature, that for those homes in the sample, an increase in initial adjusted sales price decreases the average percentage appreciation rate. ACRES (0.002, *p* value 0.10) and SQFT_1000 (0.02, *p* value 0.00) are both positive, as expected, and statistically significant.

Of particular interest are the intercept term and the associated study-area fixed effect coefficients, and what they collectively say about Area Stigma. The coefficient for the intercept (β_0) is 0.005 (*p* value 0.81), which is both extremely small and not statistically significant. Likewise, the study-area fixed effects are all relatively small (less than 0.03 in absolute terms) and none are statistically significant. As discussed above, if a pervasive Area Stigma existed, it would be expected to be represented in these coefficients. Because all are small and statistically insignificant, it can again be concluded that there is no persuasive evidence of an Area Stigma among this sample of home transactions.

[93] All results are produced using White's corrected standard errors to control for heteroskedasticity. Spatial autocorrelation, with this small sample, is impossible to control. Because of the small sample, an even smaller number of neighboring sales exist, which are required to construct the spatial matrix. As such, spatial autocorrelation is not addressed in the repeat sales model. As with the hedonic models, some multicollinearity might exist, but that multicollinearity is unlikely to be correlated with the variables of interest. Outliers are investigated and dealt with as discussed in footnote 91 on page 56.

[94] McCluskey and Rausser (2003) had a sample of over 30,000 repeat sales and had an *F*-test statistic of 105; Kiel and McClain (1995) produced an R^2 that ranged from 0.40 to 0.63 with samples ranging from 53 to 145, but all sales took place in North Andover, MA.

Table 28: Results from Repeat Sales Model

	Coef.	SE	p Value	*n*
Intercept	0.005	0.02	0.81	354
WAOR	Omitted	Omitted	Omitted	6
TXHC	-0.01	0.02	0.63	57
OKCC	0.03	0.02	0.11	102
IABV	0.02	0.02	0.14	59
ILLC	-0.01	0.02	0.38	18
WIKCDC	0.02	0.03	0.50	8
PASC	-0.01	0.02	0.67	32
PAWC	0.02	0.02	0.16	35
NYMCOC	0.02	0.02	0.23	24
NYMC	0.03	0.02	0.13	13
SalePrice96_Pre	-0.000001	0.0000002	0.00	354
SalePrice96_Pre_Sqr	0.0000000	0.0000000	0.00	354
Acres	0.002	0.001	0.10	354
Sqft_1000	0.02	0.01	0.00	354
No View	Omitted	Omitted	Omitted	305
Minor View	-0.02	0.01	0.02	35
Moderate View	0.03	0.03	0.29	5
Substantial/Extreme View	-0.02	0.01	0.09	9
Less than 1 Mile	0.03	0.01	0.01	14
Between 1 and 3 Miles	0.01	0.01	0.59	199
Between 3 and 5 Miles	0.01	0.01	0.53	116
Outside 5 Miles	Omitted	Omitted	Omitted	25

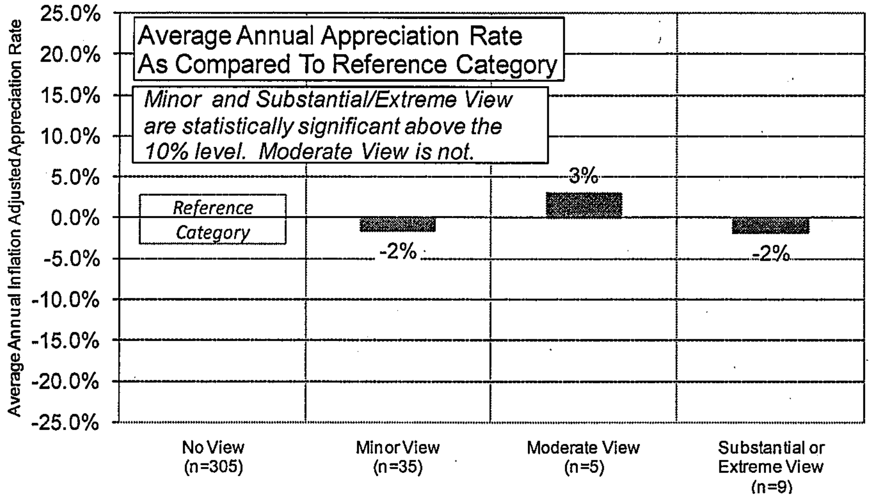
"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	11
Dependent Variable	SalePrice96_AAR
Number of Cases	354
Number of Predictors (k)	19
F Statistic	5.2
Adjusted R2	0.19

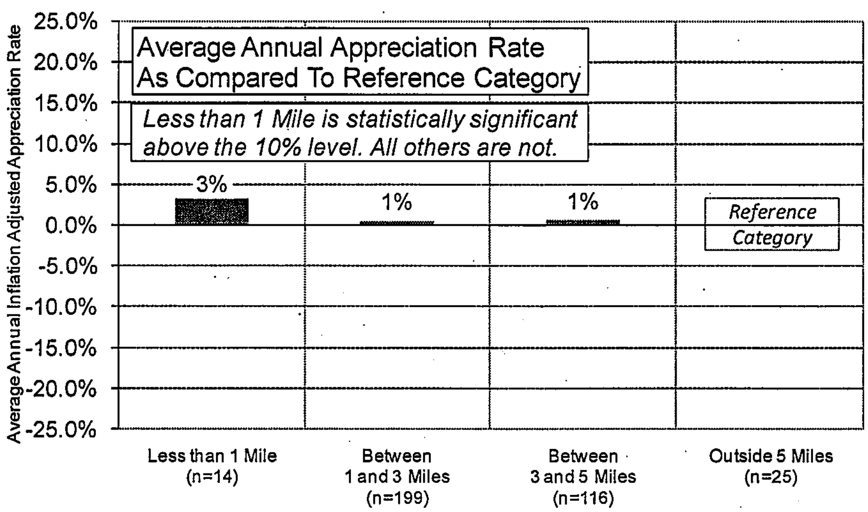
Turning to the variables of interest, mixed results (see Figure 9 and Figure 10) are found. For homes with MINOR or SUBSTANTIAL/EXTREME VIEWS, despite small sample sizes, appreciation rates after adjusting for inflation are found to decrease by roughly 2% annually (*p* values of 0.02 and 0.09, respectively) compared to homes with NO VIEW. Though these findings initially seem to suggest the presence of Scenic Vista Stigma, the coefficients are not monotonically ordered, counter to what one might expect: homes with a MODERATE rated view appreciated on average 3% annually (*p* value 0.29) compared to homes with NO VIEW. Adding to the suspicion of these VIEW results, the DISTANCE coefficient for homes situated inside of one mile, where eight out of the nine SUBSTANTIAL/EXTREME rated homes are located, is positive and statistically significant (0.03, *p* value 0.01). If interpreted literally, these results suggest that a home inside of one mile with a SUBSTANTIAL/EXTREME rated view would experience a decrease in annual appreciation of 2% compared to homes with no views of turbines, but simultaneously would experience an increase of 3% in appreciation compared to homes outside of five miles. Therefore, when compared to those homes outside of five miles and with no view of the wind facilities, these homes would experience an overall increase in AAR by 1%. These results are counterintuitive and are likely driven by the small number of sales pairs that are located within one mile of the wind turbines and experience a dramatic view of those turbines.

Figure 9: Repeat Sales Model Results for VIEW



The reference category consists of tranasctions of homes that had no view of the turbines

Figure 10: Repeat Sales Model Results for DISTANCE



The reference category consists of tranasctions of homes that are situated outside of five miles from the nearest turbine

Regardless of the reason for this result, again no persuasive evidence of consistent and widespread adverse effects is found from the presence of the wind facilities in the sample, reinforcing the findings from the previous hedonic analysis. Specifically, there is no evidence that an Area Stigma exists in that homes outside of one mile and inside of five miles do not appreciate differently than homes farther away. Similarly, there is no evidence of a Nuisance Stigma. Appreciation rates for homes inside of one mile are not adversely affected; in fact, significantly higher appreciation rates are found for these homes than for those homes located outside of five miles from the nearest wind facility. Finally, though some evidence is found that a Scenic Vista Stigma may exist in the sample of repeat sales, it is weak, fairly small, and somewhat counter-intuitive. This result is likely driven by the small number of sales pairs that are located within one mile of the wind turbines and that experience a dramatic view of those turbines.

7. Sales Volume Analysis

The analysis findings to this point suggest that, among the sample of sales transactions analyzed in this report, wind facilities have had no widespread and statistically identifiable impact on residential property values. A related concern that has not yet been addressed is that of sales volume: does the presence of wind facilities either increase or decrease the rate of home sales transactions? On the one hand, a decrease in sales volumes might be expected. This might occur if homeowners expect that their property values will be impacted by the presence of the wind facility, and therefore simply choose not to sell their homes as a result, or if they try to sell but are not easily able to find willing buyers. Alternatively, an increase in sales volume might be expected if homeowners that are located near to or have a dominating view of wind turbines are uncomfortable with the presence of those turbines. Though those homes may sell at a market value that is not impacted by the presence of the wind facilities, self-selection may lead to accelerated transaction volumes shortly after facility announcement or construction as homeowners who view the turbines unfavorably sell their homes to individuals who are not so stigmatized. To address the question of whether and how sales volumes are impacted by nearby wind facilities, sales volumes are analyzed for those homes located at various distances from the wind facilities in the sample, during different facility development periods.

7.1. Dataset

To investigate whether sales volumes are affected by the presence of wind facilities two sets of data are assembled: (1) the number of homes available to sell annually within each study area, and (2) the number of homes that actually did sell annually in those areas. Homes potentially "available to sell" are defined as all single family residences within five miles of the nearest turbine that are located on a parcel of land less than 25 acres in size, that have only one residential structure, and that had a market value (for land and improvements) above $10,000.[95] Homes that "did sell" are defined as every valid sale of a single family residence within five miles of the nearest turbine that are located on a parcel of land less than 25 acres in size, that have only one residential structure, and that sold for more than $10,000.

The sales data used for this analysis are slightly different from those used in the hedonic analysis reported earlier. As mentioned in Section 3.3, a number of study areas were randomly sampled to limit the transactions outside of 3 miles if the total number of transactions were to exceed that which could efficiently be visited in the field (n ~1,250). For the sales volume analysis, however, field data collection was not required, and all relevant transactions could therefore be used. Secondly, two study areas did not provide the data necessary for the sales volume analysis (WAOR and OKCC), and are therefore excluded from the sample. Finally, data for some homes that were "available to sell" were not complete, and rather than including only a small selection of these homes, these subsets of data were simply excluded from the analysis. These excluded homes include those located outside of five miles of the nearest wind turbine, and those available to sell or that did sell more than three years before wind facility announcement.[96] The resulting

[95] "Market value" is the estimated price at which a home would sell as of a given point in time.

[96] For instance, some providers supplied sales data out to ten miles, but only provided homes available to sell out to five miles. As well, data on homes that did sell were not consistently available for periods many years before announcement.

dataset spans the period starting three years prior to facility announcement and ending four years after construction. All homes in this dataset are situated inside of five miles, and each is located in one of the eight represented study areas.[97]

The final set of homes potentially "available to sell" and that actually "did sell" are then segmented into three distance categories: inside of one mile, between one and three miles, and between three and five miles. For each of these three distance categories, in each of the eight study areas, and for each of the three years prior to announcement, the period between announcement and construction, and each of the four years following construction, the number of homes that sold as a percentage of those available to sell is calculated.[98] This results in a total of 24 separate sales volume calculations in each study area, for a total of 192 calculations across all study areas. Finally, these sales volumes are averaged across all study areas into four development period categories: less than three years before announcement, after announcement but before construction, less than two years after construction, and between two and four years after construction.[99] The resulting average annual sales volumes, by distance band and development period, are shown in Table 29 and Figure 11.

Table 29: Sales Volumes by PERIOD and DISTANCE

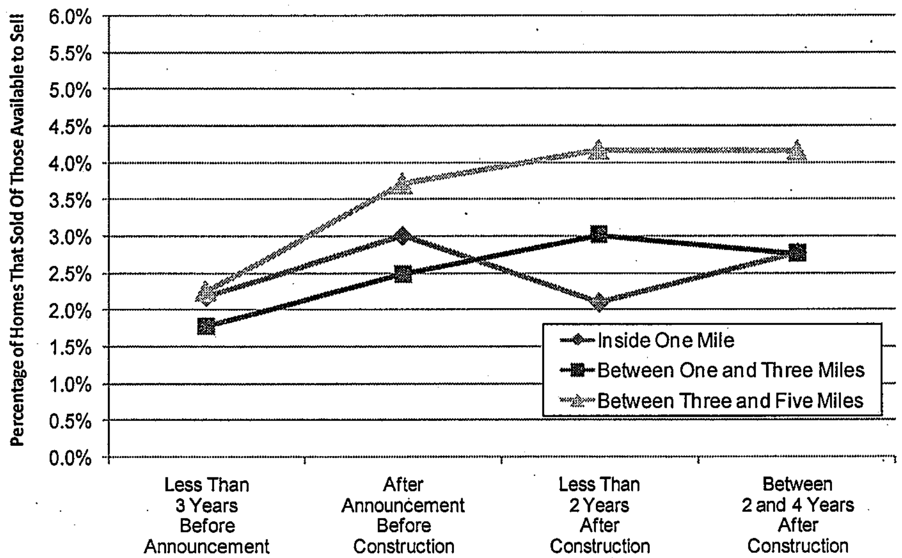
	Inside 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles
Less Than 3 Years Before Announcement	2.2%	1.8%	2.3%
After Announcement Before Construction	3.0%	2.5%	3.7%
Less Than 2 Years After Construction	2.1%	3.0%	4.2%
Between 2 and 4 Years After Construction	2.8%	2.8%	4.2%

[97] The number of homes "available to sell" is constructed for each year after 1996 based on the year the homes in each study area were built. For many homes in the sample, the year built occurred more than three years before wind facility announcement, and therefore those homes are "available to sell" in all subsequent periods. For some homes, however, the home was built during the wind facility development process, and therefore becomes "available" some time after the first period of interest. For those homes, the build year is matched to the development dates so that it becomes "available" during the appropriate period. For this reason, the number of homes "available to sell" increases in later periods.

[98] For the period after announcement and before construction, which in all study areas was not exactly 12 months, the sales volume numbers are adjusted so that they corresponded to an average over a 12 month period.

[99] These temporal groupings are slightly different from those used in the hedonic Temporal Aspects Model. Namely, the period before announcement is not divided into two parts – more than two years before announcement and less than two years before announcement – but rather only one – less than three years before announcement. This simplification is made to allow each of the interaction categories to have enough data to be meaningful.

Figure 11: Sales Volumes by PERIOD and DISTANCE



7.2. Model Form

To investigate whether the rate of sales transactions is measurably affected by the wind facilities, the various resulting sales volumes shown above in Table 29 and Figure 11 are compared using a *t*-Test, as follows:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (12)$$

where

$\bar{x}_1$ and $\bar{x}_2$ are the mean sales volumes from the two categories being compared,

s_1^2 and s_2^2 are variances of the sales volumes from the two categories being compared, and

n_1 and n_2 are numbers of representative volumes in the two categories.[100]

The degrees of freedom used to calculate the *p*-value of the *t* statistic equals the lower of $(n_1 - 1)$ or $(n_2 - 1)$.

Three sets of *t*-Tests are conducted. First, to test whether sales volumes have changed with time and are correlated with wind facility construction, the volumes for each DISTANCE group in later periods (x_1) are compared to the volume in that same group in the pre-announcement period (x_2). Second, to test whether sales volumes are impacted by distance to the nearest wind turbine, the volumes for each PERIOD group at distances closer to the turbines (x_1) are compared to the volume in that same group in the three to five mile distance band (x_2). Finally, for reasons that will become obvious later, the sales volumes for each PERIOD group at distances within one

[100] The number of representative volumes could differ between the two categories. For instance, the "less than three years before announcement" category represents three years – and therefore three volumes – for each study area for each distance band, while the "less than two years after construction" category represents two years – and therefore two volumes – for each study area for each distance band.

mile and outside of three miles of the turbines (x_1) are compared to the sales volume in that same group in the one to three mile distance band (x_2). These three tests help to evaluate whether sales volumes are significantly different after wind facilities are announced and constructed, and whether sales volumes near the turbines are affected differently than for those homes located farther away.[101]

7.3. Analysis of Results

Table 29 and Figure 11 above show the sales volumes in each PERIOD and DISTANCE category, and can be interpreted as the percentage of homes that are available to sell that did sell in each category, on an annual average basis. The sales volume between one and three miles and before facility announcement is the lowest, at 1.8%, whereas the sales volumes for homes located between three and five miles in both periods following construction are the highest, at 4.2%.

The difference between these two sales volumes can be explained, in part, by two distinct trends that are immediately noticeable from the data presented in Figure 11. First, sales volumes in all periods are highest for those homes located in the three to five mile distance band. Second, sales volumes at virtually all distances are higher after wind facility announcement than they were before announcement.[102]

To test whether these apparent trends are borne out statistically the three sets of *t*-Tests described earlier are performed, the results of which are shown in Table 30, Table 31, and Table 32. In each table, the difference between the subject volume (x_1) and the reference volume (x_2) is listed first, followed by the *t* statistic, and whether the statistic is significant at or above the 90% level ("*").

Table 30 shows that mean sales volumes in the post-announcement periods are consistently greater than those in the pre-announcement period, and that those differences are statistically significant in four out of the nine categories. For example, the post-construction sales volumes for homes in the three to five mile distance band in the period less than two years after construction (4.2%) and between three and four years after construction (4.2%) are significantly greater than the pre-announcement volume of 2.3% (1.9%, $t = 2.40$; 1.9%, $t = 2.31$). Similarly, the post-construction sales volumes between one and three miles are significantly greater than the pre-announcement volume. These statistically significant differences, it should be noted, could be as much related to the low reference volume (i.e., sales volume in the period less than

[101] An alternative method to this model would be to pool the homes that "did sell" with the homes "available to sell" and construct a Discrete Choice Model where the dependent variable is zero (for "no sale") or one (for "sale") and the independent variables would include various home characteristics and the categorical distance variables. This would allow one to estimate the probability that a home sells dependent on distance from the wind facility. Because home characteristics data for the homes "available to sell," was not systematically collected it was not possible to apply this method to the dataset.

[102] It is not entirely clear why these trends exist. Volumes may be influenced upward in areas farther from the wind turbines, where homes, in general, might be more densely sited and homogenous, both of which might be correlated with greater home sales transactions. The converse might be true in more rural areas, nearer the wind turbines, where homes may be more unique or homeowners less prone to move. The increasing sales volumes seen in periods following construction, across all distance bands, may be driven by the housing bubble, when more transactions were occurring in general.

three years before announcement), as they are to the sales volumes to which the reference category is compared. Finally, when comparing post-construction volumes inside of a mile, none are statistically different than the 2.2% pre-announcement level.

Table 30: Equality Test of Sales Volumes between PERIODS

	Inside 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles
Less Than 3 Years Before Announcement	Reference	Reference	Reference
After Announcement Before Construction	0.8% (0.72)	0.7% (0.99)	1.5% (1.49)
Less Than 2 Years After Construction	-0.1% (-0.09)	1.2% (2.45) *	1.9% (2.4) *
Between 2 and 4 Years After Construction	0.6% (0.54)	1% (2.24) *	1.9% (2.31) *

Numbers in parenthesis represent t-Test statistics. "" = significantly different at or below the 10% level*

Turning to sales volumes in the same development period but between the different distance bands, consistent but less statistically significant results are uncovered (see Table 31). Although all sales volumes inside of three miles, for each period, are less than their peers outside of three miles, those differences are statistically significant in only two out of eight instances. Potentially more important, when one compares the sales volumes inside of one mile to those between one and three miles (see Table 32), small differences are found, none of which are statistically significant. In fact, on average, the sales volumes for homes inside of one mile are greater or equal to the volumes of those homes located between one and three miles in two of the three post-announcement periods. Finally, it should be noted that the volumes for the inside one mile band, in the period immediately following construction, are less than those in the one to three mile band in the same period. Although not statistically significant, this difference might imply an initial slowing of sales activity that, in later periods, returns to more normal levels. This possibility is worth investigating further and is therefore recommended for future research.

Table 31: Equality Test of Volumes between DISTANCES using 3-5 Mile Reference

	Inside 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles
Less Than 3 Years Before Announcement	-0.1% (-0.09)	-0.5% (-0.88)	Reference
After Announcement Before Construction	-0.7% (-0.56)	-1.2% (-1.13)	Reference
Less Than 2 Years After Construction	-2.1% (-2.41) *	-1.2% (-1.48)	Reference
Between 2 and 4 Years After Construction	-1.4% (-1.27)	-1.4% (-1.82) *	Reference

Numbers in parenthesis represent t-Test statistics. "" = significantly different at or below the 10% level*

Table 32: Equality Test of Sales Volumes between DISTANCES using 1-3 Mile Reference

	Inside 1 Mile	Between 1 and 3 Miles	Between 3 and 5 Miles
Less Than 3 Years Before Announcement	0.4% (0.49)	Reference	0.5% (0.88)
After Announcement Before Construction	0.5% (0.47)	Reference	1.2% (1.13)
Less Than 2 Years After Construction	-0.9% (-1.38)	Reference	1.2% (1.48)
Between 2 and 4 Years After Construction	0% (0.01)	Reference	1.4% (1.82) *

Numbers in parenthesis represent t-Test statistics. "" = significantly different at or below the 10% level*

Taken together, these results suggest that sales volumes are not conclusively affected by the announcement and presence of the wind facilities analyzed in this report. At least among this sample, sales volumes increased in all distance bands after the announcement and construction of the wind facilities. If this result was driven by the presence of the wind facilities, however, one would expect that such impacts would be particularly severe for those homes in close proximity to wind facilities. In other words, sales volumes would be the most affected inside of one mile, where views of the turbines are more frequent and where other potential nuisances are more noticeable than in areas farther away. This is not borne out in the data - no statistically significant differences are found for sales volumes inside of one mile as compared to those between one and three miles, and sales volumes outside of three miles are higher still. Therefore, on the whole, this analysis is unable to find persuasive evidence that wind facilities have a widespread and identifiable impact on overall residential sales volumes. It is again concluded that neither Area nor Nuisance Stigma are in evidence in this analysis.

8. Wind Projects and Property Values: Summary of Key Results

This report has extensively investigated the potential impacts of wind power facilities on the value (i.e., sales prices) of residential properties that are in proximity to and/or that have a view of those wind facilities. In so doing, three different potential impacts of wind projects on property values have been identified and analyzed: Area Stigma, Scenic Vista Stigma, and Nuisance Stigma. To assess these potential impacts, a primary (Base) hedonic model has been applied, seven alternative hedonic models have been explored, a repeat sales analysis has been conducted, and possible impacts on sales volumes have been evaluated. Table 33 outlines the resulting ten tests conducted in this report, identifies which of the three potential stigmas those tests were designed to investigate, and summarizes the results of those investigations. This section synthesizes these key results, organized around the three potential stigmas.

Table 33: Impact of Wind Projects on Property Values: Summary of Key Results

	Is there statistical evidence of:			
Statistical Model	**Area Stigma?**	**Scenic Vista Stigma?**	**Nuisance Stigma?**	**Section Reference**
Base Model	No	No	No	*Section 4*
View Stability	Not tested	No	Not tested	*Section 5.1*
Distance Stability	No	Not tested	No	*Section 5.1*
Continuous Distance	No	No	No	*Section 5.2*
All Sales	No	No	Limited	*Section 5.3*
Temporal Aspects	No	No	No	*Section 5.4*
Orientation	No	No	No	*Section 5.5*
Overlap	No	Limited	No	*Section 5.6*
Repeat Sales	No	Limited	No	*Section 6*
Sales Volume	No	Not tested	No	*Section 7*

"No" .... *No statistical evidence of a negative impact*
"Yes" .... *Strong statistical evidence of a negative impact*
"Limited" .... *Limited and inconsistent statistical evidence of a negative impact*
"Not tested" .... *This model did not test for this stigma*

8.1. Area Stigma

Area Stigma is defined as a concern that the general area surrounding a wind energy facility will appear more developed, which may adversely affect home values in the local community regardless of whether any individual home has a view of the wind turbines. Though these impacts might be expected to be especially severe at close range to the turbines, the impacts could conceivably extend for a number of miles around a wind facility. Modern wind turbines are visible from well outside of five miles in many cases, so if an Area Stigma exists, it is possible that all of the homes in the study areas inside of five miles would be affected.

As summarized in Table 33, Area Stigma is investigated with the Base, Distance Stability, Continuous Distance, All Sales, Temporal Aspects, Orientation, and Overlap hedonic models. It is also tested, somewhat differently, with the Repeat Sales and Sales Volume analyses. In each case, if an Area Stigma exists, it is expected that the sales prices (and/or sales volume) of homes located near wind facilities would be broadly affected by the presence of those facilities, with effects decreasing with distance.

The Base Model finds little evidence of an Area Stigma, as the coefficients for the DISTANCE variables are all relatively small and none are statistically different from zero. For homes in this sample, at least, there is no statistical evidence from the Base Model that the distance from a home to the nearest wind turbine impacts sales prices, regardless of the distance band. Perhaps a more direct test of Area Stigma, however, comes from the Temporal Aspects Model. In this model, homes in all distance bands that sold after wind facility announcement are found to sell, on average, for prices that are not statistically different from those for homes that sold more than two years prior to wind facility announcement. Again, no persuasive evidence of an Area Stigma is evident.

The Repeat Sales and Sales Volume Models also investigate Area Stigma. The Repeat Sales Model's 354 homes, each of which sold once before facility announcement and again after construction, show average inflation-adjusted annual appreciation rates that are small and not statistically different from zero. If homes in all study areas were subject to an Area Stigma, one would expect a negative and statistically significant intercept term. Similarly, if homes in any individual study area experienced an Area Stigma, the fixed effect terms would be negative and statistically significant. Neither of these expectations is borne out in the results. The Sales Volume Model tells a similar story, finding that the rate of residential transactions is either not significantly different between the pre- and post-announcement periods, or is greater in later periods, implying, in concert with the other tests, that increased levels of transactions do not signify a rush to sell, and therefore lower prices, but rather an increase in the level of transactions with no appreciable difference in the value of those homes.

The All Sales, Distance Stability, Continuous Distance, Orientation, and Overlap Models corroborate these basic findings. In the All Sales and Distance Stability Models, for example, the DISTANCE coefficients for homes that sold outside of one mile but within five miles, compared to those that sold outside of five miles, are very similar: they differ by no more than 2%, and this small disparity is not statistically different from zero. The same basic findings resulted from the Orientation and Overlap Models. Further, homes with No View as estimated in the All Sales Model are found to appreciate in value, after adjusting for inflation, when compared to homes that sold before wind facility construction (0.02, p value 0.06); an Area Stigma effect should be reflected as a negative coefficient for this parameter. Finally, despite using all 4,937 cases in a single distance variable and therefore having a correspondingly small standard error, the Continuous Distance Model discovers no measurable relationship between distance from the nearest turbine and the value of residential properties.

Taken together, the results from these models are strikingly similar: there is no evidence of a widespread and statistically significant Area Stigma among the homes in this sample. Homes in these study areas are not, on average, demonstrably and measurably stigmatized by the arrival of a wind facility, regardless of when they sold in the wind project development process and regardless of whether those homes are located one mile or five miles away from the nearest wind facility.

Drawing from the previous literature on environmental disamenities discussed in Section 2.1, one likely explanation for this result is simply that any effects that might exist may have faded to a level indistinguishable from zero at distances outside of a mile from the wind facilities. For other disamenities, some of which would seemingly be more likely to raise concerns, effects have been found to fade quickly with distance. For example, property value effects near a chemical plant have been found to fade outside of two and a half miles (Carroll et al., 1996), near a lead smelter (Dale et al., 1999) and fossil fuel plants (Davis, 2008) outside of two miles, and near landfills and confined animal feeding operations outside of 2,400 feet and 1,600 feet, respectively (Ready and Abdalla, 2005). Further, homes outside of 300 feet (Hamilton and Schwann, 1995) or even as little as 150 feet (Des-Rosiers, 2002) from a high voltage transmission line have been found to be unaffected. A second possible explanation for these results could be related to the view of the turbines. In the sample used for this analysis, a large majority of the homes outside of one mile ($n = 4,812$) that sold after wind-facility construction commenced cannot see the turbines ($n = 4,189$, 87%), and a considerably larger portion have – at worst – a minor view of the turbines ($n = 4,712$, 98%). Others have found that the sales prices for homes situated at similar distances from a disamenity (e.g., HVTL) depend, in part, on the view of that disamenity (Des-Rosiers, 2002). Similarly, research has sometimes found that annoyance with a wind facility decreases when the turbines cannot be seen (Pedersen and Waye, 2004). Therefore, for the overwhelming majority of homes outside of a mile that have either a minor rated view or no view at all of the turbines, the turbines may simply be out of sight, and therefore, out of mind.

8.2. Scenic Vista Stigma

Scenic Vista Stigma is defined as concern that a home may be devalued because of the view of a wind energy facility, and the potential impact of that view on an otherwise scenic vista. It has as its basis an admission that home values are, to some degree, derived from the quality of what can be seen from the property and that if those vistas are altered, sales prices might be measurably affected. The Base, View Stability, Continuous Distance, All Sales, Temporal Aspects, Orientation, Overlap, and Repeat Sales Models each test whether Scenic Vista Stigma is present in the sample.

The Base Model, as well as subsequent Alternative Hedonic Models, demonstrates persuasively that the quality of the scenic vista – absent wind turbines – impacts sales prices. Specifically, compared to homes with an AVERAGE VISTA, those having a POOR or a BELOW AVERAGE rating are estimated to sell for 21% (p value 0.00) and 8% (p value 0.00) less, on average. Similarly, homes with an ABOVE AVERAGE or PREMIUM rating are estimated to sell for 10% (p value 0.00) and 13% (p value 0.00) more than homes with an AVERAGE vista rating. Along the same lines, homes in the sample with water frontage or situated on a cul-de-sac sell for 33% (p value 0.00) and 10% (p value 0.00) more, on average, than those homes that lack these characteristics. Taken together, these results demonstrate that home buyers and sellers consistently take into account what can be seen from the home when sales prices are established, and that the models presented in this report are able to clearly identify those impacts.[103]

[103] Of course, cul-de-sacs and water frontage bestow other benefits to the home owner beyond the quality of the scenic vista, such as safety and privacy in the case of a cul-de-sac, and recreational potential and privacy in the case of water frontage.

Despite this finding, those same hedonic models are unable to identify a consistent and statistically significant Scenic Vista Stigma associated with wind facilities. Home buyers and sellers, at least among this sample, do not appear to be affected in a measurable way by the visual presence of wind facilities. Regardless of which model was estimated, the value of homes with views of turbines that were rated MODERATE, SUBSTANTIAL, or EXTREME are found to be statistically indistinguishable from the prices of homes with no view of the turbines. Specifically, the 25 homes with EXTREME views in the sample, where the home site is "unmistakably dominated by the [visual] presence of the turbines," are not found to have measurably different property values, and neither are the 31 homes with a SUBSTANTIAL view, where "the turbines are dramatically visible from the home."[104] The same finding holds for the 106 homes that were rated as having MODERATE views of the wind turbines. Moreover, the Orientation and Overlap Models show that neither the orientation of the home with respect to the view of wind turbines, nor the overlap of that view with the prominent scenic vista, have measurable impacts on home prices.

The All Sales Model compares homes with views of the turbines (in the post-construction period) to homes that sold before construction (when no views were possible), and finds no statistical evidence of adverse effects within any VIEW category. Moreover, when a *t*-Test is performed to compare the NO VIEW coefficient to the others, none of the coefficients for the VIEW ratings are found to be statistically different from the NO VIEW homes. The Repeat Sales Model comes to a similar result, with homes with MODERATE views appreciating at a rate that was not measurably different from that of homes with no views (0.03, *p* value 0.29). The same model also finds that homes with SUBSTANTIAL/EXTREME views appreciate at a rate 2% slower per year (*p* value 0.09) than their NO VIEW peers. Homes situated inside of one mile, however, are found to appreciate at a rate 3% more (*p* value 0.01) than reference homes located outside of five miles. Eight of the nine homes situated inside of one mile had either a SUBSTANTIAL or EXTREME view. Therefore, to correctly interpret these results, one would add the two coefficients for these homes, resulting in a combined 1% increase in appreciation as compared to the reference homes situated outside of five miles with no view of turbines, and again yielding no evidence of a Scenic Vista Stigma.

Although these results are consistent across most of the models, there are some individual coefficients from some models that differ. Specifically, homes with MINOR rated views in the Overlap and Repeat Sales Models are estimated to sell for 3% less (*p* value 0.10) and appreciate at a rate 2% less (*p* value 0.02) than NO VIEW homes. Taken at face value, these MINOR VIEW findings imply that homes where "turbines are visible, but, either the scope is narrow, there are many obstructions, or the distance between the home and the facility is large" are systematically impacted in a modest but measurable way. Homes with more dramatic views of a wind facility in the same models, on the other hand, are found to not be measurably affected. Because of the counterintuitive nature of this result, and because it is contradicted in the results of other models presented earlier, it is more likely that there is some aspect of these homes that was not modeled appropriately in the Overlap and Repeat Sales Models, and that the analysis is picking up the effect of omitted variable(s) rather than a systematic causal effect from the wind facilities.

[104] See Section 3.2.3 and Appendix C for full description of VIEW ratings.

Taken together, the results from all of the models and all of the VIEW ratings support, to a large degree, the Base Model findings of no evidence of a Scenic Vista Stigma. Although there are 160 residential transactions in the sample with more dramatic views than MINOR, none of the model specifications is able to find any evidence that those views of wind turbines measurably impacted average sales prices, despite the fact that those same models consistently find that home buyers and sellers place value on the quality of the scenic vista.

8.3. Nuisance Stigma

Nuisance Stigma is defined as a concern that factors that may occur in close proximity to wind turbines, such as sound and shadow flicker, will have a unique adverse influence on home values. If these factors impact residential sales prices, those impacts are likely to be concentrated within a mile of the wind facilities. The Base, Distance Stability, Continuous Distance, All Sales, Temporal Aspects, Orientation, Overlap, Repeat Sales, and Sales Volume Models all investigate the possible presence of a Nuisance Stigma.

The Base Model finds that those homes within 3000 feet and those between 3000 feet and one mile of the nearest wind turbine sold for roughly 5% less than similar homes located more than five miles away, but that these differences are not statistically significant (*p* values of 0.40 and 0.30, respectively). These results remain unchanged in the Distance Stability Model, as well as in the Orientation and Overlap Models. Somewhat similarly, in the All Sales Model, when all transactions occurring after wind facility announcement are assumed to potentially be impacted (rather than just those occurring after construction, as in the Base Model), and a comparison is made to the average of all transactions occurring pre-announcement (rather than the average of all transactions outside of five miles, as in the Base Model), these same coefficients grow to -6% (*p* value 0.23) and -8% (*p* value 0.08) respectively. Although only one of these coefficients was statistically significant, they are large enough to warrant further scrutiny.

The Temporal Aspects Model provides a clearer picture of these findings. It finds that homes that sold prior to wind facility announcement and that were situated within one mile of where the turbines were eventually located sold, on average, for between 10% and 13% less than homes located more than five miles away and that sold in the same period. Therefore, the homes nearest the wind facility's eventual location were already depressed in value before the announcement of the facility. Most telling, however, is what occurred after construction. Homes inside of one mile are found to have inflation-adjusted sales prices that were either statistically undistinguishable from, or in some cases greater than, pre-announcement levels. Homes sold in the first two years after construction, for example, have higher prices (0.07, *p* value 0.32), as do those homes that sold between two and four years after construction (0.13, *p* value 0.06) and more than four years after construction (0.08, *p* value 0.24). In other words, there is no indication that these homes experienced a decrease in sales prices after wind facility construction began. Not only does this result fail to support the existence of a Nuisance Stigma, but it also indicates that the relatively large negative coefficients estimated in the Base and All Sales Models are likely caused by conditions that existed prior to wind facility construction and potentially prior to facility announcement.[105]

[105] See footnote 82 on page 46 for a discussion of possible alternative explanations to this scenario.

These results are corroborated by the Continuous Distance Model, which finds no statistically significant relationship between an inverse DISTANCE function and sales prices (-0.01, sig 0.46). Similarly, in the Repeat Sales Model, homes within one mile of the nearest turbine are not found to be adversely affected; somewhat counter-intuitively, they are found to appreciate faster (0.03, *p* value 0.01) than their peers outside of five miles. Finally, the Sales Volume analysis does not find significant and consistent results that would suggest that the ability to sell one's home within one mile of a wind facility is substantially impacted by the presence of that facility.

Taken together, these models present a consistent set of results: the sales prices of homes in this sample that are within a mile of wind turbines, where various nuisance effects have been posited, are not measurably affected compared to those homes that are located more than five miles away from the facilities or that sold well before the wind projects were announced. These results imply that widespread Nuisance Stigma effects are either not present in the sample, or are too small or sporadic to be statistically identifiable.

Though these results may appear counterintuitive, it may simply be that property value impacts fade rapidly with distance, and that few of the homes in the sample are close enough to the subject wind facilities to be substantially impacted. As discussed earlier, studies of the property value impacts of high voltage transmission lines often find that effects fade towards zero at as little distance as 200 feet (see, e.g., Gallimore and Jayne, 1999; Watson, 2005). None of the homes in the present sample are closer than 800 feet to the nearest wind turbine, and all but eight homes are located outside of 1000 feet of the nearest turbine. It is therefore possible that, if any effects do exist, they exist at very close range to the turbines, and that those effects are simply not noticeable outside of 800 feet. Additionally, almost half of the homes in the sample that are located within a mile of the nearest turbine have either no view or a minor rated view of the wind facilities, and some high voltage transmission line (HVTL) studies have found a decrease in adverse effects if the towers are <u>not</u> visible (Des-Rosiers, 2002) and, similarly, decreases in annoyance with wind facility sounds if turbines cannot be seen (Pedersen and Waye, 2004). Finally, effects that existed soon after the announcement or construction of the wind facilities might have faded over time. More than half of the homes in the sample sold more than three years after the commencement of construction, while studies of HVTLs have repeatedly found that effects fade over time (Kroll and Priestley, 1992) and studies of attitudes towards wind turbines have found that such attitudes often improve after facility construction (Wolsink, 1989). Regardless of the explanation, the fact remains that, in this sizable sample of residential transactions, no persuasive evidence of a widespread Nuisance Stigma is found, and if these impacts do exist, they are either too small or too infrequent to result in any widespread and consistent statistically observable impact.

9. Conclusions

Though surveys generally show that public acceptance towards wind energy is high, a variety of concerns with wind development are often expressed at the local level. One such concern that is often raised in local siting and permitting processes is related to the potential impact of wind projects on the property values of nearby residences.

This report has investigated the potential impacts of wind power facilities on the sales prices of residential properties that are in proximity to and/or that have a view of those wind facilities. It builds and improve on the previous literature that has investigated these potential effects by collecting a large quantity of residential transaction data from communities surrounding a wide variety of wind power facilities, spread across multiple parts of the U.S. Each of the homes included in this analysis was visited to clearly determine the degree to which the wind facility was visible at the time of home sale and to collect other essential data. To frame the analysis, three potentially distinct impacts of wind facilities on property values are considered: Area, Scenic Vista, and Nuisance Stigma. To assess these potential impacts, the authors applied a base hedonic model, explored seven alternative hedonic models, conducted a repeat sales analysis, and evaluated possible impacts on sales volumes. The result is the most comprehensive and data-rich analysis to date on the potential impacts of wind projects on nearby property values.

Although each of the analysis techniques used in this report has strengths and weaknesses, the results are strongly consistent in that each model fails to uncover conclusive evidence of the presence of any of the three property value stigmas. Based on the data and analysis presented in this report, no evidence is found that home prices surrounding wind facilities are consistently, measurably, and significantly affected by either the view of wind facilities or the distance of the home to those facilities. Although the analysis cannot dismiss the possibility that individual or small numbers of homes have been or could be negatively impacted, if these impacts do exist, they are either too small and/or too infrequent to result in any widespread and consistent statistically observable impact. Moreover, to the degree that homes in the present sample are similar to homes in other areas where wind development is occurring, the results herein are expected to be transferable.

Finally, although this work builds on the existing literature in a number of respects, there remain a number of areas for further research. The primary goal of subsequent research should be to concentrate on those homes located closest to wind facilities, where the least amount of data are available. Additional research of the nature reported in this paper could be pursued, but with a greater number of transactions, especially for homes particularly close to wind facilities. Further, it is conceivable that cumulative impacts might exist whereby communities that have seen repetitive development are affected uniquely, and these cumulative effects may be worth investigating. A more detailed analysis of sales volume impacts may also be fruitful, as would an assessment of the potential impact of wind facilities on the length of time homes are on the market in advance of an eventual sale. Finally, it would be useful to conduct a survey of those homeowners living close to existing wind facilities, and especially those residents who have bought and sold homes in proximity to wind facilities after facility construction, to assess their opinions on the impacts of wind project development on their home purchase and sales decisions.

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Appendix A: Study Area Descriptions

The analysis reported in the body of the report used data from ten different wind-project study areas, across nine different states and 14 counties, and surrounding 24 different wind facilities. Each of the study areas is unique, but as a group they provide a good representation of the range of wind facility sizes, hub heights, and locations of recent wind development activity in the U.S. (see Figure A - 1 and Table A - 1). This appendix describes each of the ten study areas, and provides the following information: a map of the study area; a description of the area; how the data were collected; statistics on home sales prices in the sample and census-reported home values for the towns, county, and state that encompass the area; data on the wind facilities contained within the study area; and frequency tables for the variables of interest (i.e., views of turbines, distance to nearest turbine ,and development period).

Figure A - 1: Map of Study Areas

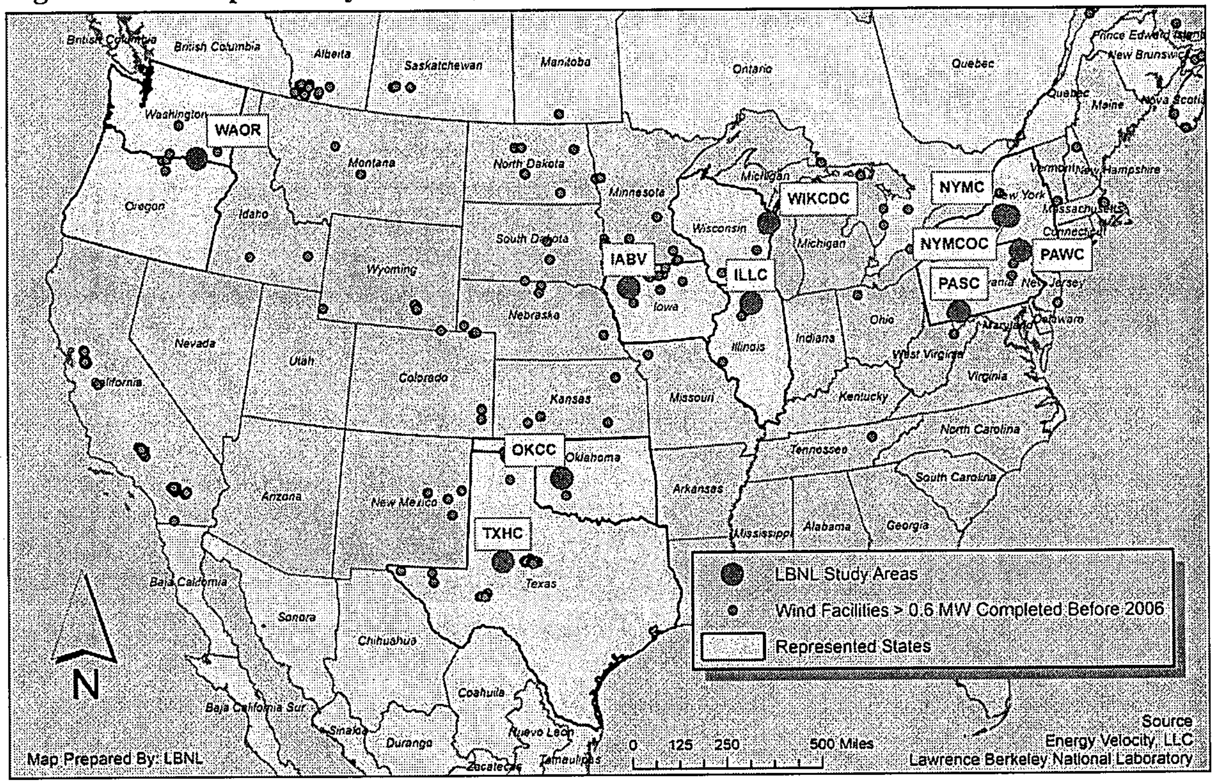
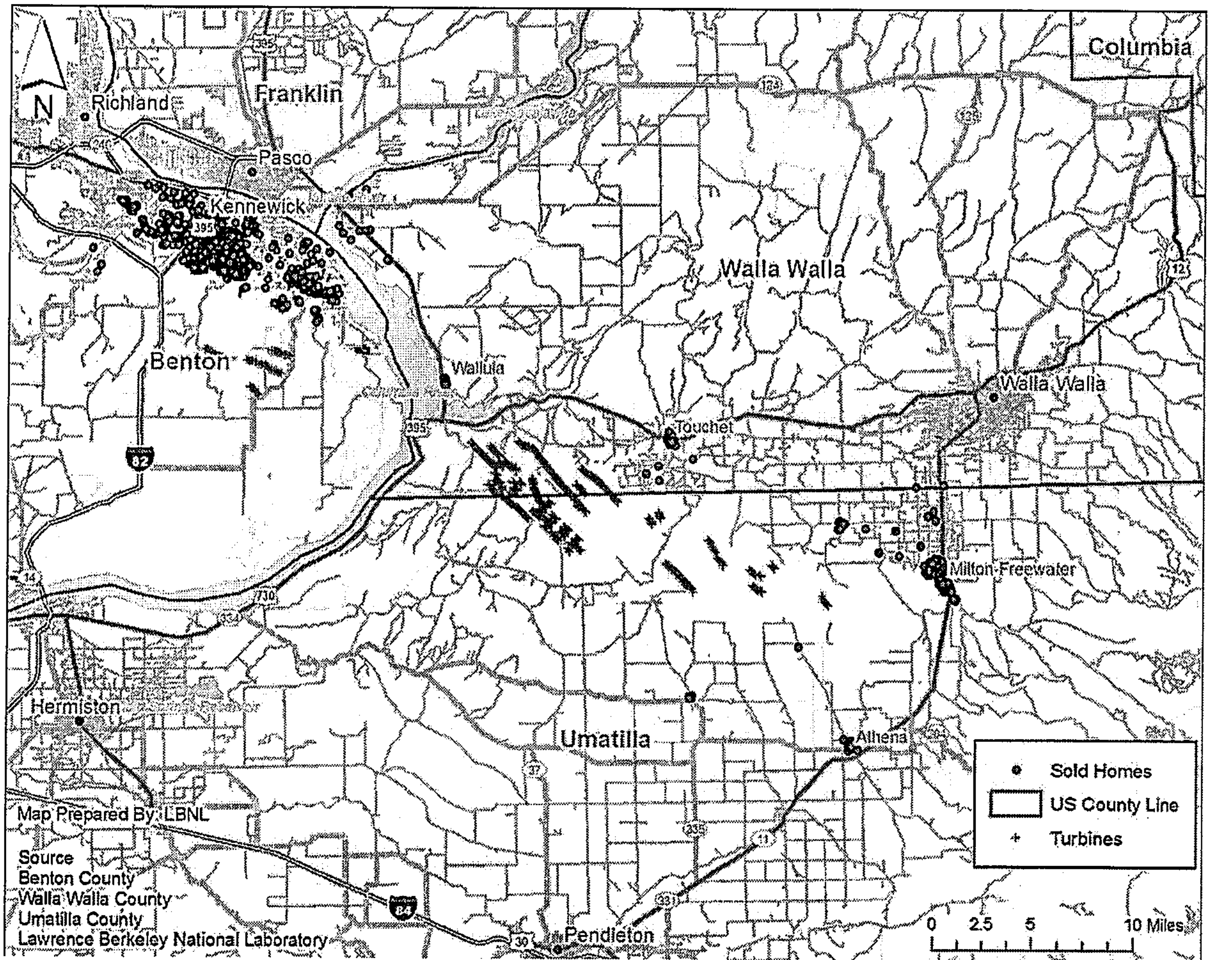


Table A - 1: Summary of Study Areas

Study Area Code	Study Area Counties, States	Facility Names	Number of Turbines	Number of MW	Max Hub Height (meters)	Max Hub Height (feet)
WAOR	Benton and Walla Walla Counties, WA and Umatilla County, OR	Vansycle Ridge, Stateline, Nine Canyon I & II, Combine Hills	582	429	60	197
TXHC	Howard County, TX	Big Spring I & II	46	34	80	262
OKCC	Custer County, OK	Weatherford I & II	98	147	80	262
IABV	Buena Vista County, IA	Storm Lake I & II, Waverly, Intrepid I & II	381	370	65	213
ILLC	Lee County, IL	Mendota Hills, GSG Wind	103	130	78	256
WIKCDC	Kewaunee and Door Counties, WI	Red River, Lincoln	31	20	65	213
PASC	Somerset County, PA	Green Mountain, Somerset, Meyersdale	34	49	80	262
PAWC	Wayne County, PA	Waymart	43	65	65	213
NYMCOC	Madison and Oneida Counties, NY	Madison	7	12	67	220
NYMC	Madison County, NY	Fenner	20	30	66	218
		TOTAL	1345	1286		

A.1 WAOR Study Area: Benton and Walla Walla Counties (Washington), and Umatilla County (Oregon)

Figure A - 2: Map of WAOR Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area combines data from the three counties - Benton and Walla Walla in Washington, and Umatilla in Oregon - that surround the Vansycle Ridge, Stateline, Combine Hills, and Nine Canyon wind projects. Wind development began in this area in 1997 and, within the sample of wind projects, continued through 2003. In total, the wind facilities in this study area include 582 turbines and 429 MW of nameplate capacity, with hub heights that range from 164 feet to almost 200 feet. The wind facilities are situated on an East-West ridge that straddles the Columbia River, as it briefly turns South. The area consists of undeveloped highland/plateau grassland, agricultural tracks for winter fruit, and three towns: Kennewick (Benton County), Milton-Freewater (Umatilla County), and Walla Walla (Walla Walla County). Only the first two of these towns are represented in the dataset because Walla Walla is situated more than 10 miles from the nearest wind turbine. Also in the area are Touchet and Wallula, WA, and Athena, OR, all very small communities with little to no services. Much of the area to the North and South of the ridge, and outside of the urban areas, is farmland, with homes situated on small parcels adjoining larger agricultural tracts.

Data Collection and Summary

Data for this study area were collected from a myriad of sources. For Benton County, sales and home characteristic data and GIS parcel shapefiles were collected with the assistance of county officials Eric Beswick, Harriet Mercer, and Florinda Paez, while state official Deb Mandeville (Washington Department of State) provided information on the validity of the sales. In Walla Walla County, county officials Bill Vollendorff and Tiffany Laposi provided sales, house characteristic, and GIS data. In Umatilla County, county officials Jason Nielsen, Tracie Diehl, and Tim McElrath provided sales, house characteristic, and GIS data.

Based on the data collection, more than 8,500 homes are found to have sold within ten miles of the wind turbines in this study area from January 1996 to June 2007. Completing field visits to this number of homes would have been overly burdensome; as a result, only a sample of these home sales was used for the study. Specifically, all valid sales within three miles of the nearest turbine are used, and a random sample of those homes outside of three miles but inside of five miles in Benton County and inside ten miles in Walla Walla and Umatilla Counties. This approach resulted in a total of 790 sales, with prices that ranged from $25,000 to $647,500, and a mean of $134,244. Of those 790 sales, 519 occurred after wind facility construction commenced, and 110 could see the turbines at the time of sale, though all but four of these homes had MINOR views. No homes within this sample were located within one mile of the nearest wind turbine, with the majority occurring outside of three miles.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
1/23/1996	6/29/2007	790	$ 125,803	$ 134,244	$ 25,000	$ 647,500

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Vansycle Ridge	25	38	Aug-97	Feb-98	Aug-98	Vestas	50
Stateline Wind Project, Phase I (OR)	83	126	Jun-00	Sep-01	Dec-01	Vestas	50
Stateline Wind Project, Phase I (WA)	177	268	Jun-00	Feb-01	Dec-01	Vestas	50
Stateline Wind Project, Phase II	40	60	Jan-02	Sep-02	Dec-02	Vestas	50
Nine Canyon Wind Farm	48	37	Jun-01	Mar-02	Sep-02	Bonus	60
Combine Hills Turbine Ranch I	41	41	Apr-02	Aug-03	Dec-03	Mitsubishi	55
Nine Canyon Wind Farm II	16	12	Jun-01	Jun-03	Dec-03	Bonus	60

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Benton/Walla Walla, WA & Umatilla, OR (WAOR)	226	45	76	59	384	790

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Benton/Walla Walla, WA & Umatilla, OR (WAOR)	271	409	106	4	0	0	790

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Benton/Walla Walla, WA & Umatilla, OR (WAOR)	271	0	0	20	277	222	790

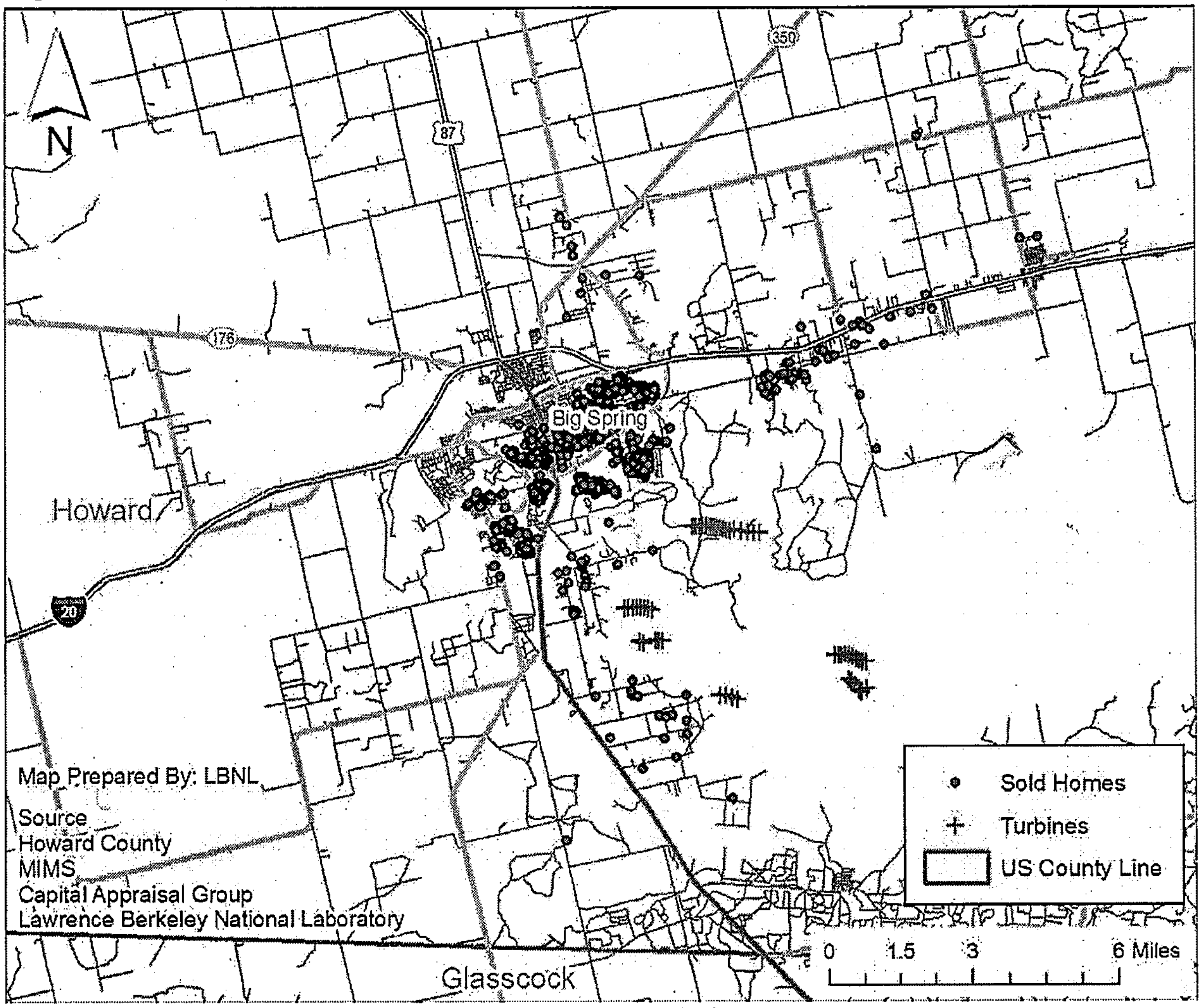
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Kennewich, WA	City	62,182	12.5%	2,711	32.3	$ 45,085	$ 155,531	46%
Walla Walla, WA	City	30,794	4.0%	2,847	33.8	$ 38,391	$ 185,706	91%
Milton Freewater, OR	Town	6,335	-2.0%	3,362	31.7	$ 30,229	$ 113,647	47%
Touchet, WA	Town	413	n/a	340	33.6	$ 47,268	$ 163,790	81%
Benton	County	159,414	3.6%	94	34.4	$ 51,464	$ 162,700	46%
Walla Walla	County	57,709	1.0%	45	34.9	$ 43,597	$ 206,631	89%
Umatilla	County	73,491	0.6%	23	34.6	$ 38,631	$ 138,200	47%
Washington	State	6,488,000	10.1%	89	35.3	$ 55,591	$ 300,800	79%
Oregon	State	3,747,455	9.5%	36	36.3	$ 48,730	$ 257,300	69%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

A.2 TXHC Study Area: Howard County (Texas)

Figure A - 3: Map of TXHC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area is entirely contained within Howard County, Texas, and includes the city of Big Spring, which is situated roughly 100 miles South of Lubbock and 275 miles West of Dallas in West Texas. On top of the Northern end of the Edwards Plateau, which runs from the Southeast to the Northwest, sits the 46 turbine (34 MW) Big Spring wind facility, which was constructed in 1998 and 1999. Most of the wind turbines in this project have a hub height of 213 feet, but four are taller, at 262 feet. The plateau and the wind facility overlook the city of Big Spring which, when including its suburbs, wraps around the plateau to the South and East. Surrounding the town are modest farming tracks and arid, undeveloped land. These lands, primarily to the South of the facility towards Forsan (not shown on map), are dotted with small oil rigs. Many of the homes in Big Spring do not have a view of the wind facility, but others to the South and East do have such views.

Data Collection and Summary

County officials Brett McKibben, Sally Munoz, and Sheri Proctor were extremely helpful in answering questions about the data required for this project, and the data were provided by two firms that manage it for the county. Specifically, Erin Welch of the Capital Appraisal Group provided the sales and house characteristic data and Paul Brandt of MIMS provided the GIS data.

All valid single-family home sales transactions within five miles of the nearest turbine and occurring between January 1996 and March 2007 were included in the dataset, resulting in 1,311 sales.[106] These sales ranged in price from $10,492 to $490,000, with a mean of $74,092. Because of the age of the wind facility, many of the sales in the sample occurred after wind facility construction had commenced (*n* = 1,071). Of those, 104 had views of the turbines, with 27 having views more dramatic than MINOR. Four homes sold within a mile of the facility, with the rest falling between one and three miles (*n* = 584), three to five miles (*n* = 467), and outside of five miles (*n* = 16).

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
1/2/1996	3/30/2007	1,311	$66,500	$74,092	$10,492	$490,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Big Spring I	27.7	42	Jan-98	Jul-98	Jun-99	Vestas	65
Big Spring II	6.6	4	Jan-98	Jul-98	Jun-99	Vestas	80

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Howard, TX (TXHC)	169	71	113	131	827	1311

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Howard, TX (TXHC)	240	967	77	22	5	0	1311

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Howard, TX (TXHC)	240	0	4	584	467	16	1311

[106] If parcels intersected the five mile boundary, they were included in the sample, but were coded as being outside of five miles.

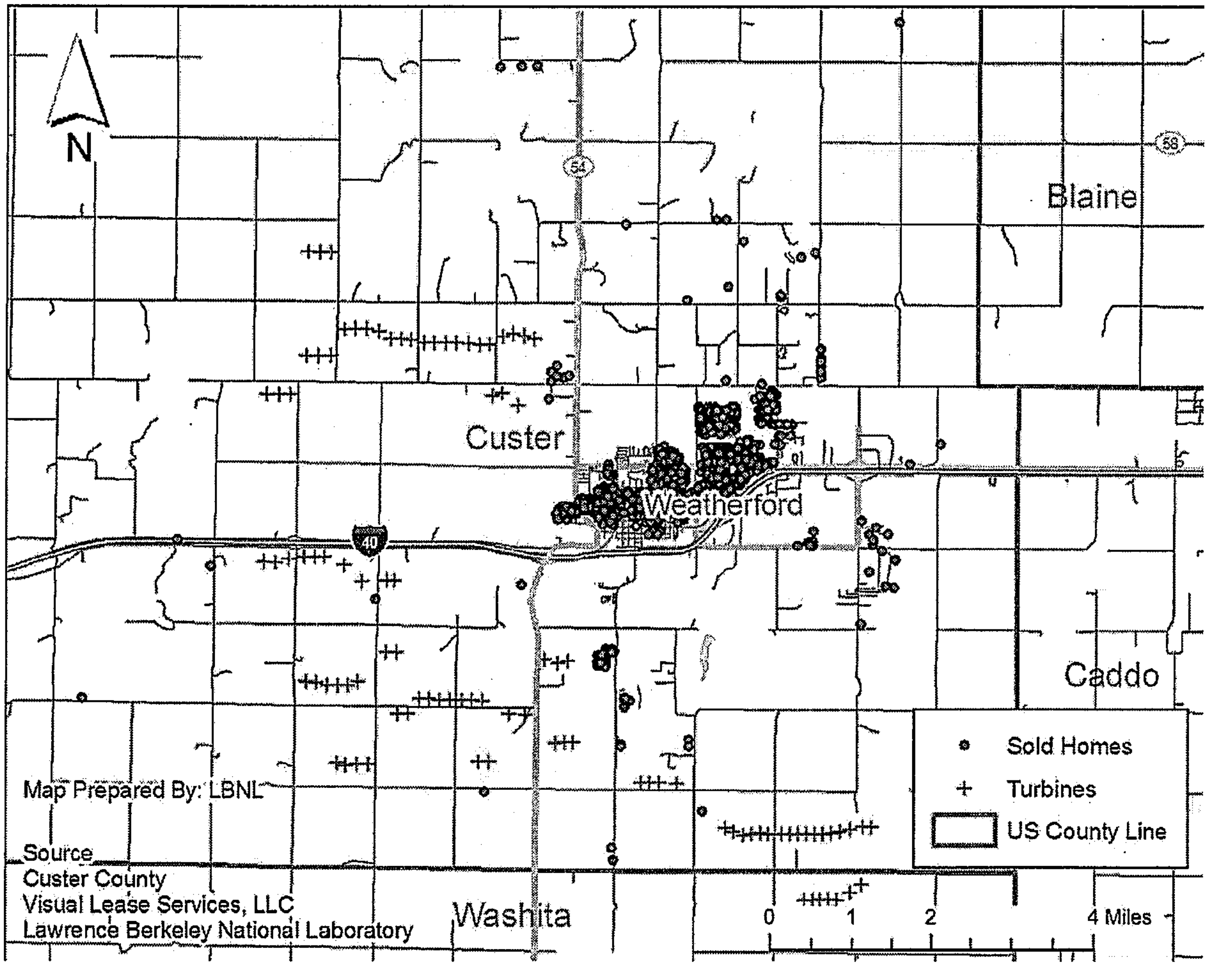
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Big Spring	City	24,075	-5.4%	1,260	35.1	$ 32,470	$ 54,442	50%
Forsan	Town	220	-4.0%	758	36.8	$ 50,219	$ 64,277	84%
Howard	County	32,295	-1.9%	36	36.4	$ 36,684	$ 60,658	58%
Texas	State	23,904,380	14.6%	80	32.3	$ 47,548	$ 120,900	47%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants.

A.3 OKCC Study Area: Custer County (Oklahoma)

Figure A - 4: Map of OKCC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area is entirely contained within Custer County, Texas, and includes the Weatherford wind facility, which is situated near the city of Weatherford, 70 miles due west of Oklahoma City and near the western edge of the state. The 98 turbine (147 MW) Weatherford wind facility straddles Highway 40, which runs East-West, and U.S. County Route 54, which runs North-South, creating an "L" shape that is more than six miles long and six miles wide. Development began in 2004, and was completed in two phases ending in 2006. The turbines are some of the largest in the sample, with a hub height of 262 feet. The topography of the study area is mostly flat plateau, allowing the turbines to be visible from many parts of the town and the surrounding rural lands. There are a number of smaller groupings of homes that are situated to the North and South of the city, many of which are extremely close to the turbines and have dramatic views of them.

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Data Collection and Summary

County Assessor Debbie Collins and mapping specialist Karen Owen were extremely helpful in gathering data and answering questions at the county level. Data were obtained directly from the county and from Visual Lease Services, Inc and OKAssessor, where representatives Chris Mask, Terry Wood, Tracy Leniger, and Heather Brown helped with the request.

All valid single-family residential transactions within five miles of the nearest wind turbine and occurring between July 1996 and June 2007 were included in the dataset, resulting in 1,113 sales.[107] These sales ranged in price from $11,000 to $468,000, with a mean of $100,445. Because of the relatively recent construction of the facility, 58% of the sales (n = 637) occurred before construction, leaving 476 sales with possible views of the turbines. Of those 476 sales, 25 had more-dramatic view ratings than MINOR and 17 sales occurred inside of one mile.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
7/7/1996	6/29/2007	1,113	$91,000	$100,445	$11,000	$468,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Weatherford Wind Energy Center	106.5	71	Mar-04	Dec-04	May-05	GE Wind	80
Weatherford Wind Energy Center Expansion	40.5	27	May-05	Oct-05	Jan-06	GE Wind	80

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Custer, OK (OKCC)	484	153	193	187	96	1113

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Custer, OK (OKCC)	637	375	76	6	7	12	1113

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Custer, OK (OKCC)	637	16	1	408	50	1	1113

[107] Portions of the town of Weatherford, both North and South of the town center, were not included in the sample due to lack of available data. The homes that were mapped, and for which electronic data were provided, however, were situated on all sides of these unmapped areas and were similar in character to those that were omitted. None of the unmapped homes were within a mile of the nearest wind turbine.

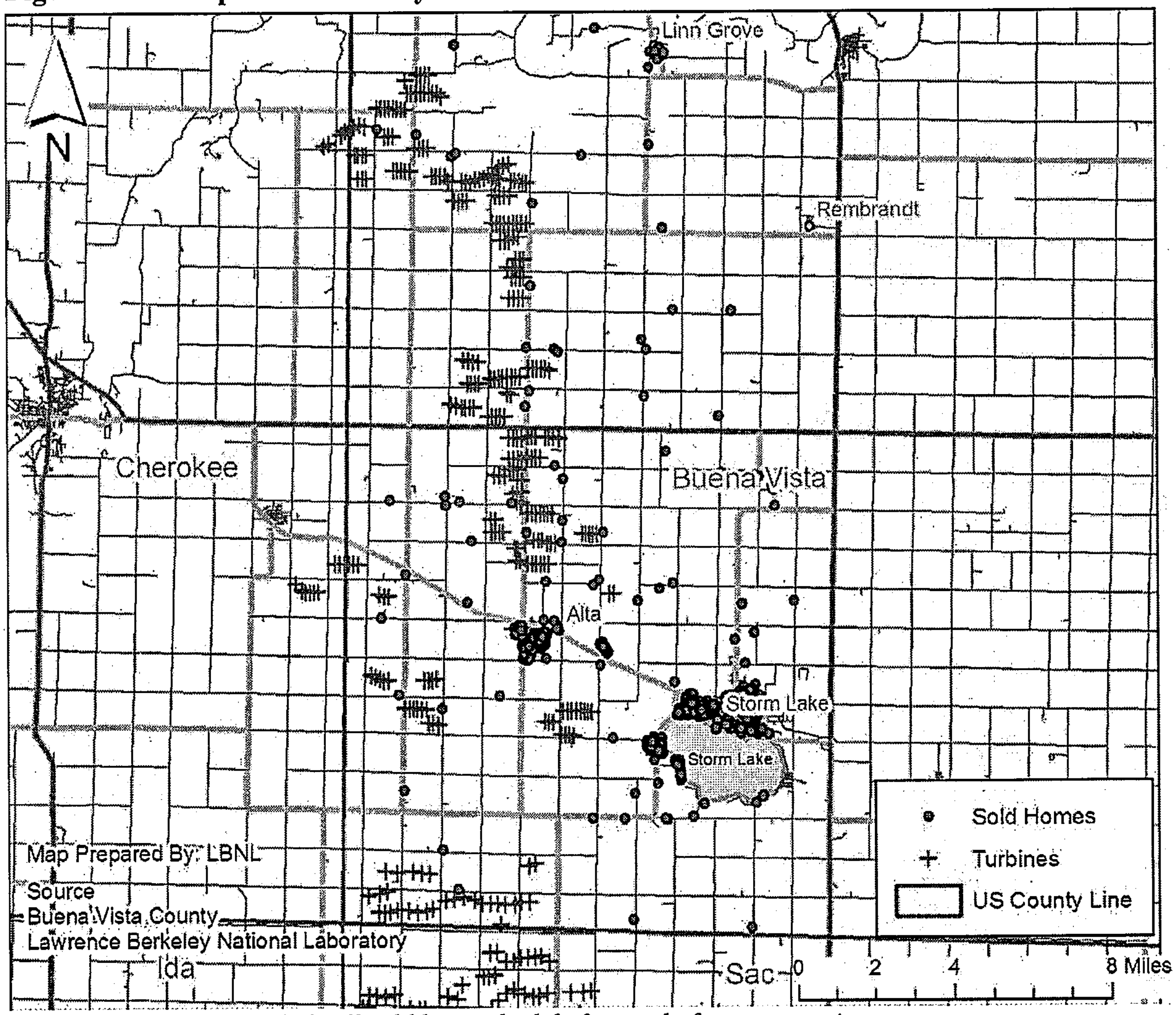
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Weatherford	City	10,097	1.2%	1,740	24.1	$ 32,543	$ 113,996	45%
Hydro	Town	1,013	-3.7%	1,675	39.2	$ 35,958	$ 66,365	68%
Custer	County	26,111	3.6%	26	32.7	$ 35,498	$ 98,949	52%
Oklahoma	State	3,617,316	4.8%	53	35.5	$ 41,567	$ 103,000	46%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants.

A.4 IABV Study Area: Buena Vista County (Iowa)

Figure A - 5: Map of IABV Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area includes the sizable Storm Lake and Intrepid wind facilities, which are mostly situated in Buena Vista County, located in Northwestern Iowa, 75 miles East of Sioux City. The facilities also stretch into Sac County to the South and Cherokee County to the West. The facilities total 381 turbines (370 MW) and are more than 30 miles long North to South and eight miles wide East to West. Development began on the first Storm Lake facility in 1998 and the last of the Intrepid development was completed in 2006. The largest turbines have a hub height of 213 feet at the hub, but most are slightly smaller at 207 feet. The majority of the homes in the sample surround Storm Lake (the body of water), but a large number of homes are situated on small residential plots located outside of the town and nearer to the wind facility. Additionally, a number of sales occurred in Alta - a small town to the East of Storm Lake -thatis straddled by the wind facilities and therefore provides dramatic views of the turbines. In general, except for the depression in which Storm Lake sits, the topography is very flat, largely made up corn fields, and the turbines are therefore visible from quite far away. The housing market is driven, to some extent, by the water body, Storm Lake, which is a popular recreational tourist destination, and therefore development is occurring to the East and South of the lake. Some development is also occurring, to a lesser degree, to the East of Alta.

Data Collection and Summary

County Assessor Kathy A. Croker and Deputy Assessor Kim Carnine were both extremely helpful in answering questions and providing GIS data. Sales and home characteristic data were provided by Vanguard Appraisals, Inc., facilitated by the county officials. David Healy from MidAmerican provided some of the necessary turbine location GIS files.

The county provided data on valid single-family residential transactions between 1996 and 2007 for 1,743 homes inside of five miles of the nearest wind turbine. This sample exceeded the number for which field data could reasonably be collected; as a result, only a sample of these homes sales was used for the study. Specifically, all transactions that occurred within three miles of the nearest turbine were used, in combination with a random sample (totaling roughly 10%) of those homes between three and five miles. This approach resulted in 822 sales, with prices that ranged from $12,000 to $525,000, and a mean of $94,713. Development of the wind facilities in this area occurred relatively early in the sample period, and therefore roughly 75% of the sales (*n* = 605) occurred after project construction had commenced. Of those 605 sales, 105 had views of the turbines, 37 of which were ranked with a view rating more dramatic than MINOR, and 30 sales occurred within one mile of the nearest wind turbine.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
1/2/1996	3/30/2007	822	$79,000	$94,713	$12,000	$525,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Storm Lake I	112.5	150	Feb-98	Oct-98	Jun-99	Enron	63
Storm Lake II	80.3	107	Feb-98	Oct-98	Apr-99	Enron	63
Waverly	1.5	2	Feb-98	Oct-98	Jun-99	Enron	65
Intrepid	160.5	107	Mar-03	Oct-04	Dec-04	GE Wind	65
Intrepid Expansion	15.0	15	Jan-05	Apr-05	Dec-05	Mitsubishi	65

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Buena Vista, IA (IABV)	152	65	80	70	455	822

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Buena Vista, IA (IABV)	217	500	68	18	8	11	822

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Buena Vista, IA (IABV)	217	22	8	472	101	2	822

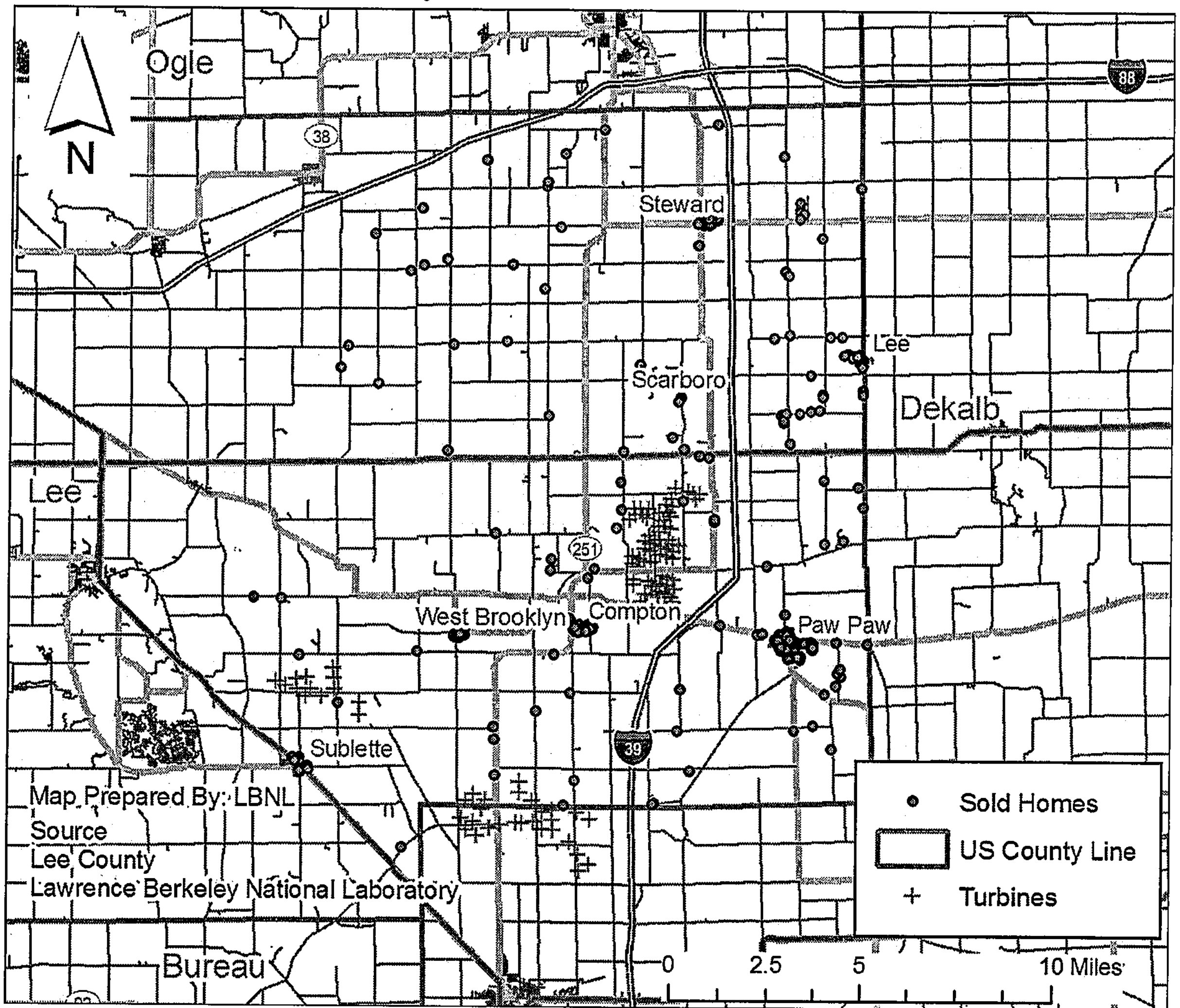
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Storm Lake	City	9,706	-3.9%	2,429	31.7	$ 39,937	$ 99,312	41%
Alta	Town	1,850	-1.0%	1,766	35.1	$ 40,939	$ 98,843	48%
Buena Vista	County	19,776	-3.1%	36	36.4	$ 42,296	$ 95,437	45%
Iowa	State	3,002,555	2.6%	52	36.6	$ 47,292	$ 117,900	43%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants.

A.5 ILLC Study Area: Lee County (Illinois)

Figure A - 6: Map of ILLC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area is situated roughly 80 miles due West of Chicago, in Lee County, Illinois, and includes two wind facilities. The 63 turbine (53 MW) Mendota Hills Wind Project sits just West of North-South Highway 39, and 10 miles South of East-West Highway 88. Development began on the facility in 2001 and was completed in 2003. The second facility, the 40 turbine (80 MW) GSG Wind Farm is South and West of the Mendota Hills facility, and is broken into two parts: roughly one third of the turbines are situated two miles due north of the small town of Sublette, with the remainder located roughly six miles to the southeast and spanning the line separating Lee from La Salle County. Development began on this project in the fall of 2006 and was completed in April of the following year. The town of Paw Paw, which is East of Highway 38 and both facilities, is the largest urban area in the study area, but is further away from the facilities than the towns of Compton, West Brooklyn, Scarboro, and Sublette. Also, to the North of the facilities are the towns of Lee, to the East of Highway 38, and Steward, just to the West. Although many home sales occurred in these towns, a significant number of additional sales occurred on small residential tracts in more-rural areas or in small developments. The topography of the area is largely flat, but falls away slightly to the East towards Paw Paw. The area enjoyed significant development during the real estate boom led by commuters from the Chicago metropolitan area, which was focused in the Paw Paw area but was also seen in semi-rural subdivisions to the Southwest and North of the wind facility.

Data Collection and Summary

County Supervisor Wendy Ryerson was enormously helpful in answering questions and providing data, as were Carmen Bollman and GIS Director, Brant Scheidecker, who also work in the county office. Wendy and Carmen facilitated the sales and home characteristic data request and Brant provided the GIS data. Additionally, real estate brokers Neva Grevengoed of LNG Realtor, Alisa Stewart of AC Corner Stone, and Beth Einsely of Einsely Real Estate were helpful in understanding the local market.

The county provided information on 412 valid single-family transactions that occurred between 1998 and 2007 within 10 miles of the nearest wind turbine, all of which were included in the sample.[108] These sales ranged in price from $14,500 to $554,148, with a mean of $128,301. Of those sales, 213 occurred after construction commenced on the wind facility and, of those, 36 had views of the turbines – nine of which were rated more dramatically than MINOR. Only two sales occurred within one mile of the nearest wind turbine.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
5/1/1998	3/2/2007	412	$113,250	$128,301	$14,500	$554,148

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Mendota Hills	50.4	63	Nov-01	Aug-03	Nov-03	Gamesa	65
GSG Wind Farm	80	40	Dec-05	Sep-06	Apr-07	Gamesa	78

Source: AWEA & Ventyx Inc.

[108] This county was not able to provide data electronically back to 1996, as would have been preferred, but because wind project development did not occur until 2001, there was ample time in the study period to establish pre-announcement sale price levels.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Lee, IL (ILLC)	115	84	62	71	80	412

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Lee, IL (ILLC)	199	177	27	7	1	1	412

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Lee, IL (ILLC)	199	1	1	85	69	57	412

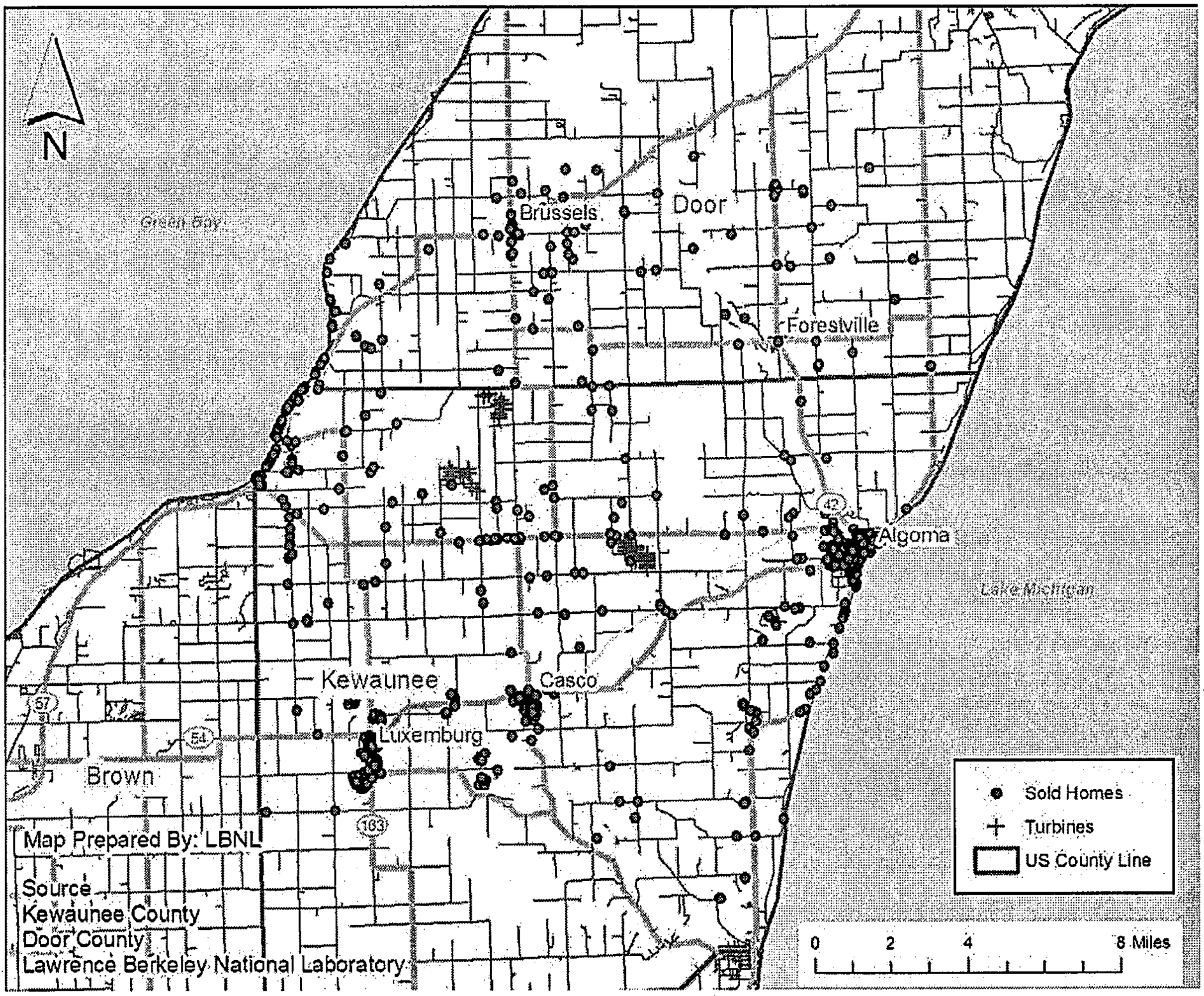
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Paw Paw	Town	884	2.6%	1,563	38.0	$ 48,399	$ 151,954	n/a
Compton	Town	337	-2.9%	2,032	32.8	$ 44,023	$ 114,374	n/a
Steward	Town	263	-3.0%	2,116	35.2	$ 59,361	$ 151,791	n/a
Sublette	Town	445	-2.4%	1,272	37.7	$ 55,910	$ 133,328	n/a
Lee	County	35,450	-1.7%	49	37.9	$ 47,591	$ 136,778	64%
Illinois	State	12,852,548	3.5%	223	34.7	$ 54,124	$ 208,800	60%
US	Country	301,139,947	7.0%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

A.6 WIKCDC Study Area: Kewaunee and Door Counties (Wisconsin)

Figure A - 7: Map of WIKCDC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area includes the Red River (17 turbines, 14 MW) and Lincoln (14 turbines, 9 MW) wind facilities. It is situated on the "thumb" jutting into Lake Michigan, Northeast of Green Bay, Wisconsin, and spans two counties, Kewaunee and Door. There is a mix of agricultural, small rural residential, waterfront, and urban land use in this area. The three largest towns are Algoma to the East of the facilities and on the lake, Casco, which is six miles due South of the turbines, and Luxemburg, four miles West of Casco. There is a smaller village, Brussels, to the North in Door County. The remainder of the homes is situated on the water or in small rural residential parcels between the towns. Topographically, the "thumb" is relatively flat except for a slight crown in the middle, and then drifting lower to the edges. The East edge of the "thumb" ends in bluffs over the water, and the western edge drops off more gradually, allowing those parcels to enjoy small beaches and easy boat access. There is some undulation of the land, occasionally allowing for relatively distant views of the wind turbines, which stand at a hub height of 213 feet.

Data Collection and Summary

Kewaunee and Door Counties did not have a countywide system of electronic data storage for either sales or home characteristic data. Therefore, in many cases, data had to be collected directly from the town or city assessor. In Kewaunee County, Joseph A. Jerabek of the town of Lincoln, Gary Taicher of the town of Red River, Melissa Daron of the towns of Casco, Pierce, and West Kewaunee, Michael Muelver of the town of Ahnapee and the city of Algoma, William Gerrits of the town of Casco, Joseph Griesbach Jr. of the town of Luxemburg, and David Dorschner of the city of Kewaunee all provided information. In Door County, Scott Tennessen of the town of Union and Gary Maccoux of the town of Brussels were similarly very helpful in providing information. Additionally, Andy Pelkey of Impact Consultants, Inc., John Holton of Associated Appraisal Consultants, Andy Bayliss of Dash Development Group, and Lue Van Asten of Action Appraisers & Consultants all assisted in extracting data from the myriad of storage systems used at the town and city level. The State of Wisconsin provided additional information on older sales and sales validity, with Mary Gawryleski, James Bender, and Patrick Strabala from the Wisconsin Department of Revenue being extremely helpful. GIS data were obtained from Steve Hanson from Kewaunee County and Tom Haight from Door County.

After collecting data from each municipality, a total of 810 valid single-family home sales transactions were available for analysis, ranging in time from 1996 to 2007. These sales ranged in price from $20,000 to $780,000, with a mean of $116,698. Because development of the wind facilities occurred relatively early in the study period, a large majority of the sales transactions, 75% (n = 725), occurred after project construction had commenced. Of those, 64 had views of the turbines, 14 of which had more dramatic than MINOR views, and 11 sales occurred within one mile.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
2/2/1996	6/30/2007	810	$98,000	$116,698	$20,000	$780,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Red River	11.2	17	Apr-98	Jan-99	Jun-99	Vestas	65
Lincoln	9.2	14	Aug-98	Jan-99	Jun-99	Vestas	65

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Kewaunee/Door, WI (WIKCDC)	44	41	68	62	595	810

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Kewaunee/Door, WI (WIKCDC)	85	661	50	9	2	3	810

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Kewaunee/Door, WI (WIKCDC)	85	7	4	63	213	438	810

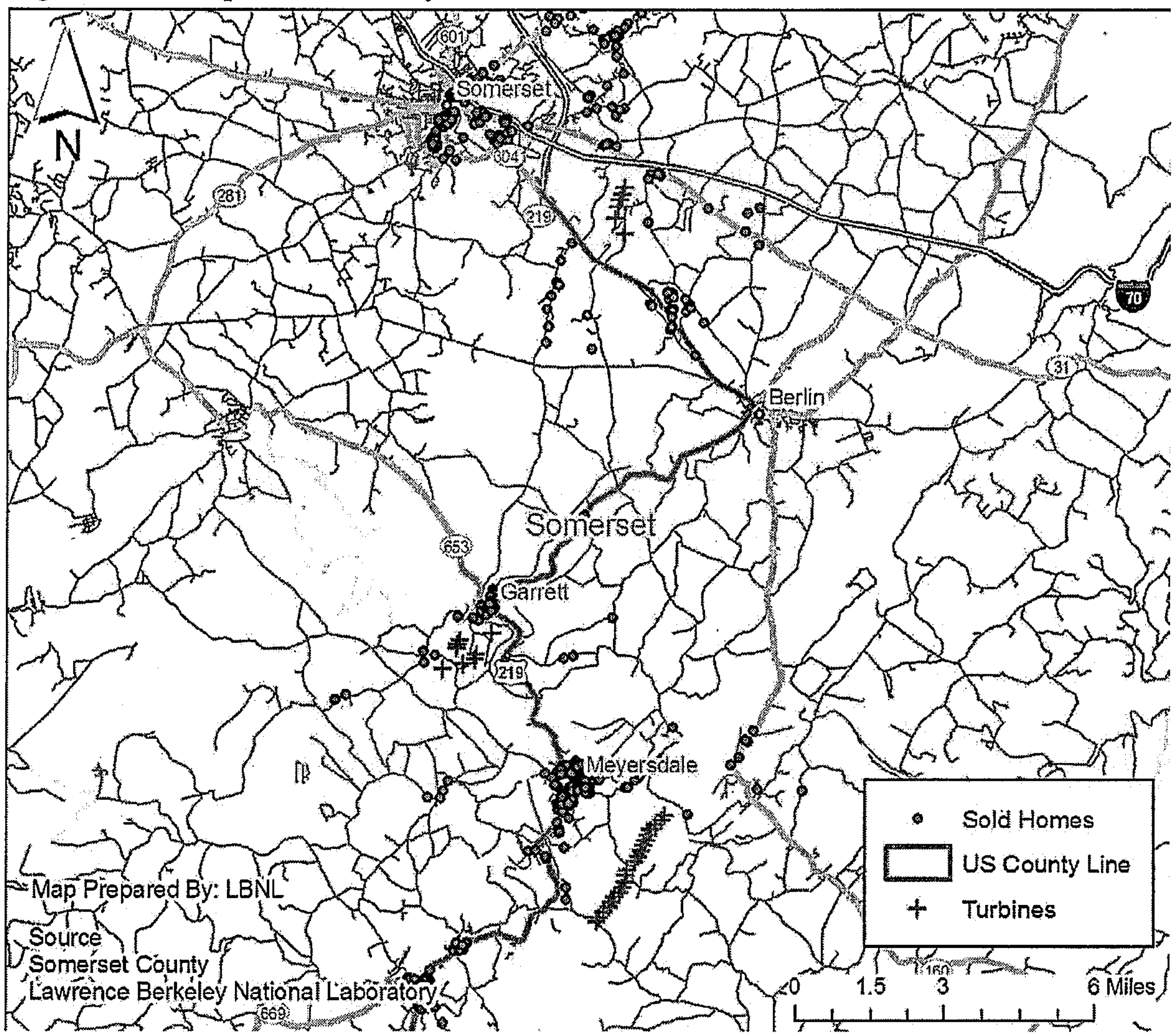
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Algoma	Town	3,186	-4.7%	1,305	41.8	$ 39,344	$ 112,295	51%
Casco	Town	551	-2.8%	985	35.6	$ 53,406	$ 141,281	n/a
Luxemburg	Town	2,224	15.3%	1,076	32.0	$ 53,906	$ 167,403	n/a
Kewaunee	County	20,533	1.4%	60	37.5	$ 50,616	$ 148,344	57%
Door	County	27,811	2.4%	58	42.9	$ 44,828	$ 193,540	57%
Wisconsin	State	5,601,640	0.3%	103	36.0	$ 50,578	$ 168,800	50%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

A.7 PASC Study Area: Somerset County (Pennsylvania)

Figure A - 8: Map of PASC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

<u>Area Description</u>

This study area includes three wind facilities, Somerset (6 turbines, 9 MW, 210 ft hub height) to the North, Meyersdale (20 turbines, 30 MW, 262 ft hub height) to the South, and Green Mountain (8 turbines, 10 MW, 197 ft hub height) between them. All of the projects are located in Somerset County, roughly 75 miles southeast of Pittsburg in the Southwest section of Pennsylvania. None of the three facilities are separated by more than 10 miles, so all were included in one study area. To the North of the facilities is East-West U.S. Highway 70, which flanks the city of Somerset. Connecting Somerset with points South is County Route 219, which zigzags Southeast out of Somerset to the smaller towns of Berlin (not included in the data), Garret to the Southwest, and Meyersdale, which is Southeast of Garret. These towns are flanked by two ridges that run from the Southwest to the Northeast. Because of these ridges and the relatively high elevations of all of the towns, this area enjoys winter recreation, though the coal industry, which once dominated the area, is still an integral part of the community with mining occurring in many places up and down the ridges. Although many of the home sales in the sample occurred in the towns, a number of the sales are for homes situated outside of town corresponding to either rural, rural residential, or suburban land uses.

Data Collection and Summary

The County Assessor, Jane Risso, was extremely helpful, and assisted in providing sales and home characteristic data. Glen Wagner, the IT director, worked with Gary Zigler, the county GIS specialist, to extract both GIS and assessment data from the county records. Both Gary and Jane were extremely helpful in fielding questions and providing additional information as needs arose.

The county provided a total of 742 valid residential single-family home sales transactions within four miles of the nearest wind turbine. All of the sales within three miles were used ($n = 296$), and a random sample (~ 44%) of those between three and four miles were used, yielding a total of 494 sales that occurred between May 1997 and March 2007. These sales ranged in price from $12,000 to $360,000, with a mean of $69,770. 291 sales (~ 60% of the 494) occurred after construction commenced on the nearest wind facility. Of these 291 sales, 73 have views of the turbines, 18 of which are more dramatic than MINOR, and 35 sales occurred within one mile.[109]

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
5/1/1997	3/1/2007	494	$62,000	$69,770	$12,000	$360,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
GreenMountain Wind Farm	10.4	8	Jun-99	Dec-99	May-00	Nordex	60
Somerset	9.0	6	Apr-01	Jun-01	Oct-01	Enron	64
Meyersdale	30.0	20	Jan-03	Sep-03	Dec-03	NEG Mico	80

Source: AWEA & Ventyx Inc.

[109] This study area was one of the earliest to have field work completed, and therefore the field data collection process was slower resulting in a lower number of transactions than many other study areas.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Somerset, PA (PASC)	175	28	46	60	185	494

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Somerset, PA (PASC)	203	218	55	15	2	1	494

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Somerset, PA (PASC)	203	17	18	132	124	0	494

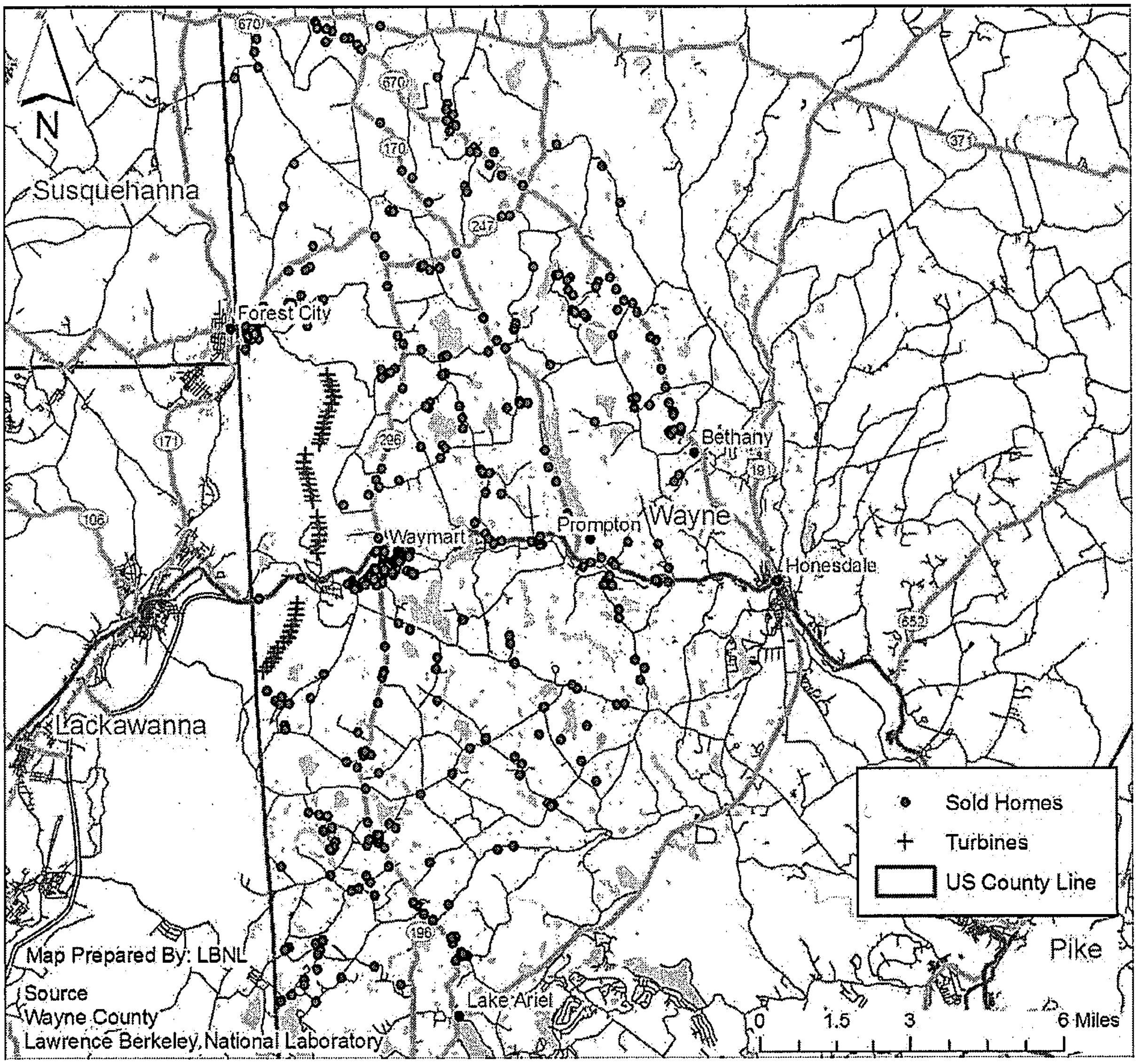
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Somerset	Town	6,398	-4.8%	2,333	40.2	$ 35,293	$ 123,175	n/a
Berlin	Town	2,092	-4.0%	2,310	41.1	$ 35,498	$ 101,704	n/a
Garrett	Town	425	-4.7%	574	34.5	$ 29,898	$ 54,525	n/a
Meyersdale	Town	2,296	-6.6%	2,739	40.9	$ 29,950	$ 79,386	n/a
Somerset Co	County	77,861	-2.7%	72	40.2	$ 35,293	$ 94,500	41%
Pennsylvania	State	12,440,621	1.3%	277	38.0	$ 48,576	$ 155,000	60%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

A.8 PAWC Study Area: Wayne County (Pennsylvania)

Figure A - 9: Map of PAWC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area includes the Waymart wind facility, which sits atop the North-South ridge running along the line separating Wayne County from Lackawanna and Susquehanna Counties in Northeast Pennsylvania. The 43 turbine (65 MW, 213 ft hub height) facility was erected in 2003, and can be seen from many locations in the study area and especially from the towns of Waymart, which sits East of the facility, and Forest City, which straddles Wayne and Susquehanna Counties North of the facility. The study area is dominated topographically by the ridgeline on which the wind turbines are located, but contains rolling hills and many streams, lakes, and natural ponds. Because of the undulating landscape, views of the wind facility can be maintained from long distances, while some homes relatively near the turbines have no view of the turbines whatsoever. The area enjoys a substantial amount of second home ownership because of the bucolic scenic vistas, the high frequency of lakes and ponds, and the proximity to larger metropolitan areas such as Scranton, roughly 25 miles to the Southwest, and Wilkes-Barre a further 15 miles Southwest.

Data Collection and Summary

John Nolan, the County Chief Assessor, was very helpful in overseeing the extraction of the data from county records. GIS specialist Aeron Lankford provided the GIS parcel data as well as other mapping layers, and Bruce Grandjean, the IT and Data Specialist, provided the sales and home characteristic data as well as fielding countless questions as they arose. Additionally, real estate brokers Dotti Korpics of Bethany, Kent Swartz of Re Max, and Tom Cush of Choice #1 Country Real Estate were instrumental providing context for understanding the local market.

The county provided data on 551 valid single-family transactions that occurred between 1996 and 2007, all of which were included in the sample. These sales ranged in price from $20,000 to $444,500, with a mean of $111,522. Because of the relatively recent development of the wind facility, only 40% (*n* = 222) of the sales transaction occurred after the construction of the facility had commenced. Of those sales, 43 (19%) had views of the turbines, ten of which had more dramatic than MINOR views, and 11 were situated within one mile.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
7/12/1996	9/25/2006	551	$96,000	$111,522	$20,000	$444,500

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Waymart Wind Farm	64.5	43	Feb-01	Jun-03	Oct-03	GE Wind	65

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Wayne, PA (PAWC)	223	106	64	71	87	551

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Wayne, PA (PAWC)	329	179	33	8	2	0	551

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Wayne, PA (PAWC)	329	1	10	95	55	61	551

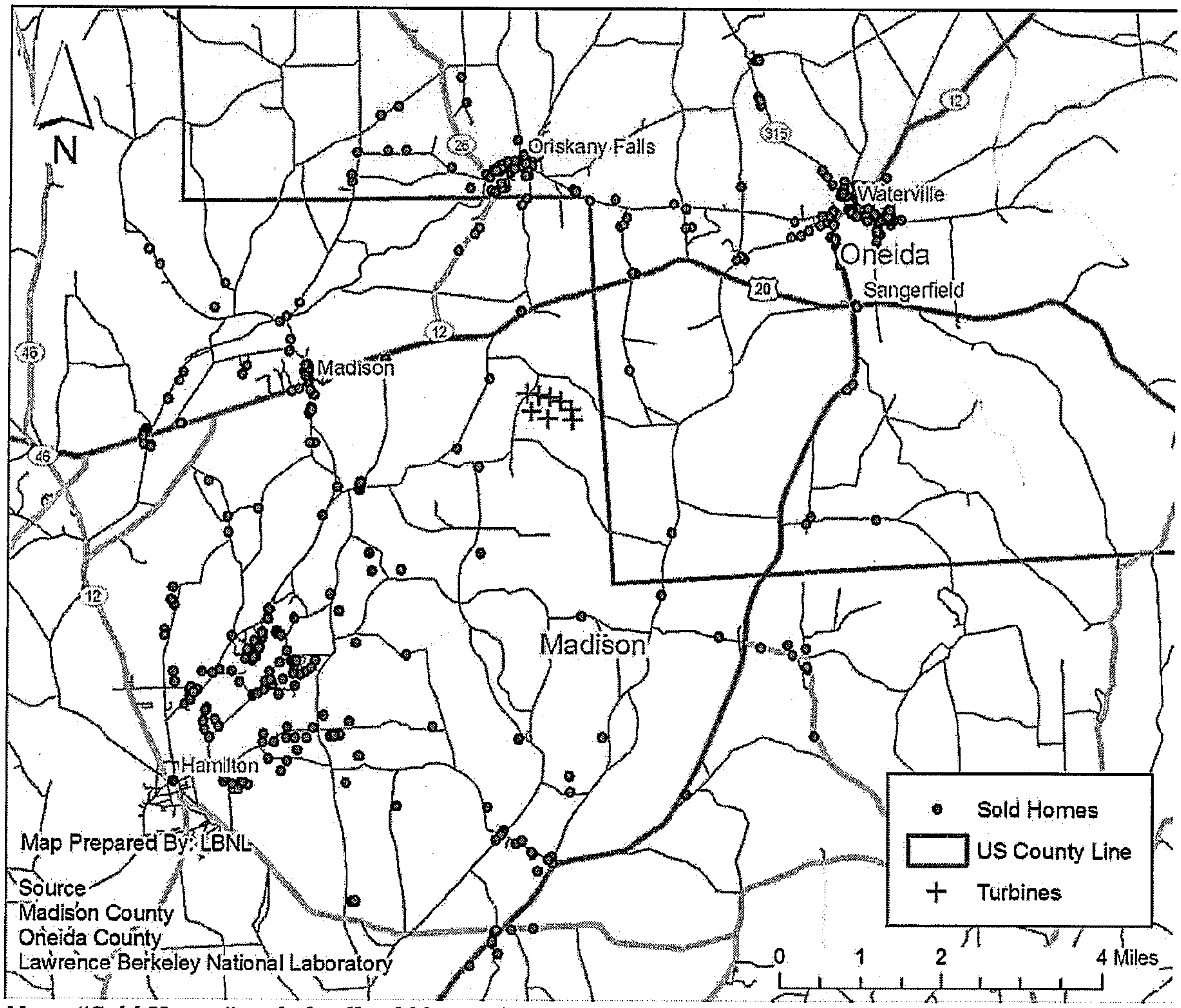
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Waymart	Town	3,075	116.0%	1,111	41.7	$ 43,797	$ 134,651	56%
Forest City	Town	1,743	-5.2%	1,929	45.6	$ 32,039	$ 98,937	67%
Prompton	Town	237	-1.6%	149	41.9	$ 30,322	$ 162,547	56%
Wayne	County	51,708	5.9%	71	40.8	$ 41,279	$ 163,060	57%
Lackawanna	County	209,330	-1.9%	456	40.3	$ 41,596	$ 134,400	48%
Pennsylvania	State	12,440,621	1.3%	277	38.0	$ 48,576	$ 155,000	60%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants.

A.9 NYMCOC Study Area: Madison and Oneida Counties (New York)

Figure A - 10: Map of NYMCOC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area surrounds the seven turbine (12 MW, 220 ft hub height) Madison wind facility, which sits atop an upland rise in Madison County, New York. The area is roughly 20 miles Southwest of Utica and 40 miles Southeast of Syracuse. The facility is flanked by the towns moving from the Southwest, clockwise around the rise, from Hamilton and Madison in Madison County, NY, to Oriskany Falls, Waterville, and Sangerfield in Oneida County, NY. Hamilton is the home of Colgate University, whose staff lives throughout the area around Hamilton and stretching up into the town of Madison. Accordingly, some development is occurring near the college. To the Northeast, in Oneida County, the housing market is more depressed and less development is apparent. The study area in total is a mix of residential, rural residential, and

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rural landscapes, with the largest portion being residential homes in the towns or immediately on their outskirts. The topography, although falling away from the location of the wind facility, does not do so dramatically, so small obstructions can obscure the views of the facility.

Data Collection and Summary

Data were obtained from both Madison and Oneida Counties for this study area. In Madison County, Kevin Orr, Mike Ellis, and Carol Brophy, all of County's Real Property Tax Services Department, were extremely helpful in obtaining the sales, home characteristic, and GIS data. In Oneida County, Jeff Quackenbush and Richard Reichert in the Planning Department were very helpful in obtaining the county data. Additionally, discussions with real estate brokers Susanne Martin of Martin Real Estate, Nancy Proctor of Prudential, and Joel Arsenault of Century 21 helped explain the housing market and the differences between Madison and Oneida Counties.

Data on 463 valid sales transactions of single family residential homes that occurred between 1996 and 2006 were obtained, all of which were located within seven miles of the wind facility. These sales ranged in price from $13,000 to $380,000, with a mean of $98,420. Roughly 75% ($n$ = 346) of these sales occurred after construction commenced on the wind facility, of which 20 could see the turbines, all of which were rated as having MINOR views, except one which had a MODERATE rating; only two sales involved homes that were situated inside of one mile.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
1/6/1996	12/26/2006	463	$77,500	$98,420	$13,000	$380,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Madison Windpower	11.6	7	Jan-00	May-00	Sep-00	Vestas	67

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Madison/Oneida, NY (MYMCOC)	108	9	48	30	268	463

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Madison/Oneida, NY (MYMCOC)	117	326	19	1	0	0	463

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Madison/Oneida, NY (MYMCOC)	117	1	1	80	193	71	463

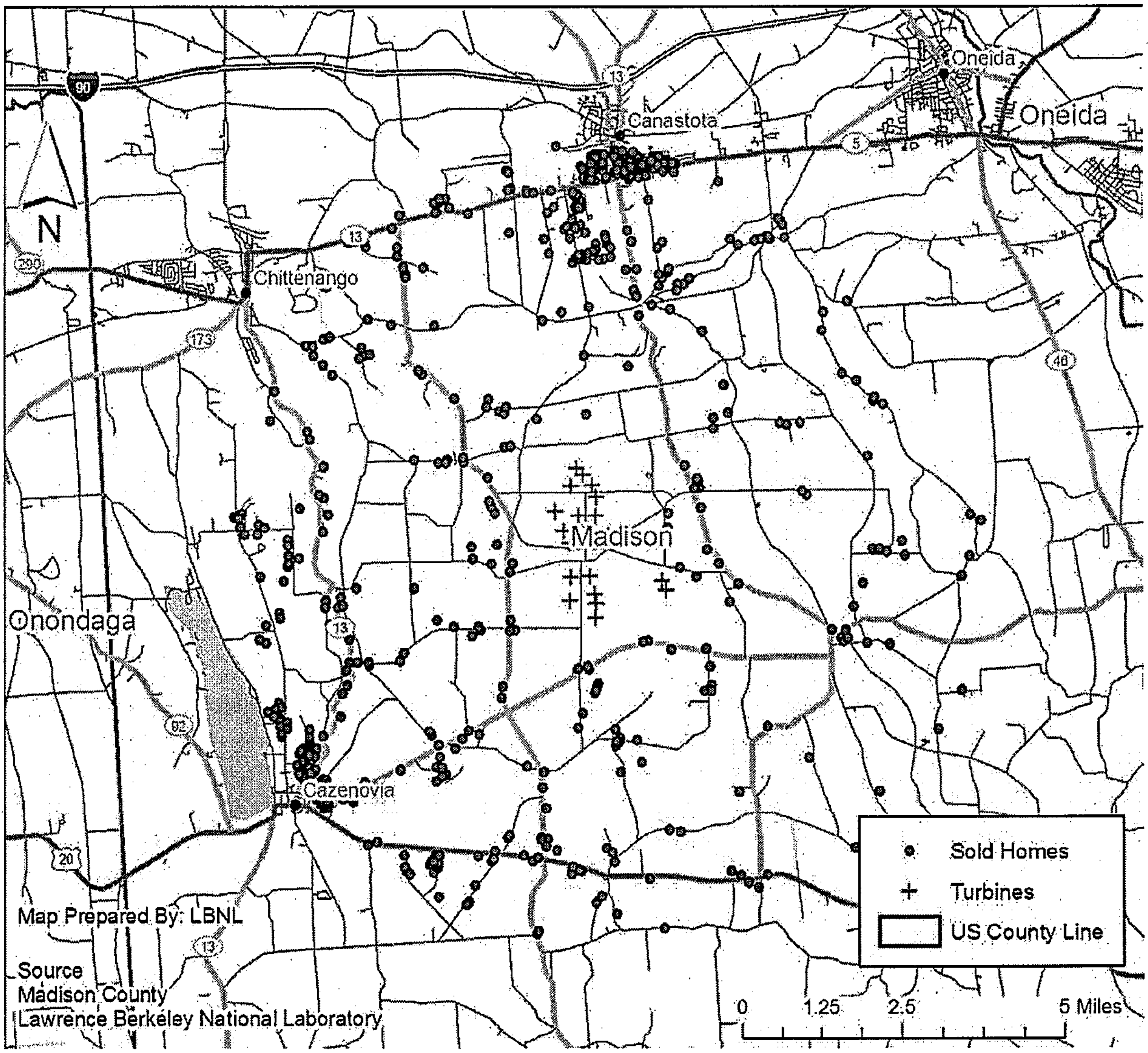
Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Madison	Town	304	-2.9%	605	38.1	$ 36,348	$ 94,734	n/a
Hamilton	Town	3,781	7.9%	1,608	20.8	$ 48,798	$ 144,872	n/a
Orinkany Fal	Town	1,413	-2.9%	1,703	40.8	$ 47,689	$ 105,934	n/a
Waterville	Town	1,735	-3.2%	1,308	37.8	$ 46,692	$ 104,816	n/a
Sangerfield	Town	2,626	-1.4%	85	37.6	$ 47,563	$ 106,213	n/a
Madison	County	69,829	0.6%	106	36.1	$ 53,600	$ 109,000	39%
Oneida	County	232,304	-1.3%	192	38.2	$ 44,636	$ 102,300	40%
New York	State	19,297,729	1.7%	408	35.9	$ 53,514	$ 311,000	109%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

A.10 NYMC Study Area: Madison County (New York)

Figure A - 11: Map of NYMC Study Area



Note: "Sold Homes" include all sold homes both before and after construction.

Area Description

This study area surrounds the 20 turbine (30 MW, 218 ft hub height) Fenner wind facility in Madison County, New York, roughly 20 miles East of Syracuse and 40 miles West of Utica in the middle of New York. The study area is dominated by two roughly parallel ridges. One, on which the Fenner facility is located, runs Southeast to Northwest and falls away towards the town of Canastota. The second ridge runs roughly North from Cazenovia, and falls away just South of the town of Chittenango. Surrounding these ridges is an undulating landscape with many water features, including the Chittenango Falls and Lake Cazenovia. A number of high-priced homes are situated along the ridge to the North of Cazenovia, some of which are afforded views of the lake and areas to the West, others with views to the East over the wind facility, and a few having significant panoramic views. The west side of the study area has a number of drivers to its real estate economy: it serves as a bedroom community for Syracuse, is the home to Cazenovia College, and enjoys a thriving summer recreational population. Canastota to the North, and Oneida to the East, are older industrial towns, both of which now serve as feeder communities for Syracuse because of easy access to Highway 90. Between the towns of Cazenovia and Canastota are many rural residential properties, some of which have been recently developed, but most of which are homes at least a half century old.

Data Collection and Summary

Data were obtained from the Madison County Real Property Tax Services department directed by Carol Brophy. As the first study area that was investigated, IT and mapping specialists Kevin Orr and Mike Ellis were subjected to a large number of questions from the study team and were enormously helpful in helping shape what became the blueprint for other study areas. Additionally, real estate brokers Nancy Proctor of Prudential, Joel Arsenault of Century 21, Don Kinsley of Kingsley Real Estate, and Steve Harris of Cazenovia Real Estate were extremely helpful in understanding the local market.

Data on 693 valid sales transactions of single family residential structures that occurred between 1996 and 2006 were obtained, most of which were within five miles of the wind facility. These sales ranged in price from $26,000 to $575,000, with a mean of $124,575. Roughly 68% of these sales (n = 469) occurred after construction commenced on the wind facility, 13 of which were inside of one mile, and 74 of which had views of the turbines. Of that latter group, 24 have more dramatic than MINOR views of the turbines.

Area Statistics

Study Period Begin	Study Period End	Number of Sales	Median Price	Mean Price	Minimum Price	Maximum Price
1/31/1996	9/29/2006	693	$109,900	$124,575	$26,000	$575,000

Facility Statistics

Facility Name	Number of MW	Number of Turbines	Announce Date	Construction Begin Date	Completion Date	Turbine Maker	Hub Height (Meters)
Fenner Wind Power Project	30	20	Dec-98	Mar-01	Nov-01	Enron	66

Source: AWEA & Ventyx Inc.

Variables of Interest Statistics

Development Period	Pre Announcement	Post Announcement Pre Construction	1st Year After Construction	2nd Year After Construction	2+ Years After Construction	Total
Madison, NY (NYMC)	59	165	74	70	325	693

View of Turbines	Pre Construction	None	Minor	Moderate	Substantial	Extreme	Total
Madison, NY (NYMC)	224	395	50	16	8	0	693

Distance to Nearest Turbine	Pre Construction	< 0.57 Miles	0.57 - 1 Miles	1 - 3 Miles	3 - 5 Miles	> 5 Miles	Total
Madison, NY (NYMC)	224	2	11	80	374	2	693

Census Statistics

Name	Type	2007 Population	% Change Since 2000	Population Per Mile^2	Median Age	Median Income	Median House 2007	% Change Since 2000
Cazenovia	Town	2,835	8.6%	1,801	32.3	$ 58,172	$ 159,553	n/a
Chittenango	Town	4,883	-0.5%	2,000	36.0	$ 58,358	$ 104,845	n/a
Canastota	Town	4,339	-1.7%	1,306	37.3	$ 45,559	$ 93,349	n/a
Oneida	City	10,791	-1.7%	490	36.9	$ 47,173	$ 99,305	n/a
Morrisville	Town	2,155	0.6%	1,869	20.4	$ 45,852	$ 102,352	n/a
Madison	County	69,829	0.6%	106	36.1	$ 53,600	$ 109,000	39%
New York	State	19,297,729	1.7%	408	35.9	$ 53,514	$ 311,000	109%
US	Country	301,139,947	6.8%	86	37.9	$ 50,233	$ 243,742	46%

Source: City-Data.com & Wikipedia. "% Change Since 2000" refers to the percentage change between 2000 and 2007 for the figures in the column to the left (population or median house price). "Town" signifies any municipality with less than 10,000 inhabitants. "n/a" signifies data not available.

Appendix B: Methodology for Calculating Distances with GIS

For each of the homes in the dataset, accurate measurements of the distance to the nearest wind turbine at the time of sale were needed, and therefore the exact locations of both the turbines and the homes was required. Neither of these locations was available from a single source, but through a combination of techniques, turbine and home locations were derived. This section describes the data and techniques used to establish accurate turbine and home locations, and the process for then calculating distances between the two.

There were a number of possible starting points for mapping accurate wind turbine locations. First, the Energy Velocity data, which covered all study areas, provided a point estimate for project location, but did not provide individual turbine locations. The Federal Aviation Administration (FAA), because of permitting and aviation maps, maintains data on turbine locations, but at the time of this study, that data source did not cover all locations, contained data on structures that no longer exist, and was difficult to use.[110] Finally, in some cases, the counties had mapped the wind turbines into GIS.

In the end, because no single dataset was readily available to serve all study areas, instead the variety of data sources described above was used to map and/or confirm the location of every turbine in the 10 study areas. The process began with high-resolution geocoded satellite and aerial ortho imagery that the United States Department of Agriculture (USDA) collects and maintains under its National Agriculture Imagery Program (NAIP), and which covers virtually all of the areas in this investigation. Where needed, older ortho imagery from the USDA was used. Combining these data with the Energy Velocity data, and discussions with local officials, and maps provided by the county or the developer, locating and mapping all of the turbines in each study area was possible.

Home locations were provided directly by some counties; in other cases, a parcel centroid was created as a proxy.[111] In some situations, the centroid did not correspond to the actual house location, and therefore required further refinement. This refinement was only required and conducted if the parcel was near the wind turbines, where the difference of a few hundred feet, for example, could alter its distance rating in a meaningful fashion, or when the parcel included a considerable amount of acreage, where inaccuracy in home location could be considerable. Therefore, parcels inside of 1.5 miles of the nearest wind turbine and of any size, and parcels outside of 1.5 miles and larger than 5 acres, were both examined using the USDA NAIP imagery to determine the exact home location. In cases where the parcel centroid was not centered over the home, the location was adjusted, using the ortho image as a guide, to the actual house location.

With both turbine and home locations identified, the next step was to determine distances between the two. To do so, the date when each transaction in the sample occurred was taken into

[110] A newer FAA database is now available that clears up many of these earlier concerns.

[111] A "parcel centroid" is the mathematical center point of a polygon, and was determined by XTools Pro (www.xtoolspro.com).

account, combined with the determination of which turbines were in existence at what time.[112] This required breaking the transactions in the sample into three categories: 1) those occurring before any wind facility was announced in the study area, 2) those occurring after the first wind facility was announced in the area but before all development was complete in the area, and 3) those occurring after all wind development in the area was complete. Any sale that occurred before wind development was announced in the study area was coded with a distance to the nearest turbine derived from the actual turbine locations after all wind development had occurred.[113] Homes that sold after all wind development had occurred were treated similarly, with distances derived from the set of turbines in place after all development had taken place. The final set of homes - those that sold after announcement of the first facility, but before the construction of the last - had to be treated, essentially, on a case by case basis. Some homes were located within five miles of one wind facility but more than five miles from another wind facility in the same study area (e.g., many homes in PASC). In this case the distance to that closer facility could be applied in a similar fashion as would be the case if only one facility was erected (e.g., NYMC or PAWC). Another group of homes, those that sold during the development of the first facility in the study area, were given the distance to that facility, regardless of distance to the other facilities in the study area. The final and most complicated group of homes consisted of those that were within five miles of multiple wind facilities, and that sold after the first facility had been erected. In those cases, the exact configuration of turbines was determined for each stage of the development process. In study areas with multiple facilities that were developed over multiple periods, there might be as many as six possible configurations (e.g., IABV). In this final scenario, the distance to the closest turbine was used, assuming it had been "announced" at the time of sale.

Once the above process was complete, the mechanics of calculating distances from the turbines to the homes was straightforward. After establishing the location of a set of turbines, for instance those constructed in the first development in the area, a euclidian distance raster was derived that encompassed every home in the study area.[114] The calculations were made using a 50-foot resolution state-plane projection and North American Datum from 1983 (NAD83). As discussed above, similar rasters were created for each period in the development cycle for each study area, depending on the turbine configuration at that time. Ultimately, a home's sale date was matched to the appropriate raster, and the underlying distance was extracted. Taking everything into account discussed above, it is expected that these measurements are accurate to

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[112] It is recognized that the formal date of sale will follow the date at which pricing decisions were made. It is also recognized, as mentioned in Section 3, that wind facility announcement and construction dates are likely to be preceded by "under the radar" discussions in the community. Taken together, these two factors might have the effect, in the model, of creating some apparent lag in when effects are shown, compared to the earlier period in which effects may begin to occur. For this to bias the results, however, effects would have to disappear or dramatically lesson with time (e.g., less than one year after construction) such that the effects would not be uncovered with the models in later periods. Based on evidence from other potentially analogous infrastructure (e.g., HVTL), any fading of effects would likely occur over many years, so it is assumed that any bias is likely minimal.

[113] These distances were used to compare homes sold, for instance, within 1 mile of where the turbines were eventually erected with similar homes sold after the turbines were erected (see, for example, the Temporal Aspects Model).

[114] A "Raster" is a grid of, in this case, 50 feet by 50 feet squares, each of which contains a number representing the number of feet from the center of the square to the nearest turbine.

within roughly 150 feet inside of 1.5 miles and within a maximum of roughly 1150 feet outside of 1.5 miles.[115]

[115] The resolution of the raster is 50 feet, so the hypotenuse is 70 feet. If the home is situated in the top left of a raster cell and the turbine is situated in the bottom right of a diagonally adjacent cell, they could be separated by as much as 140 feet, yet the raster distance would only be 50 feet, a difference of 90 feet. Moreover, the resolution of the Ortho image is 40 feet so that location could additionally be off by another 55 feet along the diagonal. These two uncertainties total to roughly 150 feet for homes inside of 1.5 miles. Outside of 1.5 miles the variation between centroid and house location for parcels smaller than 5 acres could be larger still. If a 4.9 acre parcel had a highly irregular rectangular shape of 102 by 2100 feet, for instance, the centroid could be as much as 1050 feet from the property line. If the home was situated 50 feet from the property line then the actual house location could be off by as much as 1000 feet. Adding this to the 150 feet from above leads to a total discrepancy of 1150 feet (0.22 miles) for homes outside of 1.5 miles on parcels smaller than 5 acres. Of course, these extreme scenarios are highly unlikely to be prevalent.

Appendix C: Field Data Collection Instrument

Figure A - 12: Field Data Collection Instrument

House # (Control/ Key #)			County		
House Address					
Home Characteristics			**House Photo Number(s)**		
Cul-De-Sac?	No(0) / Yes(1)		Waterfront?		No(0) / Yes(1)
Scenic Vista Characteristics			**Vista Photo Numbers**		
Overall Quality of Scenic Vista: Poor (1), Below Average (2), Average (3), Above Average (4), Premium (5)					
View of Turbines Characteristics			**View Photo Numbers**		
Total # of Turbines visible			Orientation of Home to View: See Below		
# of Turbines- blade tips only visible			Side (S), Front (F), Back (B), Angled (A)		
# of Turbines- nacelle/hub visible					
# of Turbines- tower visible			View Scope: Narrow(1), Medium(2), Wide(3)		
The Degree to which the View of Turbines Dominate the Site? Non-Existent (0), Minor (1), Moderate (2), Substantial (3), Extreme (4)					
Degree to which the Turbines Overlap the Prominent Scenic Vista? Not at all (0), Barely (1), Somewhat (2), Strongly (3), Entirely (4)					
Notes:					

Figure A - 13: Field Data Collection Instrument - Instructions - Page 1

Home Characteristics

Cul-De-Sac? No(0)/Yes(1)	Is the home situated on a cul-de-sac?
Waterfront? No(0)/Yes(1)	Is the home situated on the waterfront?

"Vista" Characteristics

Overall Quality of Scenic Vista: Poor (1)	This rating is reserved for vistas of unmistakably poor quality. These vistas are often dominated by visually discordant man-made alterations (not considering turbines), or are uncomfortable spaces for people, lack interest, or have virtually no recreational potential.
Overall Quality of Scenic Vista: Below Average (2)	The home's vista is of the below average quality. These vistas contain visually discordant man-made alterations (not considering turbines) but are not dominated by them. They are not inviting spaces for people, but are not uncomfortable. They have little interest, mystery and have minor recreational potential.
Overall Quality of Scenic Vista: Average (3)	The home's vista is of the average quality. These vistas include interesting views which can be enjoyed often only a narrow scope. These vistas may contain some visually discordant man-made alterations (not considering turbines), are moderately comfortable spaces for people, have some interest, and have minor recreational potential.
Overall Quality of Scenic Vista: Above Average (4)	The vista from the home is of above average quality. These vistas include interesting views which often can be enjoyed in a medium to wide scope. They might contain some man made alterations (not considering turbines), yet still possess significant interest and mystery, are moderately balanced and have some potential for recreation.
Overall Quality of Scenic Vista: Premium (5)	This rating is reserved for vistas of unmistakably premium quality. These vistas would include "picture post card" views which can be enjoyed in a wide scope. They are often free or largely free of any discordant man made alterations (not considering turbines), possess significant interest, memorable qualities, mystery and are well balanced and likely have a high potential for recreation.
Degree Turbines Overlap Prominent Vista? Not at all (0))	The vista does not contain any view of the turbines.
Degree Turbines Overlap Prominent Vista? Barely (1)	A small portion (~ 0 - 20%) of the vista is overlapped by the view of turbines therefore the vista might contain a view of a few turbines, only a few of which can be seen entirely (from below the sweep of the blades to the top of their tips).
Degree Turbines Overlap Prominent Vista? Somewhat (2)	A moderate portion (~20-50%) of the vista contains turbines, and likely contains a view of more than one turbine, some of which are likely to be seen entirely (from below the sweep of the blades to the top of their tips).
Degree Turbines Overlap Prominent Vista? Strongly (3)	A large portion (~50-80%) of the vista contains a view of turbines, many of which likely can be seen entirely (from below the sweep of the blades to the top of their tips).
Degree Turbines Overlap Prominent Vista? Entirely (4)	This rating is reserved for situations where the turbines overlap virtually the entire (~80-100%) vista from the home. The vista likely contains a view of many turbines, virtually all of which can be seen entirely (from below the sweep of the blades to the top of their tips).

Figure A - 14: Field Data Collection Instrument - Instructions - Page 2

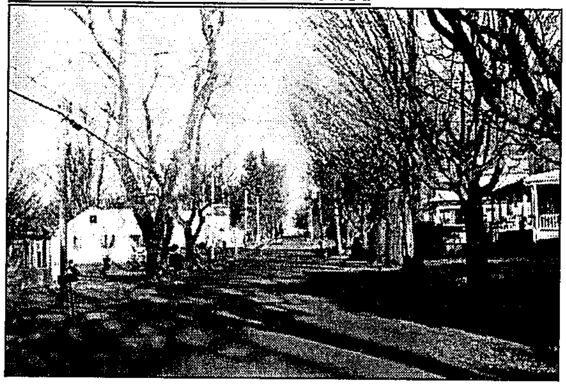
View of Turbines Characterist

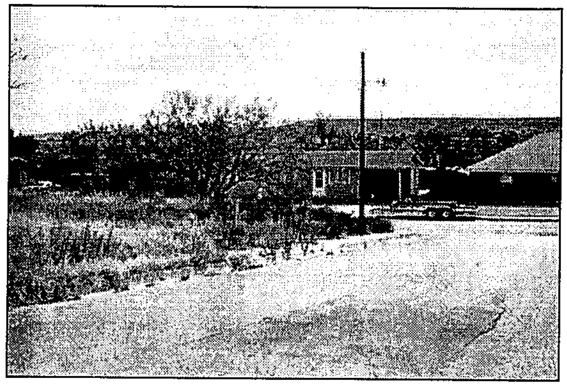
House Orientation to View of Turbines: Side (S)	Orientation of home to the view of the turbines is from the side.
House Orientation to View of Turbines: Front (F)	Orientation of home to the view of the turbines is from the front.
House Orientation to Vista of Turbines: Back (B)	Orientation of home to the view of the turbines is from the back.
House Orientation to Vista of Turbines: Angled (A)	Orientation of home to the view of the turbines is from an angle.
View of Turbines Scope: Narrow(1)	The view of the turbines is largely blocked by trees, large shrubs or man made features in the foreground (0-300 feet) allowing 0 - 30 degrees of view of the wind facility
View of Turbines Scope: Medium(2)	The view of turbines is partially blocked by trees, large shrubs or man made features in the foreground (0-300 feet) allowing only 30-90 degrees of view of the wind facility.
View of Turbines Scope: Wide(3)	The view of the turbines is free or almost free from blockages by trees, large shrubs or man made features in the foreground (0-300 feet) allowing at least 90 degrees of view of the wind facility.
Degree to which View of Turbines Dominates the Site? None (0)	The turbines are not visible at all frrom this home.
Degree to which View of Turbines Dominates the Site? Minor (1)	The turbines are visible but either the scope is narrow, there are many obstructions, or the distance between the home and the facility is large.
Degree to which View of Turbines Dominates the Site? Moderate (2)	The turbines are visible but the scope is either narrow or medium, there might be some obstructions, and the distance between the home and the facility is most likely a few miles.
Degree to which View of Turbines Dominates the Site? Substantial (3)	The turbines are dramatically visible from the home. The turbines are likely visible in a wide scope, and most likely the distance between the home and the facility is short.
Degree to which View of Turbines Dominates the Site? Extreme (4)	This rating is reserved for sites that are unmistakably dominated by the presence of the windfarm. The turbines are dramatically visible from the home and there is a looming quality to their placement. The turbines are often visible in a wide scope, or the distance to the facility is very small.

Appendix D: Vista Ratings with Photos

POOR VISTA

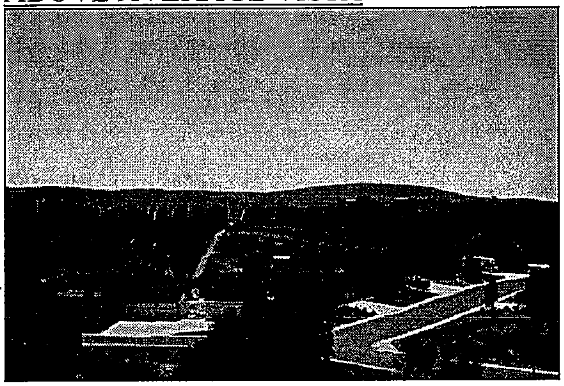
BELOW AVERAGE VISTA

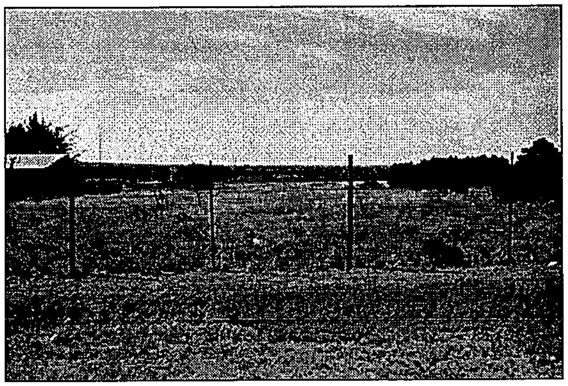




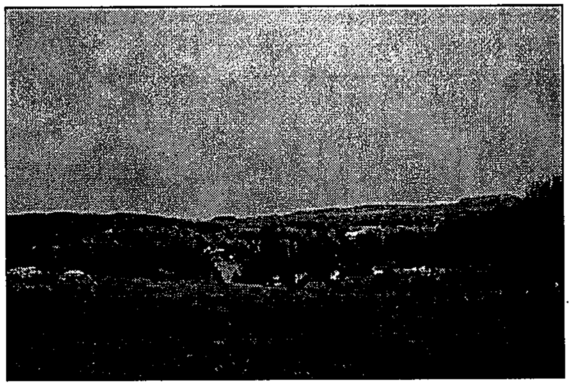
AVERAGE VISTA

ABOVE AVERAGE VISTA



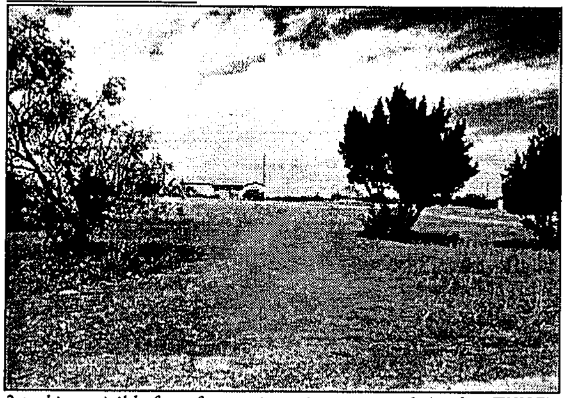


PREMIUM VISTA

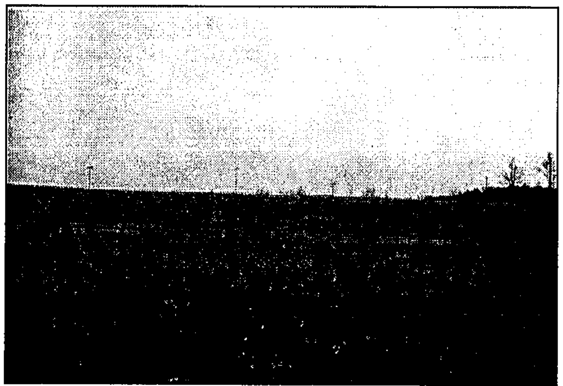


Appendix E: View Ratings with Photos

MINOR VIEW

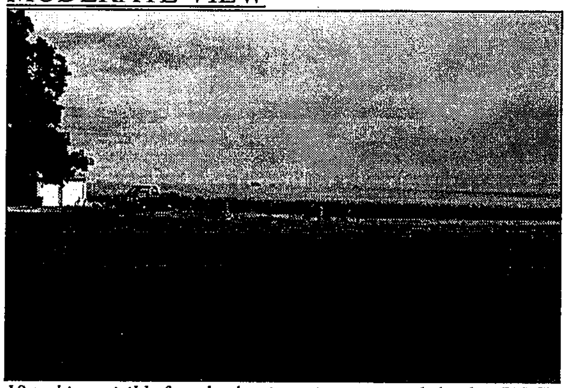


3 turbines visible from front orientation, nearest 1.4 miles (TXHC)



5 turbines visible from front orientation, nearest 0.9 miles (NYMC)

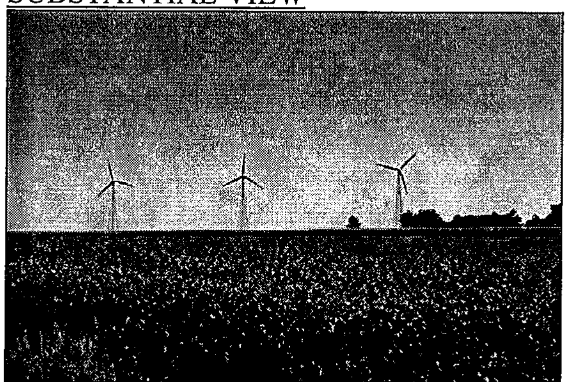
MODERATE VIEW



18 turbines visible from back orientation, nearest 1.6 miles (ILLC)

6 turbines visible from back orientation, nearest 0.8 miles (PASC)

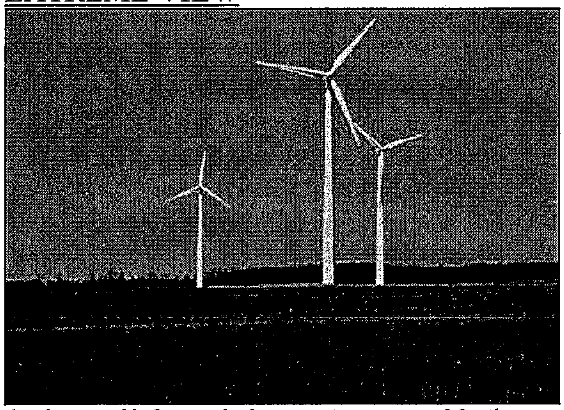
SUBSTANTIAL VIEW



90 turbines visible from all orientations, nearest 0.6 miles (IABV)

27 turbines visible from multiple orientations, nearest 0.6 miles (TXHC)

EXTREME VIEW



6 turbines visible from multiple orientations, nearest 0.2 miles (WIKCDC)

212 turbines visible from all orientations, nearest 0.4 miles (IABV)

Appendix F: Selecting the Primary ("Base") Hedonic Model

Equation (1) as described in Section 4.2 is presented in this report as the primary (or "Base") model to which all other models are compared. As noted earlier, in the Base Hedonic Model and in all subsequent models presented in Section 5 all variables of interest, spatial adjustments, and home and site characteristics are pooled, and therefore their estimates represent the average across all study areas. Ideally, one would have enough data to estimate a model at the study area level - a fully unrestricted model - rather than pooled across all areas. In this appendix, alternative model forms are presented that unrestrict these variables at the level of study areas. As shown here, these investigations ultimately encouraged the selection of the somewhat simpler pooled Base Model as the primary model, and to continue to use restricted or pooled models in the alternative hedonic analyses.

F.1 Discussion of Fully Unrestricted Model Form

The Base Model described by equation (1) has variables that are pooled, and the coefficients for these variables therefore represent the average across all study areas (after accounting for study area fixed effects). An alternative (and arguably superior) approach would be to estimate coefficients at the level of each study area, thereby allowing coefficient values to vary among study areas.[116] This fully interacted – or unrestricted – model would take the following form:

$$\ln(P) = \beta_0 + \sum_s \beta_1(N \cdot S) + \sum_c \beta_2(Y) + \sum_k \beta_3(X \cdot S) + \sum_v \beta_4(\text{VIEW} \cdot S) + \sum_d \beta_5(\text{DISTANCE} \cdot S) + \varepsilon \tag{F13}$$

where

P represents the inflation-adjusted sale price,

N is the spatially weighted neighbors' predicted sale price,

S is a vector of *s* study areas (e.g., WAOR, OKCC, etc.),

Y is a vector of *c* study area locational characteristics (e.g., census tract, school district, etc.),

X is a vector of k home and site characteristics (e.g., acres, square feet, number of bathrooms, condition of the home, age of home, VISTA, etc.),

VIEW is a vector of v categorical view of turbine variables (e.g., MINOR, MODERATE, etc.),

DISTANCE is a vector of d categorical distance to turbine variables (e.g., less than 3000 feet, between one and three miles, etc.),

β_0 is the constant or intercept across the full sample,

β_1 is a vector of *s* parameter estimates for the spatially weighted neighbor's predicted sale price for S study areas,

β_2 is a vector of *c* parameter estimates for the study area locational fixed effect variables,

β_3 is a vector of *k* parameter estimates for the home and site characteristics for S study areas,

β_4 is a vector of *v* parameter estimates for the VIEW variables as compared to homes sold with no view of the turbines for S study areas,

[116] For instance, the marginal contribution of Acres (the number of acres) to the selling price would be estimated for each study area (i.e., Acres_WAOR, Acres_TXHC etc.), as would the variables of interest: VIEW and DISTANCE.

β_5 is a vector of *d* parameter estimates for the DISTANCE variables as compared to homes sold situated outside of five miles for S study areas, and
ε is a random disturbance term.

To refresh, the fully restricted equation (1) takes the following form:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 VIEW + \sum_d \beta_5 DISTANCE + \varepsilon \quad (1)$$

where
P represents the inflation-adjusted sale price,
N is the spatially weighted neighbors' predicted sale price,
S is the vector of *s* Study Area fixed effects variables (e.g., WAOR, OKCC, etc.),
X is a vector of *k* home and site characteristics (e.g., acres, square feet, number of bathrooms, condition of the home, age of home, VISTA, etc.),
VIEW is a vector of *v* categorical view of turbine variables (e.g., MINOR, MODERATE, etc.),
DISTANCE is a vector of *d* categorical distance to turbine variables (e.g., less than 3000 feet, between one and three miles, etc.),
β_0 is the constant or intercept across the full sample,
β_1 is a parameter estimate for the spatially weighted neighbor's predicted sale price,
β_2 is a vector of *s* parameter estimates for the study area fixed effects as compared to homes sold in the Washington/Oregon (WAOR) study area,
β_3 is a vector of *k* parameter estimates for the home and site characteristics,
β_4 is a vector of *v* parameter estimates for the VIEW variables as compared to homes sold with no view of the turbines,
β_5 is a vector of *d* parameter estimates for the DISTANCE variables as compared to homes sold situated outside of five miles, and
ε is a random disturbance term.

The significant change between equations (1) and (F13) is that each of the primary groups of variables in equation (F13) is interacted with the study areas (S) so that parameters can be estimated at the study area level. For example, whereas ACRES is estimated in equation (1) across all study areas, in equation (F13) it is estimated for each study area (i.e., Acres_WAOR, Acres_TXHC, etc).[117] Similarly, when considering the possible impact of wind facilities on residential sales prices, equation (1) seeks average effects that exist over the entire sample, while equation (F13) instead looks for differential effects in each individual study area. Additionally, in equation (F13), instead of estimating fixed effects using inter-study area parameters alone (e.g., WAOR, TXHC), a set of intra-study area effects (Y) - school district and census tract delineations - are added.[118] These latter coefficients represent not only effects that are presumed

[117] This change is made because, theoretically, the contribution to sales prices of home or site characteristics may differ between study areas – for instance Central_AC in Texas vs. New York – and therefore estimating them at the study area level may increase the explanatory power of the model.

[118] In the evaluation and selection of the best model to use as the "Base Model" a set of census tract and school district delineations were used instead of the study area fixed effects. These more-granular fixed effects were extracted from GIS using house locations and census tract and school district polygons. Often, the school district and census tract delineations were not mutually exclusive. For example, in Wisconsin the WIKCDC study area contains four school districts and six census tracts, none of which completely overlap. Alternatively, in some study

to exist over each entire study area (inter-study area effects), but also intra-study area effects such as differences in home valuation due to school districts, distances to amenities, and other locationally bound influences. As with the inter-study area coefficients, because of the myriad influences captured by these variables, interpretation of any single coefficient can be difficult. However, it is expected that such coefficients would be influential, indicating significant differences in value between homes in each study area and across study areas due to school district quality and factors that differ between census tracts (e.g., crime rates).

Although the fully unrestricted model described by equation (F13) is arguably superior to the fully restricted model described in equation (1) because of its ability to resolve differences between and within study areas that are not captured by the Base Model, there are three potential drawbacks:

- Model parsimony and performance;
- Standard error magnitudes; and
- Parameter estimate stability.

Each of these potential drawbacks is discussed in turn below:

Model parsimony and performance: In general, econometricians prefer a simpler, more parsimonious statistical model. In this instance, variables should be added to a model only if their addition is strongly supported by theory and if the performance of the model is substantially improved by their inclusion. As such, if a model with a relatively small number of parameters performs well, it should be preferred to a model with more parameters unless the simple model can be "proven to be inadequate" (Newman, 1956). To prove the inadequacy of a simpler model requires a significant increase in performance to be exhibited from the more complex model. In this case, as presented later, performance is measured using the combination of Adjusted R^2, Modified R^2, and the Schwarz information criterion (see footnote 119 on page 127).

Standard error magnitudes: The magnitude of the standard errors for the variables of interest, as well as the other controlling variables, are likely to increase in the unrestricted model form because the number of cases for each variable will decrease when they are estimated at the study area level. Within each study area, there are a limited number of home transactions that meet the criteria for inclusion in the model, but even more limiting is the number of home transactions within each study area that have the characteristics of interest. For example, in Lee County, IL (ILLC), there are 205 post-construction home sales, while in Wayne County, PA (PAWC) there are 222. More importantly, in those areas, the data include a total of one and eleven sales inside of one mile, respectively, and a total of one and two homes with either EXTREME or SUBSTANTIAL rated views of turbines. With so few observations, there is increased likelihood that a single or small group of observations will strongly influence the sample mean of an independent variable. Since the standard error is derived from the variance of the parameter estimate, which in turn is derived from the summed deviation of each observation's actual level relative to its sample mean, this standard error is more likely to be larger than if a larger sample were considered. If the presence of wind facilities does have a detrimental effect on property

areas the school district and census tracts perfectly overlapped, and in those cases either both were omitted as the reference category or one was included and the other withdrawn from the model to prevent perfect collinearity.

values, that effect seems likely to be relatively small, at least outside of the immediate vicinity of the wind turbines. The smaller sample sizes for the independent variables that come with the unrestricted model, which may decrease statistical precision by producing larger standard errors, would likely decrease the ability to accurately identify these possible effects statistically. To explore the magnitude of this concern, the difference in standard errors of the variables of interest is investigated among the restricted and unrestricted models.

Parameter estimate stability: In an unrestricted model, parameter estimates are more likely to be unstable because the sample of home transactions with any particular characteristic may be small and thus not representative of the population as a whole. As mentioned above, there are a limited number of transactions within each study area that have the characteristics of interest. Restricting the sample size by using an unrestricted model increases the likelihood that a limited number of observations, which in the population as a whole represent a very small segment, will drive the results in one direction or another, thereby leading to erroneous conclusions. The difference in parameter estimates is investigated by comparing the coefficients for the unrestricted variables of interest to those for the restricted variables of interest. Additionally, the sign of any significant variables will be investigated for the unrestricted models, which might help uncover potentially spurious results.

F.2 Analysis of Alterative Model Forms

Here the spectrum of alternative models is explored, from the fully restricted equation (1) to the fully unrestricted equation (F13). To do so, not only are these two ends of the spectrum estimated, but also 14 intermediate models are estimated that consist of every combination of restriction of the four variable groups (i.e., variables of interest, spatial adjustments, study area delineations, and home and site characteristics). This produces a total of 16 models over which to assess model parsimony and performance, standard error size, and coefficient stability. This process allows for an understanding of model performance but, more importantly, to ultimately define a "Base Model" that is parsimonious (i.e., has the fewest parameters), robust (i.e., high adjusted R^2), and best fits the purpose of investigating wind facility impacts on home sales prices.

Table A - 2 presents the performance statistics for each of the 16 models defined above, moving from the fully restricted model equation (1) ("Model 1") to the fully unrestricted model equation (F13) ("Model 16"). In columns 2 – 5 of the table, the "R" represents a restriction for this variable group (i.e., not crossed with the study areas) and the "U" represents the case when the variable group is unrestricted (i.e., crossed with the study areas). Also shown are summary model statistics (i.e., Adjusted R^2, Modified R^2, and Schwarz information criterion - "SIC"), as well as the number of estimated parameters (*k*).[119] All models were run using the post-construction data subset of the sample of home sales transactions (n = 4,937).

[119] Goldberger (1991), as cited by Gujarati (2003), suggests using a Modified $R^2 = (1 - k/n) * R^2$ to adjust for added parameters. For example, Models 1 and 14 have Modified R^2 of 0.76, yet Adjusted R^2 of 0.77 and 0.78 respectively. Therefore the Modified R^2 penalizes their measure of explanatory power more than the Adjusted R^2 when taking into account the degrees of freedom. Similarly, the Schwarz information criterion penalizes the models for increased numbers of parameters (Schwarz, 1978). More importantly, practitioners often rely on the Schwarz criterion – over the Modified or Adjusted R^2 statistics - to rank models with the same dependent variable by their relative parsimony (Gujarati, 2003). Therefore it will be used for that purpose here.

Model Parsimony and Performance

Overall, the fully restricted model (1) performs well with only 37 independent variables, producing an Adjusted R^2 of 0.77. Despite the limited number of explanatory variables, the model explains ~77% of the variation in home prices in the sample. When the fully unrestricted model 16 (equation F13) is estimated, which lies at the other end of the spectrum, it performs only slightly better, with an Adjusted R^2 of 0.81, but with an additional 285 explanatory variables. It is therefore not surprising that the Modified R^2 is 0.76 for Model 1 and is only 0.77 for Model 16. Similarly, the Schwarz information criterion (SIC) increases from 0.088 to 0.110 when moving from model 1 to model 16 indicating relatively less parsimony. Combined, these metrics show that the improvement in the explanatory power of model 16 over model 1 is not enough to overcome the lack of parsimony. Turning to the 14 models that lie between Models 1 and 16, in general, little improvement in performance is found over Model 1, and considerably less parsimony, providing little initial justification to pursue a more complex specification than equation (1).

Table A - 2: Summarized Results of Restricted and Unrestricted Model Forms

Model [1]	Study Area [2]	Spatial Adjustment	Home and Site Characteristics	Variables of Interest	Adj R^2	Modified R^2	SIC	k †
1	R	R	R	R	0.77	0.76	0.088	37
2	U	R	R	R	0.74	0.73	0.110	111
3	R	U	R	R	0.77	0.76	0.088	46
4	R	R	U	R	0.80	0.78	0.095	188
5	R	R	R	U	0.77	0.76	0.093	88
6	U	U	R	R	0.78	0.76	0.094	120
7	R	U	U	R	0.80	0.77	0.096	197
8	R	R	U	U	0.80	0.77	0.101	239
9	U	R	U	R	0.80	0.77	0.107	262
10	U	R	R	U	0.76	0.75	0.107	162
11	R	U	R	U	0.77	0.76	0.094	97
12	U	U	U	R	0.81	0.77	0.103	271
13	R	U	U	U	0.80	0.77	0.103	248
14	U	U	R	U	0.78	0.76	0.100	171
15	U	R	U	U	0.80	0.76	0.113	313
16	U	U	U	U	0.81	0.77	0.110	322

"R" indicates parameters are pooled ("restricted") across the study areas.
"U" indicates parameters are not pooled ("unrestricted"), and are instead estimated at the study area level.
1 - *Model numbers do not correspond to equation numbers listed in the report; equation (1) is Model 1, and equation (F1) is Model 16.*
2 - *In its restricted form "Study Area" includes only inter-study area delineations, while unrestricted "Study Area" includes intra-study area delineations of school district and census tract.*
† - *Numbers of parameters do not include intercept or omitted variables.*

The individual contributions to model performance from unrestricting each of the variable groups in turn (as shown in Models 2-5) further emphasizes the small performance gains that are earned despite the sizable increases in the number of parameters. As a single group, the

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unrestricted Home and Site Characteristics model (Model 4) makes the largest impact on model performance, at least with respect to the Adjusted R^2 (0.80), but this comes with the addition of 151 estimated parameters a slight improvement in the Modified R^2 (0.78) and a worsening SIC (0.095). Adding unrestricted Study Area delineations (Model 2), on the other hand, adversely affects performance (Adj. $R^2 = 0.74$, Modified $R^2 = 0.73$) and adds 74 estimated parameters (SIC = 0.110). Similarly, unrestricting the Spatial Adjustments (Model 3) offers little improvement in performance (Adj. $R^2 = 0.77$, Modified $R^2 = 0.76$) despite adding nine additional variables (SIC = 0.088). Finally, unrestricting the Variables of Interest (Model 5) does not increase model performance (Adj. $R^2 = 0.77$, Modified $R^2 = 0.76$) and adds 51 variables to the model (SIC = 0.093). This pattern of little model improvement yet considerable increases in the number of estimated parameters (i.e., less parsimony) continues when pairs or trios of variable groups are unrestricted. With an Adjusted R^2 of 0.77, the fully restricted equation (1) performs more than adequately, and is, by far, the most parsimonious.

Standard Error Magnitudes

Table A - 3 summarizes the standard errors for the variables of interest for all of the 16 models, grouped into restricted and unrestricted model categories. The table specifically compares the medians, minimums, and maximums of the standard errors for the models with restricted variables of interest (1, 2, 3, 4, 6, 7, 9 and 12) to those with unrestricted variables of interest (5, 8, 10, 11, 13, 14, 15 and 16).[120] The table demonstrates that the unrestricted standard errors for the variables of interest are significantly larger than the restricted standard errors. In fact, the minimum standard errors in the unrestricted models are often higher than the maximum standard errors produced in the restricted models. For example, the maximum standard error for an EXTREME VIEW in the restricted models is 0.09, yet the minimum in the unrestricted models is 0.12, with a maximum of 0.34. To put this result in a different light, a median standard error for the unrestricted EXTREME VIEW variable of 0.25 would require an effect on house prices larger than 50% to be considered statistically significant at the 90% level. Clearly, the statistical power of the unrestricted models is weak.[121] Based on other disamenities, as discussed in Section 2.1, an effect of this magnitude is very unlikely. Therefore, based on these standard errors, there is no apparent reason to unrestrict the variables of interest.

[120] For the restricted models, the medians, minimums, and maximums are derived across all eight models for each variable of interest. For the unrestricted models, they are derived across all study areas and all eight models for each variable of interest.

[121] At 90% confidence a standard error of 0.25 would produce a confidence interval of roughly +/- 0.42 (0.25 * 1.67). An effect of this magnitude represents a 52% change in sales prices because sales price is in a natural log form (e ^ 0.42-1 = 0.52).

Table A - 3: Summary of VOI Standard Errors for Restricted and Unrestricted Models

Standard Errors	Restricted Models Standard Errors			Unrestricted Models Standard Errors		
	Median	Min	Max	Median	Min	Max
Minor View	0.01	0.01	0.02	0.05	0.03	0.07
Moderate View	0.03	0.03	0.03	0.10	0.06	0.18
Substantial View	0.05	0.05	0.06	0.19	0.10	0.29
Extreme View	0.08	0.08	0.09	0.25	0.12	0.34
Inside 3000 Feet	0.05	0.05	0.06	0.21	0.09	0.33
Between 3000 Feet and 1 Mile	0.04	0.04	0.05	0.13	0.08	0.40
Between 1 and 3 Miles	0.02	0.02	0.02	0.05	0.02	0.11
Between 3 and 5 Miles	0.01	0.01	0.02	0.05	0.02	0.10

Parameter Estimate Stability

Table A - 4 summarizes the coefficient estimates for the variables of interest for all of the 16 models. The table specifically compares the medians, minimums, and maximums of the coefficients for the models with restricted variables of interest (1, 2, 3, 4, 6, 7, 9 and 12) to those with unrestricted variables of interest (5, 8, 10, 11, 13, 14, 15 and 16). As shown, the coefficients in the unrestricted models diverge significantly from those in the restricted models. For example, in the restricted models, the median coefficient for homes inside of 3000 feet is -0.03, with a minimum of -0.06 and a maximum of -0.01, yet in the unrestricted models the median coefficient is 0.06, with a minimum of -0.38 and a maximum of 0.32. Similarly, a MODERATE VIEW in the restricted models has a median of 0.00, with a minimum of -0.01 and a maximum of 0.03, whereas the unrestricted models produce coefficients with a median of -0.05 and with a minimum of -0.25 and a maximum of 0.35.

Table A - 4: Summary of VOI Coefficients for Restricted and Unrestricted Models

Parameters	Restricted Models Coefficients			Unrestricted Models Coefficients		
	Median	Min	Max	Median	Min	Max
Minor View	-0.02	-0.03	0.00	-0.02	-0.16	0.24
Moderate View	0.00	-0.01	0.03	-0.05	-0.25	0.35
Substantial View	-0.01	-0.04	0.02	-0.08	-0.31	0.13
Extreme View	0.03	0.02	0.05	-0.03	-0.23	0.09
Inside 3000 Feet	-0.03	-0.06	-0.01	0.06	-0.38	0.32
Between 3000 Feet and 1 Mile	-0.04	-0.06	-0.01	-0.10	-0.44	0.52
Between 1 and 3 Miles	-0.01	-0.03	0.02	0.00	-0.23	0.40
Between 3 and 5 Miles	0.02	0.01	0.04	0.05	-0.05	0.32

Turning from the levels of the coefficients to the stability of their statistical significance and sign across models more reasons for concern are found. Table A - 5 summarizes the results of the unrestricted models, and presents the number of statistically significant variables of interest as a percent of the total estimated. The table also breaks these results down into two groups, those with coefficients above zero and those with coefficients below zero.[122] It should be emphasized here that it is the *a priori* expectation that, if effects exist, all of these coefficients would be less than zero, indicating an adverse effect on home prices from proximity to and views of wind turbines. Despite that expectation, when the variables of interest are unrestricted it is found that they are as likely to be above zero as they are below.[123] In effect, the small numbers of cases available for analysis at the study area level produce unstable results, likely because the estimates are being unduly influenced by either study area specific effects that are not captured by the model or by a limited number of observations that represents a larger fraction of the overall sample in that model.[124]

Table A - 5: Summary of Significant VOI Above and Below Zero in Unrestricted Models

Significant Variables	Unrestricted Models		
	Total	Below Zero	Above Zero
Minor View	32%	14%	18%
Moderate View	23%	11%	13%
Substantial View	4%	4%	0%
Extreme View	0%	0%	0%
Inside 3000 Feet	23%	15%	8%
Between 3000 Feet and 1 Mile	30%	14%	16%
Between 1 and 3 Miles	56%	32%	24%
Between 3 and 5 Miles	45%	3%	43%

F.3 Selecting a Base Model

To conclude, it was found that all three concerns related to the estimation and use of an unrestricted model form are borne out in practice. Despite experimenting with 16 different combinations of interactions, little overall improvement in performance is discovered. Where performance gains are found they are at the expense of parsimony as reflected in the lack of increase in the Modified R^2 and the relatively higher Schwartz information criterion. Further, divergent and spurious coefficients of interest and large standard errors are associated with those coefficients. Therefore the fully restricted model, equation (1), is used in this report as the "Base Model".

[122] The "Total" percentage of significant coefficients is calculated by counting the total number of significant coefficients across all 8 unrestricted models for each variable of interest, and dividing this total by the total number of coefficients. Therefore, a study area that did not have any homes in a group (for example, homes with EXTREME VIEWS) was not counted in the "total number of coefficients" sum. Any differences between the sum of "above" and "below" zero groups from the total are due to rounding errors.

[123] The relatively larger number of significant variables for the MINOR rated view, MODERATE rated view, Mile 1 to 3, and Mile 3 to 5 parameters are likely related to the smaller standard errors for those categories, which result from larger numbers of cases.

[124] Another possible explanation for spurious results in general is measurement error, when parameters do not appropriately represent what one is testing for. In this case though, the VIEW variables have been adequately "ground truthed" during the development of the measurement scale, and are similar to the VISTA variables, which were found to be very stable across study areas. DISTANCE, or for that matter, distance to any disamenity, has been repeatedly found to be an appropriate proxy for the size of effects. As a result, it is not believed that measurement error is a likely explanation for the results presented here.

Appendix G: OLS Assumptions, and Tests for the Base Model

A number of criteria must be met to ensure that the Base Model and Alternative Hedonic Models produce unbiased coefficient estimates and standard errors: 1) appropriate controls for outliers and influencers; 2) homoskedasticity; 3) absence of serial or spatial autocorrelation; and 4) reasonably limited multicollinearity. Each of these criteria, and how they are addressed, is discussed below.

Outliers and Influencers: Home sale prices that are well away from the mean, also called outliers and influencers, can cause undue influence on parameter estimates. A number of formal tests are available to identify these cases, the most common being Mahalanobis' Distance ("M Distance") (Mahalanobis, 1936) and standardized residual screening. M Distance measures the degree to which individual observations influence the mean of the residuals. If any single observation has a strong influence on the residuals, it should be inspected and potentially removed. An auxiliary, but more informal, test for identifying these potentially influential observations is to see when the standardized absolute value of the residual exceeds some threshold. Both the Base Model and the All Sales Model were run using the original dataset of 7,464 transactions and the 4,940 transactions which occurred post-construction respectively. For both models the standardized residuals and the M Distance statistics were saved.[125] The histograms of these two sets of statistics from the two regressions are shown in Figure A - 15 through Figure A - 18.

[125] For the M Distance statistics all variables of interest were removed from the model. If they were left in the M-Distance statistics could be influenced by the small numbers of cases in the variables of interest. If these parameters were strongly influenced by a certain case, it could drive the results upward. Inspecting the controlling variables in the model, and how well they predicted the sale prices of the transactions in the sample, was of paramount importance therefore the variables of interest were not included.

Figure A - 15: Histogram of Standardized Residuals for Base Model

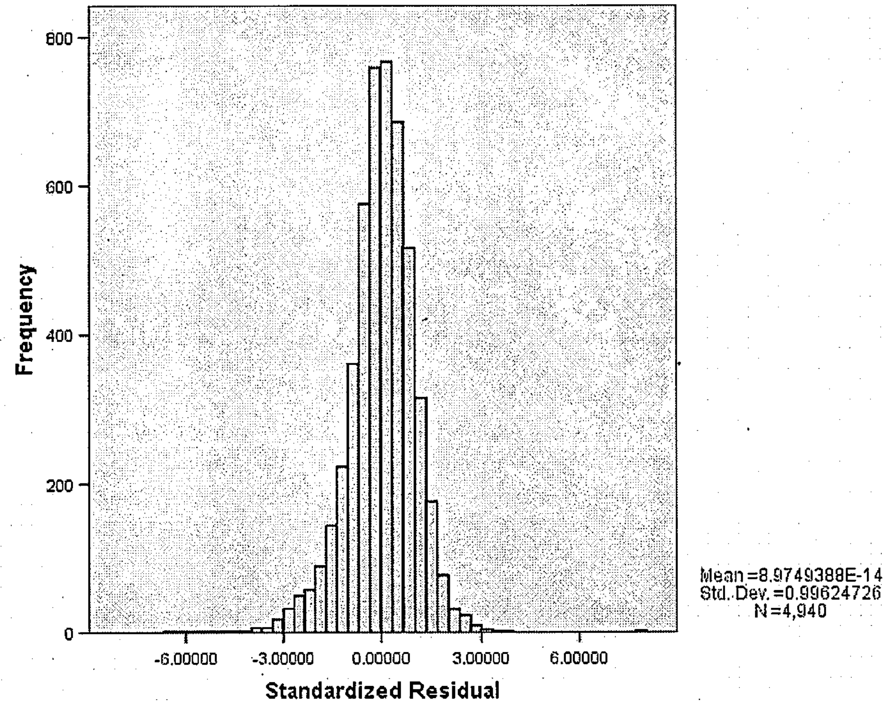

Figure A - 16: Histogram of Mahalanobis Distance Statistics for Base Model

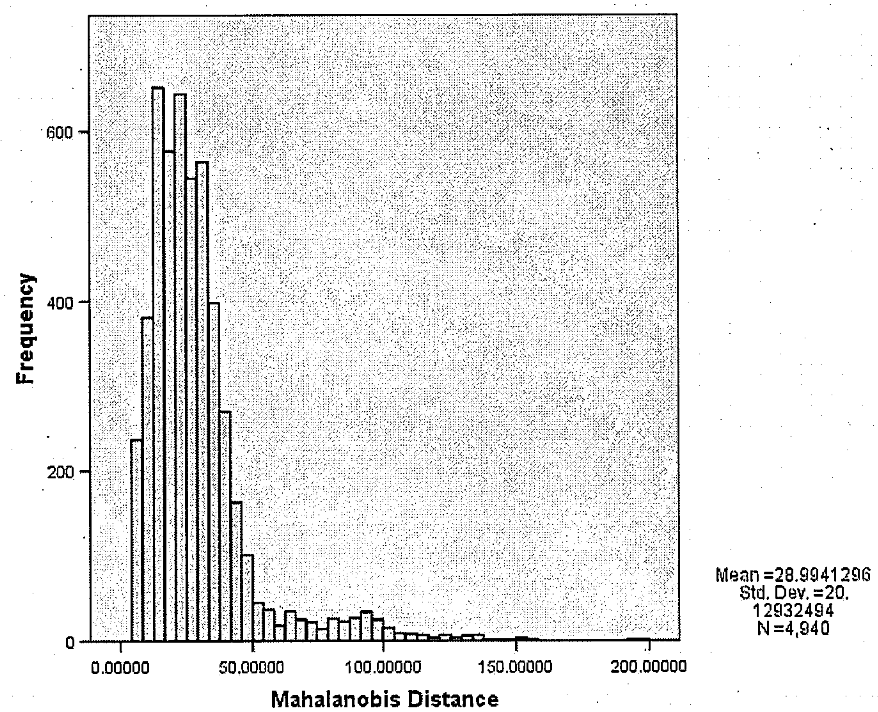

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Figure A - 17: Histogram of Standardized Residuals for All Sales Model

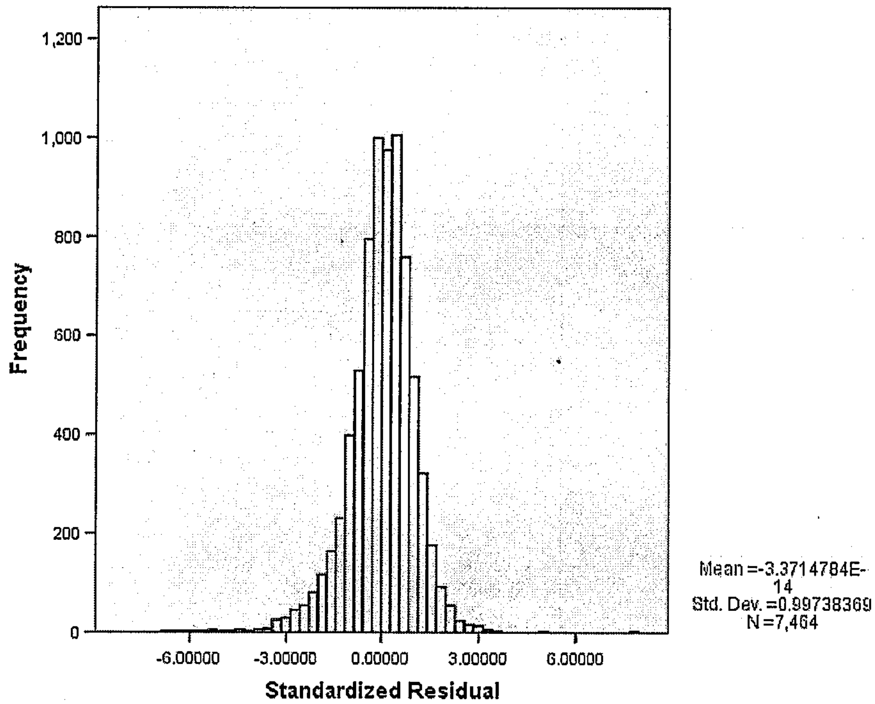
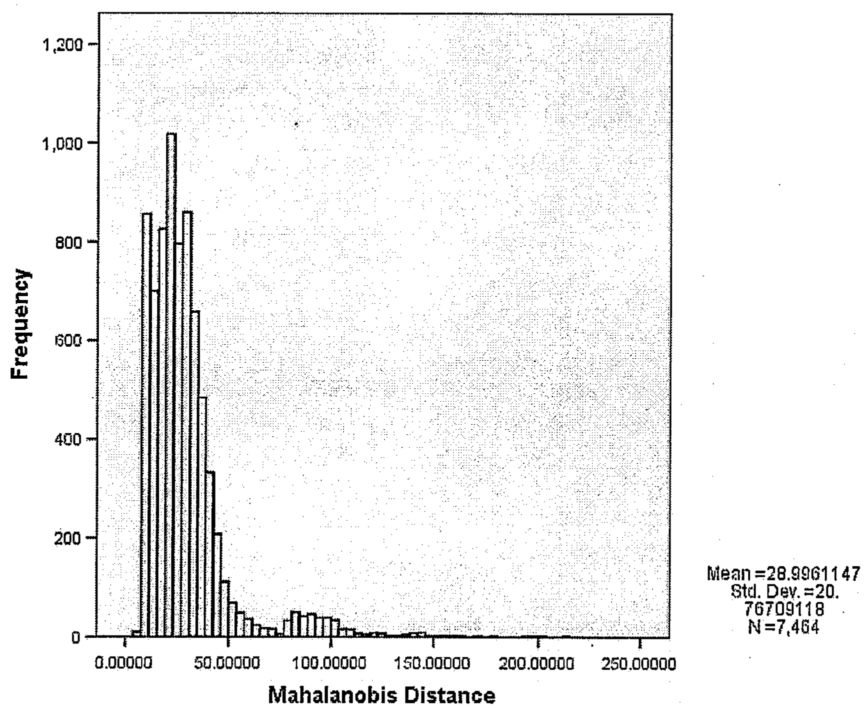


Figure A - 18: Histogram of Mahalanobis Distance Statistics for All Sales Model



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The M Distance histograms suggested that a cutoff of 150 may be appropriate, which would exclude 15 cases from the All Sales Model and seven cases from the Base Model (all of the latter of which were among the 15 outliers in the All Sales Model). The Standardized Residual histograms suggested a cutoff of 4, 5, or 6, which would exclude 13, 8, and 3 cases from the Base Model, and 22, 12, and 5 cases from the All Sales Model. A case-by-case investigation of each of these sales transactions was then conducted by comparing their home characteristics (e.g., square feet, baths, age, etc.) against their study area and panel model cohorts to ensure that none had been inappropriately coded. None of the M Distance flagged cases seemed to be inappropriately coded, and none of those cases were removed from the final dataset as a result. Five cases that were flagged from the All Sales Model (which corresponded to three cases in the Base Model) with a Standardized Residual greater than six, however, were clearly outliers. One had a sale price that was more than $200,000 more than any other transaction in the model, and the other four had exceptionally low prices, yet high numbers of corresponding characteristics that would suggest higher home sales prices (such as over 2000 square feet – all four cases – or more than two bathrooms – three cases).

As a result of these investigations, these five cases were removed from the model. One of the five cases occurred prior to announcement, one occurred after announcement and before construction, and the other three occurred after construction began. None were within three miles of the nearest wind turbine except one, which was 0.6 miles from the nearest turbine and had a MINOR view of the wind facility. The other two had no views of the turbines. Although there was hesitancy in removing any cases from the model, these transactions were considered appropriately influential and keeping them in the model would bias the results inappropriately. Further, the one home that was situated inside of one mile was surrounded by five other transactions in the same study area that also occurred after construction began and were a similar distance from the turbines, but that were not flagged by the outliers screen. Therefore, its removal was considered appropriate given that other homes in the sample would likely experience similar effects.

After removing these five cases, the sensitivity of the model results were tested to the inclusion or exclusion of the "greater than five" and "greater than four" Standardized Residuals observations and the cases flagged by the M Distance screen, finding that parameter estimates for the variables of interest moved slightly with these cases removed but not enough to change the results significantly. Because they did not show a unique grouping across the variables of interest, nor any unusual potentially inappropriate coding, and, more importantly, did not substantially influence the results, no substantive reason was found to remove any additional transactions from the sample. Therefore, the final dataset included a total of 7,459 cases, of which 4,937 occurred post-construction.

Homoskedasticity: A standard formal test for the presence of homoskedastic error terms is the White's statistic (White, 1980). However, the requirements to perform this test were overly burdensome for the computing power available. Instead, an informal test was applied, which plots the regression errors against predicted values and various independent variables to observe whether a "heteroskedastic pattern" is in evidence (Gujarati, 2003). Although no evidence of heteroskedasticity was found using this method, to be conservative, nonetheless all models were run with White's heteroskedasticity correction to the parameter estimates' standard errors (which will not adversely influence the errors if they are homoskedastic).

Serial Autocorrelation: A standard formal test for the presence of serial autocorrelation in the error term is the Durbin-Watson statistic (Durbin and Watson, 1951). Applying this test as proposed by Durbin and Watson to the full panel dataset was problematic because the test looks at the error structure based on the order that observations are included in the statistical regression model. Any ordering choice over the entire panel data set invariably involves mixing home transactions from various study areas. Ideally, one would segment the data by study area for purposes of calculating this test, but that method was not easily implemented with the statistical software package used for this analysis (i.e., SAS). Instead, study area specific regression models were run with the data chronologically ordered in each to produce twelve different Durbin-Watson statistics, one for each study area specific model. The Durbin-Watson test statistics ranged from 1.98–2.16, which are all within the acceptable range.[126] Given that serial autocorrelation was not found to be a significant concern for each study area specific model, it is assumed that the same holds for the full dataset used in the analysis presented in this report.

Spatial Autocorrelation: It is well known that the sales price of a home can be systematically influenced by the sales prices of those homes that have sold nearby (Dubin, 1998; LeSage, 1999). Both the seller and the buyer use information from comparable surrounding sales to inform them of the appropriate transaction price, and nearby homes often experience similar amenities and disamenities. Therefore, the price for any single home is likely to be weakly dependent of the prices of homes in close temporal and spatial proximity. This lack of independence of home sale prices could bias the hedonic results (Dubin, 1998; LeSage, 1999), if not adequately addressed. A number of techniques are available to address this concern (Case et al., 2004; Espey et al., 2007), but because of the large sample and computing limits, a variation of the Spatial Auto Regressive Model (SAR) was chosen (Espey et al., 2007).

Specifically, an independent variable is included in the models: the predicted values of the weighted nearest neighbor's natural log of sales price in 1996 dollars.[127] To construct this vector of predicted prices, an auxiliary regression is developed using the spatially weighted average natural log of sales price in 1996 dollars as the independent variable and the spatially weighted average set of home characteristics as the dependent variables. This regression was used to produce the predicted weighted nearest neighbor's natural log of sales price in 1996 dollars that is then included in the Base and Alternative Models. This process required the following steps:

1) Selecting the neighbors for inclusion in the calculation;
2) Calculating a weighted sales price from these neighbors' transactions;
3) Selecting and calculating the weighted neighbors home characteristics; and
4) Forecasting the weighted average neighbor's sales price.

- **Selecting the neighbors**: To select the neighbors whose home transactions would most likely have affected the sales price of the subject home under review, all of the homes that

[126] The critical values for the models were between 1.89 and 2.53, assuming 5% significance, greater than 20 variables, and more than 200 cases (Gujarati, 2003).

[127] The predicted value was used, instead of the actual value, to help correct for simultaneity or endogeneity problems that might otherwise exist.

sold within the preceding six months of a subject home's sale date in the same study area are identified and, from those, the five nearest neighbors based on Euclidian distance are selected. The inverse of each selected nearest neighbors' distance (in quarter miles) to the subject home was then calculated. Each of these values was then divided by the sum of the five nearest neighbor's inverse distance values to create a neighbor's distance weight (NDW) for each of the five nearest neighbors.[128]

- **Creating the weighted sales price**: Each of the neighbor's natural log of sales price in 1996 dollars (LN_Saleprice96) is multiplied by its distance weight (NDW). Then, each weighted neighbor's LN_Saleprice96 is summed to create a weighted nearest neighbor LN_Saleprice96 (Nbr_LN_Saleprice96).

- **Selecting and calculating the weighted neighbors home characteristics**: Nine independent variables are used from each of the neighbor's homes: square feet, age of the home at the time of sale, age of the home at the time of sale squared, acres, number of full baths, and condition (1-5, with Poor = 1, Below Average = 2, etc.). A weighted average is created of each of the characteristics by multiplying each of the neighbor's individual characteristics by their NDW, and then summing those values across the five neighbors to create the weighted average nearest neighbors' home characteristic.[129] Then each of the independent variables is interacted with the study area to allow each one to be independently estimated for each study area.

- **Forecasting the weighted average neighbors sales price**: To create the final predicted neighbor's price, the weighted nearest neighbor LN_Saleprice96 is regressed on the weighted average nearest neighbors' home characteristics to produce a predicted weighted nearest neighbor LN_Saleprice96 (Nbr_LN_SalePrice96_hat). These predicted values are then included in the Base and Alternative Models as independent variables to account for the spatial and temporal influence of the neighbors' home transactions.

In all models, the coefficient for this spatial adjustment parameter meets the expectations for sign and magnitude and is significant well above the 99% level, indicating both the presence of spatial autocorrelation and the appropriateness of the control for it.

Multicollinearity: There are several standard formal tests for detecting multicollinearity within the independent variables of a regression model. The Variance-Inflation Factor and Condition Index is applied to test for this violation of OLS assumptions. Specifically, a Variance-Inflation Factor (VIF) greater than 4 and/or a Condition Index of greater than 30 (Kleinbaum et al., 1988) are strong indicators that multicollinearity may exist. Multicollinearity is found in the model using both tests. Such a result is not uncommon in hedonic models because a number of characteristics, such as square feet or age of a home, are often correlated with other characteristics, such as the number of acres, bathrooms, and fireplaces. Not surprisingly, age of the home at the time of sale (AgeofHome) and the age of the home squared (AgeatHome_Sqrd)

[128] Put differently, the weight is the contribution of that home's inverse distance to the total sum of the five nearest neighbors' inverse distances.

[129] Condition requires rounding to the nearest integer and then creating a dummy from the 1-5 integers.

exhibited some multicollinearity (VIF equaled 11.8 and 10.6, respectively). Additionally, the home condition shows a fairly high Condition Index with square feet, indicating collinearity. More importantly, though, are the collinearity statistics for the variables of interest. The VIF for the VIEW variables range from 1.17 to 1.18 and for the DISTANCE variables they range from 1.2 to 3.6, indicating little collinearity with the other variables in the model. To test for this in another way, a number of models are compared with various identified highly collinear variables removed (e.g., AgeatSale, Sqft) and found that the removal of these variables had little influence on the variables of interest. Therefore, despite the presence of multicollinearity in the model, it is not believed that the variables of interest are inappropriately influenced. Further, any corrections for these issues might cause more harm to the model's estimating efficiency than taking no further action (Gujarati, 2003); as such, no specific adjustments to address the presence of multicollinearity are pursued further.

Appendix H: Alternative Models: Full Hedonic Regression Results

Table A - 6: Full Results for the Distance Stability Model

	Coef.	SE	p Value	n
Intercept	7.61	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.33	0.04	0.00	87
Cnd Low	-0.45	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.13	0.01	0.00	1,445
Cnd High	0.23	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.03	0.00	1,071
OKCC	-0.44	0.02	0.00	476
IABV	-0.24	0.02	0.00	605
ILLC	-0.08	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.30	0.03	0.00	291
PAWC	-0.07	0.03	0.01	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
Mile Less 0 57	-0.04	0.04	0.29	67
Mile 0 57to1	-0.06	0.05	0.27	58
Mile 1to3	-0.01	0.02	0.71	2,019
Mile 3to5	0.01	0.01	0.26	1,923
Mile Gtr5	Omitted	Omitted	Omitted	870

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	2
Model Name	Distance Stability
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	33
F Statistic	496.7
Adjusted R Squared	0.77

Table A - 7: Full Results for the View Stability Model

	Coef.	SE	Sig	*n*
Intercept	7.64	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.34	0.04	0.00	87
Cnd Low	-0.45	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.13	0.01	0.00	1,445
Cnd High	0.23	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.02	0.00	1,071
OKCC	-0.45	0.02	0.00	476
IABV	-0.25	0.02	0.00	605
ILLC	-0.09	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.31	0.03	0.00	291
PAWC	-0.08	0.03	0.00	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
Post Con NoView	Omitted	Omitted	Omitted	4,207
View Minor	-0.02	0.01	0.25	561
View Mod	0.00	0.03	0.90	106
View Sub	-0.04	0.06	0.56	35
View Extrm	-0.03	0.06	0.61	28

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	3
Model Name	View Stability
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	33
F Statistic	495.9
Adjusted R Squared	0.77

Table A - 8: Full Results for the Continuous Distance Model

	Coef.	SE	p Value	*n*
Intercept	7.64	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.34	0.04	0.00	87
Cnd Low	-0.45	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.13	0.01	0.00	1,445
Cnd High	0.23	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.02	0.00	1,071
OKCC	-0.44	0.02	0.00	476
IABV	-0.25	0.02	0.00	605
ILLC	-0.09	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.31	0.03	0.00	291
PAWC	-0.07	0.03	0.00	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
No View	Omitted	Omitted	Omitted	4,207
Minor View	-0.01	0.01	0.33	561
Moderate View	0.01	0.03	0.77	106
Substantial View	-0.02	0.07	0.72	35
Extreme View	0.01	0.10	0.88	28
InvDISTANCE	-0.01	0.02	0.46	4,937

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	5
Model Name	Continuous Distance Model
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	34
F Statistic	481.3
Adjusted R Squared	0.77

Table A - 9: Full Results for the All Sales Model

	Coef.	SE	p Value	*n*
Intercept	9.08	0.14	0.00	
Nbr LN SP96 hat All OI	0.16	0.01	0.00	7,459
AgeatSale	-0.007	0.0003	0.00	7,459
AgeatSale Sqrd	0.00003	0.000002	0.00	7,459
Sqft 1000	0.28	0.01	0.00	7,459
Acres	0.02	0.00	0.00	7,459
Baths	0.08	0.01	0.00	7,459
ExtWalls Stone	0.21	0.01	0.00	2,287
CentralAC	0.12	0.01	0.00	3,785
Fireplace	0.11	0.01	0.00	2,708
FinBsmt	0.09	0.01	0.00	990
Cul De Sac	0.09	0.01	0.00	1,472
Water Front	0.35	0.03	0.00	107
Cnd Low	-0.43	0.04	0.00	101
Cnd BAvg	-0.21	0.02	0.00	519
Cnd Avg	Omitted	Omitted	Omitted	4,357
Cnd AAvg	0.13	0.01	0.00	2,042
Cnd High	0.22	0.02	0.00	440
Vista Poor	-0.25	0.02	0.00	470
Vista BAvg	-0.09	0.01	0.00	4,301
Vista Avg	Omitted	Omitted	Omitted	1,912
Vista AAvg	0.10	0.01	0.00	659
Vista Prem	0.09	0.03	0.00	117
WAOR	Omitted	Omitted	Omitted	790
TXHC	-0.82	0.02	0.00	1,311
OKCC	-0.53	0.02	0.00	1,113
IABV	-0.31	0.02	0.00	822
ILLC	-0.05	0.02	0.02	412
WIKCDC	-0.17	0.01	0.00	810
PASC	-0.37	0.03	0.00	494
PAWC	-0.15	0.02	0.00	551
NYMCOC	-0.25	0.02	0.00	463
NYMC	-0.15	0.02	0.00	693
Pre-Construction Sales	Omitted	Omitted	Omitted	2,522
No View	0.02	0.01	0.06	4,207
Minor View	0.00	0.02	0.76	561
Moderate View	0.03	0.03	0.38	106
Substantial View	0.03	0.07	0.63	35
Extreme View	0.06	0.08	0.43	28
Inside 3000 Feet	-0.06	0.05	0.23	80
Between 3000 Feet and 1 Mile	-0.08	0.05	0.08	65
Between 1 and 3 Miles	0.00	0.01	0.79	2,359
Between 3 and 5 Miles	0.01	0.01	0.58	2,200
Outside 5 Miles	0.00	0.02	0.76	1,000
Pre-Announcement Sales	Omitted	Omitted	Omitted	1,755

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	6
Model Name	All Sales Model
Dependent Variable	LN SalePrice96
Number of Cases	7459
Number of Predictors (k)	39
F Statistic	579.9
Adjusted R Squared	0.75

Table A - 10: Full Results for the Temporal Aspects Model

	Coef.	SE	p Value	*n*
Intercept	9.11	0.14	0.00	
Nbr LN SP96 hat All OI	0.16	0.01	0.00	7,459
AgeatSale	-0.007	0.0003	0.00	7,459
AgeatSale Sqrd	0.00003	0.000002	0.00	7,459
Sqft 1000	0.28	0.01	0.00	7,459
Acres	0.02	0.00	0.00	7,459
Baths	0.08	0.01	0.00	7,459
ExtWalls Stone	0.21	0.01	0.00	2,287
CentralAC	0.12	0.01	0.00	3,785
Fireplace	0.12	0.01	0.00	2,708
FinBsmt	0.09	0.01	0.00	990
Cul De Sac	0.09	0.01	0.00	1,472
Water Front	0.35	0.03	0.00	107
Cnd Low	-0.43	0.04	0.00	101
Cnd BAvg	-0.21	0.02	0.00	519
Cnd Avg	Omitted	Omitted	Omitted	4,357
Cnd AAvg	0.13	0.01	0.00	2,042
Cnd High	0.22	0.02	0.00	440
Vista Poor	-0.25	0.02	0.00	470
Vista BAvg	-0.09	0.01	0.00	4,301
Vista Avg	Omitted	Omitted	Omitted	1,912
Vista AAvg	0.10	0.01	0.00	659
Vista Prem	0.09	0.03	0.00	117
WAOR	Omitted	Omitted	Omitted	790
TXHC	-0.82	0.02	0.00	1,311
OKCC	-0.52	0.02	0.00	1,113
IABV	-0.30	0.02	0.00	822
ILLC	-0.04	0.02	0.05	412
WIKCDC	-0.17	0.02	0.00	810
PASC	-0.37	0.03	0.00	494
PAWC	-0.14	0.02	0.00	551
NYMCOC	-0.25	0.02	0.00	463
NYMC	-0.15	0.02	0.00	693

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Note: Results for variables of interest shown on following page

	Coef.	SE	p Value	*n*
No View	Omitted	Omitted	Omitted	6,729
Minor View	-0.02	0.01	0.20	561
Moderate View	0.00	0.03	0.97	106
Substantial View	0.01	0.07	0.87	35
Extreme View	0.04	0.07	0.59	28
Pre_Anc_Gtr2Yr_Lt1Mile	-0.13	0.06	0.02	38
Pre_Anc_2Yr_Lt1Mile	-0.10	0.05	0.06	40
Post_Anc_Pre_Con_Lt1Mile	-0.14	0.06	0.02	21
Post_Con_2Yr_Lt1Mile	-0.09	0.07	0.15	39
Post_Con_2_4Yr_Lt1Mile	-0.01	0.06	0.86	44
Post_Con_Gtr5Yr_Lt1Mile	-0.07	0.08	0.37	42
Pre_Anc_Gtr2Yr_1_3Mile	-0.04	0.03	0.19	283
Pre_Anc_2Yr_1_3Mile	0.00	0.03	0.91	592
Post_Anc_Pre_Con_1_3Mile	-0.02	0.03	0.53	342
Post_Con_2Yr_1_3Mile	0.00	0.03	0.90	807
Post_Con_2_4Yr_1_3Mile	0.01	0.03	0.78	503
Post_Con_Gtr5Yr_1_3Mile	0.00	0.03	0.93	710
Pre_Anc_Gtr2Yr_3_5Mile	0.00	0.04	0.93	157
Pre_Anc_2Yr_3_5Mile	0.00	0.03	0.98	380
Post_Anc_Pre_Con_3_5Mile	0.00	0.03	0.93	299
Post_Con_2Yr_3_5Mile	0.02	0.03	0.56	574
Post_Con_2_4Yr_3_5Mile	0.01	0.03	0.66	594
Post_Con_Gtr5Yr_3_5Mile	0.01	0.03	0.68	758
Pre_Anc_Gtr2Yr_Gtr5Mile	Omitted	Omitted	Omitted	132
Pre_Anc_2Yr_Gtr5Mile	-0.03	0.04	0.39	133
Post_Anc_Pre_Con_Gtr5Mile	-0.03	0.03	0.36	105
Post_Con_2Yr_Gtr5Mile	-0.03	0.03	0.44	215
Post_Con_2_4Yr_Gtr5Mile	0.03	0.03	0.42	227
Post_Con_Gtr5Yr_Gtr5Mile	0.01	0.03	0.72	424

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	7
Model Name	Temporal Aspects Model
Dependent Variable	LN_SalePrice96
Number of Cases	7459
Number of Predictors (k)	56
F Statistic	404.5
Adjusted R2	0.75

Table A - 11: Full Results for the Orientation Model

	Coef.	SE	p Value	*n*
Intercept	7.62	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.33	0.04	0.00	87
Cnd Low	-0.44	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.13	0.01	0.00	1,445
Cnd High	0.24	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.03	0.00	1,071
OKCC	-0.44	0.02	0.00	476
IABV	-0.24	0.02	0.00	605
ILLC	-0.08	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.31	0.03	0.00	291
PAWC	-0.07	0.03	0.01	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
No View	Omitted	Omitted	Omitted	4,207
Minor View	-0.01	0.06	0.92	561
Moderate View	0.00	0.06	0.97	106
Substantial View	-0.01	0.09	0.87	35
Extreme View	0.02	0.17	0.89	28
Inside 3000 Feet	-0.04	0.07	0.55	67
Between 3000 Feet and 1 Mile	-0.05	0.05	0.37	58
Between 1 and 3 Miles	0.00	0.02	0.83	2,019
Between 3 and 5 Miles	0.02	0.01	0.22	1,923
Outside 5 Miles	Omitted	Omitted	Omitted	870
Front Orientation	-0.01	0.06	0.82	294
Back Orientation	0.03	0.06	0.55	280
Side Orientation	-0.03	0.06	0.55	253

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	8
Model Name	Orientation Model
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	40
F Statistic	410.0
Adjusted R Squared	0.77

Table A - 12: Full Results for the Overlap Model

	Coef.	SE	p Value	*n*
Intercept	7.61	0.18	0.00	
Nbr LN SalePrice96 hat	0.29	0.02	0.00	4,937
AgeatSale	-0.006	0.0004	0.00	4,937
AgeatSale Sqrd	0.00002	0.000003	0.00	4,937
Sqft 1000	0.28	0.01	0.00	4,937
Acres	0.02	0.00	0.00	4,937
Baths	0.09	0.01	0.00	4,937
ExtWalls Stone	0.21	0.02	0.00	1,486
CentralAC	0.09	0.01	0.00	2,575
Fireplace	0.11	0.01	0.00	1,834
FinBsmt	0.08	0.02	0.00	673
Cul De Sac	0.10	0.01	0.00	992
Water Front	0.34	0.04	0.00	87
Cnd Low	-0.45	0.05	0.00	69
Cnd BAvg	-0.24	0.02	0.00	350
Cnd Avg	Omitted	Omitted	Omitted	2,727
Cnd AAvg	0.13	0.01	0.00	1,445
Cnd High	0.24	0.02	0.00	337
Vista Poor	-0.21	0.02	0.00	310
Vista BAvg	-0.08	0.01	0.00	2,857
Vista Avg	Omitted	Omitted	Omitted	1,247
Vista AAvg	0.10	0.02	0.00	448
Vista Prem	0.13	0.04	0.00	75
WAOR	Omitted	Omitted	Omitted	519
TXHC	-0.75	0.03	0.00	1,071
OKCC	-0.44	0.02	0.00	476
IABV	-0.24	0.02	0.00	605
ILLC	-0.09	0.03	0.00	213
WIKCDC	-0.14	0.02	0.00	725
PASC	-0.31	0.03	0.00	291
PAWC	-0.07	0.03	0.00	222
NYMCOC	-0.20	0.03	0.00	346
NYMC	-0.15	0.02	0.00	469
No View	Omitted	Omitted	Omitted	4,207
Minor View	-0.03	0.02	0.10	561
Moderate View	-0.02	0.04	0.67	106
Substantial View	-0.05	0.09	0.57	35
Extreme View	-0.03	0.10	0.77	28
Inside 3000 Feet	-0.05	0.06	0.41	67
Between 3000 Feet and 1 Mile	-0.05	0.05	0.38	58
Between 1 and 3 Miles	0.00	0.02	0.82	2,019
Between 3 and 5 Miles	0.02	0.01	0.22	1,923
Outside 5 Miles	Omitted	Omitted	Omitted	870
View Does Not Overlap Vista	Omitted	Omitted	Omitted	320
View Barely Overlaps Vista	0.05	0.03	0.09	150
View Somewhat Overlaps Vista	0.01	0.03	0.67	132
View Strongly Overlaps Vista	0.05	0.05	0.31	128

"Omitted" = reference category for fixed effects variables
"n" indicates number of cases in category when category = "1"

Model Information

Model Equation Number	9
Model Name	Overlap Model
Dependent Variable	LN SalePrice96
Number of Cases	4937
Number of Predictors (k)	40
F Statistic	409.7
Adjusted R Squared	0.77

A REAL ESTATE STUDY
OF THE PROPOSED WHITE OAK WIND ENERGY CENTER
MCLEAN AND WOODFORD COUNTIES, ILLINOIS

Prepared for
Invenergy Wind LLC

Prepared by

POLETTI AND ASSOCIATES, INC.
302 West Clay Street
Suite 100
Collinsville, Illinois
618/344-3270

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EXECUTIVE SUMMARY

Poletti and Associates, Inc. has undertaken a Real Estate Impact Study of the proposed White Oak Wind Energy Center for the purpose of determining its compliance with the applicable standards of McLean County and Woodford County. The date of the report is April 15, 2007. The effective date of the opinion is January 20, 2007.

Specifically, the subject property and plans for the proposed wind energy center have been studied. Other items considered include the uses and property values of surrounding tracts of land. The purpose of this report is to determine whether the proposed Wind Energy Center is so located as to minimize any effect on property values.

When a land use is proposed that is dependent upon a regulatory approval, such as in the case of the subject, it is important to consider its compatibility with the established and historic land uses; and its impact on the use, marketability and value of other property in the vicinity. An analysis of this type is appropriate, when addressing the standards of the State of Illinois.

The procedure followed in the analysis was generally as follows:

1. A preliminary on-site inspection of the subject property and the surrounding area was performed as well as a personal inspection of the Kewaunee County wind turbine sites (2 separate utility scale wind farms) and the Mendota Hills Wind Mill turbine sites (a large scale utility size wind farm).

2. The accumulation and review of various documents, including a map of the proposed wind turbine locations for the subject, soil maps and ownership plats, aerial photographic maps, local and regional roadway maps, data on real estate transfers in proximate areas, and discussions with various assessors, and other related materials.

3. The accumulation, review and analysis of property transactions in the surrounding area were completed.

Based upon examination, analysis and evaluation of the subject property, the surrounding area, and the data described above and contained within this report, it is concluded that the proposed White Oak Energy Center is so located as to minimize the effect on the value of the surrounding property.

The details of the analysis and the factors considered in reaching this conclusion are found on the following pages.

INTRODUCTION

This report provides an evaluation of the proposed White Oak Wind Energy Center for the purpose of determining the facility is so located as to minimize the effect on the value of the surrounding property.

LOCATION

The site is located within McLean and Woodford counties of Illinois. The proposed project is generally located between the 1300 East Road on the east, the south of Woodford County line on the north, the Township Road 2000 on the west, and Interstate 74 on the South.

SCOPE OF THE CONSULTING REPORT

The purpose of this report is to determine if the proposed White Oak Wind Energy Center is located so as to minimize any effect on the character of the surrounding area and is so located as to minimize any effect on surrounding property values. A review of published literature concerning the effect of wind generated electric facilities, and sanitary landfills on surrounding property values were made. Plans for the proposed White Oak Wind Energy Center were reviewed. Representatives of Invenergy Wind, LLC were interviewed concerning design and operating specifics. Peter J. Poletti inspected the subject project area as well as land uses within that area. Information employed in this report was gathered from a variety of sources. The record of the sales transactions for the Town of Lincoln and Town of Red River in Kewaunee County in Wisconsin and for Lee County in Illinois were reviewed for sales transactions surrounding operating large scale wind generating sites. This record included the style, age, and size of the improvements. Face-to-face discussions were also held with Gary Taicher, the Red River Town Assessor, and Joe Jerabek, the Lincoln Town Assessor concerning facts about various sales transactions including the relationship between buyer and seller, extenuating circumstances that could affect the various sales, overall quality of improvements, and general development trends in the area.

ASSUMPTIONS AND LIMITING CONDITIONS

1. The appraiser did not make a boundary survey of the property; therefore, no responsibility is assumed in connection with such matters. Sketches in this report are included only to assist the reader in visualizing the property.

2. No responsibility is assumed for matters of a legal nature affecting title to the property nor is an opinion of title rendered. The title is assumed to be good and merchantable.

3. Information furnished by others is assumed to be true, correct, and reliable. A reasonable effort has been made to verify such information; however, the appraiser assumes no responsibility for its accuracy.

4. This report considers the subject property as being under responsible ownership and competent management.

5. It is assumed that there is general compliance with all federal, state, and local environmental regulations and laws unless non-compliance is stated, defined, and considered in the consulting report.

6. It is assumed that all applicable zoning and use regulations and restrictions have been complied with, unless a nonconformity has been stated, defined, and considered in the consulting report.

7. It is assumed that all required licenses, consents, or other legislative or administrative authority from any local, state, or national governmental or private entity or organization have been or can be obtained or renewed for any use on which the value estimate contained in this report is based.

8. It is assumed that the utilization of the land and improvements is within the boundaries or property lines.

9. Any use of this appraisal report by anyone, whomsoever, constitutes acceptance of the above and any other limiting conditions that might be outlined later herein.

GENERAL LIMITING CONDITIONS

1. The appraiser or Poletti and Associates, Inc. will not be required to give testimony or appear in court because of having made this appraisal, with reference to the property in question, unless arrangements have been previously made therefore.

2. Possession of this report, or a copy thereof, does not carry with it the right of publication. It may not be used for any purpose by any person other than the party to whom it is addressed without the written consent of the appraiser or Poletti and Associates, Inc., and, in any event, only with proper written qualification and only in its entirety.

3. The distribution of the total valuation assigned in this report between land and improvements applies only under the reported highest and best use of the property. The allocations for land and improvements must not be used in conjunction with any other appraisal and are invalid if so used.

4. Neither all nor any part of the contents of this report, or copy thereof, shall be conveyed to the public through advertising, public relations, news, sales, or any other media without the expressed written consent and approval of the appraiser or Poletti and Associates, Inc. Nor shall the appraiser, firm, or professional organization of which the appraiser is a member be identified without the written consent of the appraiser.

PURPOSE AND INTENDED USER OF THE REPORT

The purpose of this report is for incorporation in the siting application and use at the siting hearing for the proposed White Oak Wind Energy Center. The intended user of this report is Invenergy Wind, LLC, their representatives, and the County Board of McLean County and the County Board of Woodford County. Use by anyone else is not permitted.

REVIEW OF LITERATURE

A review of literature concerning property value impacts from wind farms as well as sanitary landfills was made. These studies are briefly summarized below.

The best known wind farm study is The Effect of Wind Development on Local Property Values by the Renewable Energy Policy Project {REPP]. This report was produced in May 2003 and studied ten projects located in California, New York, Texas, Vermont, Wisconsin, Pennsylvania, and Iowa. The study reviewed more than 25,000 sales within the view shed areas and comparable areas. This study essentially looks at the rate of change in property values within and without a view shed of the turbines. The view shed of each project was generally defined as a five-mile radius from the outermost turbine. Data from the view shed was then compared to another comparable area that was chosen based on demographic characteristics and local assessor's impressions. This REPP analysis used three separate cases: (1) looked at how prices changed over the entire period of the study for the view shed and comparable region; (2) compared how prices changed within the view shed before and after the projects came on-line; and (3) looked at how prices changed for both the view shed and the comparable region but only for the period after the projects came on-line. The study used simple regression analysis to obtain an indication of how the rate of property value change was affected in each of the cases. The study concluded that: "the statistical analysis does not support a contention that property values within the view shed of wind developments suffer or perform poorer than in a comparable region." [REPPS, 4]

ECONorthwest produced a report in November of 2002 for the Phoenix Economic Development of Ellensburg Washington entitled the Economic Impacts of Wind Power in Kittitas County." This study looked at three impacts: (1) Property Values; (2) Economic Impacts; and (3) Tax Revenues. The property valuation section consisted of two separate analyses. One utilized interviews of the tax assessor in jurisdictions where wind farms had been constructed within the ten pervious years. The study sample included twenty-two wind farms located in thirteen different counties. Six of the counties had residential properties with view of turbines while six of the remaining had no residential view of the wind farm. The wind farm in the thirteenth county was too new for the assessor area to know if nearby property values were affected. Assessors in all six of the counties with residential views stated that they had not determined any negative impact on property values.

The second means of analysis used by ECONorthwest was a review published literature. The literature was restricted to journals where the articles are subject to peer review. ECONorthwest reported only one study on wind farms impact on property values. This 1995 Danish study reported lower prices for homes near an operating wind farm. It indicated that prices for homes near the wind farm were 94 Kroners (or about $17 per home in 1995 U.S. dollars) lower than houses located farther away. This difference was not statistically significant and was based on a small sample size. The other articles reviewed by ECONorthwest concerned power transmission lines.

It is also helpful to look at other studies that have investigated a land use that could affect surrounding property values. These studies can provide a methodological basis for any study of wind farms. Sanitary landfills are often alleged to have negative impacts on surrounding property values. Consequently, there have been a number of studies on this property use. Pettit and Johnson wrote a brief review of landfill impacts in a 1987 article in Waste Age. This article is a short digest of the various techniques that may be utilized to assess a landfill's impact on the surrounding neighborhood. Essentially, they pointed to two basic approaches: (1) use of assessments; and (2) use of comparable property sales. The weaker of these two approaches is, by far, the use of assessment data. The major limitation of this approach is that the basis of depreciation is largely political and subjective rather than based upon market data.

The second and superior approach is the use of existing sales data. In this method, sales of property located near an operating landfill are compared to selling prices of similar properties located some distance from an operating landfill.

A study that utilizes the technique of comparing sales is a 1984 study by Penn State researchers, Gamble and Downing. They investigated the historical rate of development within a designated zone surrounding nine landfills [Gamble, 1984]. The researchers concluded there was no convincing evidence that the landfill sites had any adverse impact on the rate of community growth in surrounding areas. The data, however, did suggest that there was somewhat less development growth adjacent to the landfills. Researchers found that different sets of explanatory variables and different functional forms led to nearly the same results: property characteristics other than distance to the landfill appear much more important in explaining prices. Similar conclusions were also reached in a 1983 study undertaken by Research Planning Consultants on four operating sanitary landfills [Research and Planning Consultants, Inc., 1983].

Reichert, Small, and Mohanty studied five landfills in the Cleveland Area in 1991 based upon data collected from 1985 to 1989. This study conducted both surveys of homeowner's perceptions as well as selling prices. Multiple regression techniques were then used to measure any impact. The results were somewhat mixed but the investigators finally concluded that landfills will have the most impact on property values (5.5% to 7.3%) when an expensive subdivision is located within several blocks of the landfill. The impact was less for older, less expensive areas and is essentially non-existent in predominately rural areas.

Bleich, Findlay, and Phillips produced an article for the Appraisal Journal in 1991 utilizing a multiple correlation framework [Bleich, 1991]. This technique utilizes a variety of variables to compare the selling prices of homes located near a landfill with similar homes and neighborhoods located some distance from a landfill. The results indicated that a well-designed and maintained landfill had no statistically measurable impact on the selling prices of the homes.

DESCRIPTION OF THE PROPOSED WHITE OAK WIND ENERGY CENTER

The proposed White Oak Wind Energy Center will be constructed in a defined project area containing approximately 12,000 acres. There will be a total of 131 wind turbines sites with 100 Turbine locations actually being used. Each turbine pedestal will be about 262 feet high with a blade sweep area of 274 feet. The total overall height will be 397 feet. The turbines will have a minimum setback of 1,500 feet from any non-participating residence.

Fig. 1: White Oak Wind Energy Center.

PHYSICAL CHARACTERISTICS OF THE SUBJECT AREA

ACCESS AND FRONTAGE

The proposed wind energy farm will comprise an area of about 12,000 acres within White Oak, Hudson and Dry Grove townships in McLean County and Kansas Townships in Woodford County. The site is located within McLean and Woodford counties of Illinois. The proposed project is generally located between the 1300 East Road on the east, the south of Woodford County line on the north, the Township Road 2000 on the west, and Interstate 74 on the South.

TOPOGRAPHY AND CURRENT USE

The site topography is moderately rolling. The predominant use is agriculture with some lower lying areas along creeks being wetland areas.

UTILITIES

The communities generally provide water and sewer service to area within their corporate boundaries. The surrounding rural areas are typically dependent on private wells and septic systems. Electricity within the area is furnished by either Dynergy/Illinois Power or Corn Belt Electric Cooperative, Inc. depending upon location. Natural Gas service is provided by Nicor, where available or by private propane service in other areas.

ECONOMIC AND SOCIAL DATA OF THE SUBJECT AREA

The subject property is located in White Oak, Dry Grove and the western portion of Hudson townships in McLean County and the eastern portion of Kansas Township in Woodford County. The greatest concentration of population in the area is the adjoining cities of Bloomington and Normal (see Fig. 2). Carlock is situated just to west of the project area with Hudson located just east of I39. Other nearby communities includes Congerville to the west, Danvers to the southwest, and Kappa to the northeast. The project area comprises about 12,000 acres.

TRANSPORTATION

Transportation and access to the area is good. Interstate 74 is located along the southwest side of the project area while Interstate 39 is located along the east side. Interstate 39 is a north south interstate that connects Bloomington to Rockford and Wisconsin to the north. This route is also used as a bypass for traffic around the congested Chicago area. This interstate is projected to be ex be eventually extended to southern Illinois, although there is no timetable for this completion. Interstate 74 is an east-west interstate connecting Indianapolis, Indiana on the east to Davenport, Iowa and the major east-west Interstate 80 on the west. Additionally, Interstate 55, which connects Chicago, Illinois and St. Louis Missouri passes just to the south of the project area. Besides the interstate, U.S. Highway 150 parallels Interstate 74 providing secondary access to communities. County or township maintained roads provide local access. These are generally two-lane with an asphalt surface with some roads being improved gravel roads. Overall road access is considered to be good.

Rail service is provided to the area by the Norfolk Southern Railroad. The nearest international airport is in Milwaukee. Other airports are available in Fond du Lac, Oshkosh, and Green Bay.

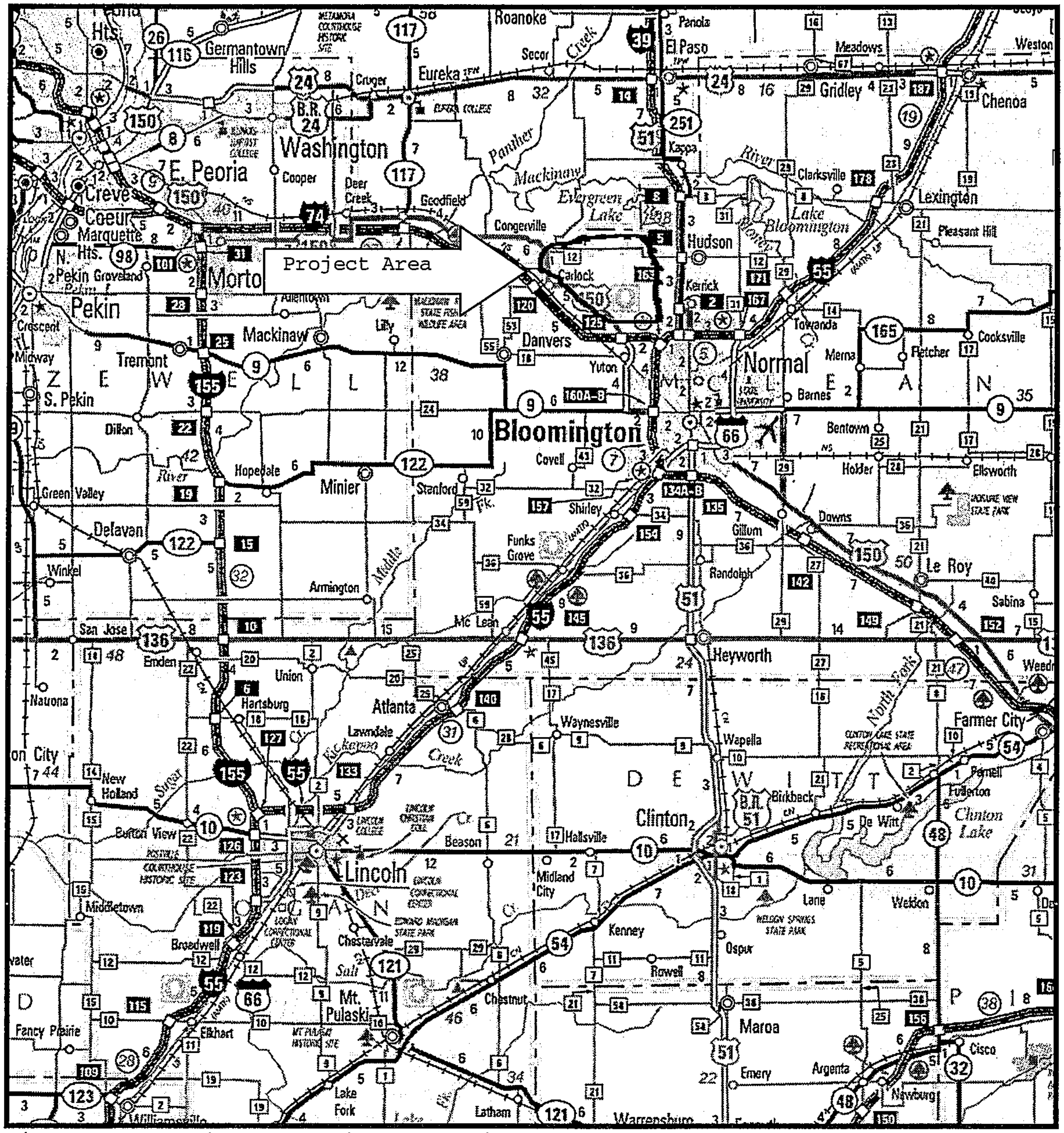


Fig. 2: Location of White Oak Wind Energy Center, McLean and Woodford Counties, Illinois.

POPULATION

A review of population for the area shows that the population has generally increased (see Table 1).

Table 1: Population.

City	1960	1970	1980	1990	2000
Places:					
Carlock:	318	477	409	418	456
Congerville:	NA	266	373	397	466
Hudson:	493	802	929	1,006	1,510
Danvers:	783	854	921	981	1,183
Kappa	119	131	170	134	170
Bloomington:	36,271	39,992	44,189	51,972	64,808
Normal:	13,357	26,396	35,672	40,023	45,386
Townships:					
White Oak Twn.	541	647	761	803	807
Hudson Twn.:	1,144	1,619	1,766	1,853	2,318
Dry Grove Twn.:	750	993	1,501	1,494	1,649
Kansas Twn.	228	189	329	319	346
Counties:					
McLean Ctn.:	83,877	104,389	119,149	129,180	150,433
Woodford Ctn.:	24,579	28,012	33,320	32,653	35,469
Illinois:	10,081,158	11,110,258	11,427,429	11,430,602	12,419,293

ECONOMIC CHARACTERISTICS

The subject area is very similar to the general land use in central Illinois. The prevalent land use is agricultural with the typical crops being corn, soybeans, and wheat. Consequently, the localized economy is primarily centered on the agricultural sector with the various communities functioning as a service centers for the surrounding farms. The various establishments reflect this function. There are a number of grain elevators throughout the area. Additionally, the area also has some residents that are employed in surrounding communities such as Bloomington/Normal area and the Peoria/Morton area.

Nonagricultural commercial uses are limited in the area. These include Ropp Jersey Cheese Store, Crump Family Gardens, East White Oak Bible Church, and the Fair Meadow Stables.

Communities in the area have services typical of similar sized communities and generally serve the local residents. The closest community to the project is Carlock. This town has an interchange on Interstate 72. Establishments in the community include a grade school, post office, a convenience store/gas station, a restaurant, a bank, and several other commercial establishments.

The other community in proximity to the project is Hudson. This town also has an interchange on Interstate 39, but this interchange remains undeveloped. Services within the village include a grade school, bank, quick shop/gas station, implement dealer, fertilizer service, grain elevator, and a lumber yard among others.

Besides local establishments, residents can also shop at several other communities. The Bloomington/Normal area can generally be reached in ten to fifteen minuets from locations within the project area. Beaver Dam can be reached ion about forty-five minutes while the greater Chicago area can be reached in about two to two and one-half hours depending upon location.

Newer residential development is relatively limited and is generally confined to the existing communities with limited residential development in remaining portions the project. The most significant area of residential development in the unincorporated areas within the project area occurs near the intersection of 2250 North Road and 825 East Road where there is a clustering of residential properties. Besides these two areas, residential development generally consists of houses on rural tracts. There are no large subdivisions within the subject area.

There are several recreational facilities available in the immediate area. Evergreen Lake is located to the north of the proposed wind farm. This county owned park, comprising 880 acres, features hiking, biking, bird watching, and fishing among its various activities. Lake Bloomington is located about three miles northeast of Hudson. The lake is owned by the City of Bloomington and is used for its water supply. It also features fishing, camping, hiking, and other recreational activities. Other recreational facilities nearby include the Funks Grove Reserve and the Moraine View State Park. In addition, there are numerous other state parks, conservation areas, and small state forest preserves throughout central and northern Illinois.

CONCLUSIONS ON ECONOMIC AND SOCIAL DATA

The subject area is typical of many similar areas in central Illinois. There is a strong reliance on the agricultural sector. With Interstate 39 along the eastern side and Interstate 74 along the southwest side of the project area, the highway access is considered superior in comparison to many rural areas of Illinois. Similarly, there is good rail access in the area. Population is also showing some growth after a period of decline. The number of recreation activities and education establishments available nearby enhance the desirability of the communities in the subject area.

IMPACT ON THE VALUE OF THE SURROUNDING PROPERTIES

One means of estimating a wind power electric generating farm's impact on surrounding property values is to compare sale prices of properties within a target area to prices of similar properties within a control area. The target area is a zone in proximity to an operating wind generating electric farm and is defined by a combination of distance, intervening land uses, and visibility of the facility. The control area is the region outside of the target area that is considered to be a zone where property values would not be affected by an operating wind farm. There is no existing wind farm at the subject site. Consequently, it was necessary to investigate property sales around two operating wind farms. The wind farms used are the Lincoln and Rosiere wind farms in Kewaunee County, Wisconsin and the Mendota Hills Wind Farm in Lee County, Illinois.

ROSIERE AND LINCOLN WIND FARMS, KEWAUNEE COUNTY, WISCONSIN

There are two wind farms located within Kewaunee County that have operated since 1998. The farms are located within Red River and Lincoln townships about midway between Lake Michigan and Green Bay. The larger of the two farms is the Rosiere Wind Farm located along Red River and Town Line Road. This wind farm is operated by Madison Gas and Electric and has a total of 17 turbines located on 476 acres. The Lincoln Wind Farm is operated by Wisconsin Public Service and is located near Gregorville. It comprises 14 turbines located on 237 acres. Although smaller than those proposed for the subject project, the design of the turbines is similar to those at the subject.

Land use in the area is primarily agricultural with some commercial establishments located in smaller communities such as Casco and Luxembourg. Most residential development consists of houses located on tracts between one and ten acres. Development throughout both townships has continued since the turbines were constructed in 1998. The topography is somewhat rolling and is generally similar to that at the subject site.

Sales were gathered from Joe Jerabek, the Town of Lincoln Assessor and Gary Taicher, the Town of Red River Assessor. The years that sales were available were from January of 1998 through December of 2004 for the Lincoln Township and January of 2001 through December of 2004 for Red River Township. Sales that occurred between related parties (such as family members), as the result of judicial actions or in lieu of foreclosure, or involved governmental units were eliminated from consideration. Such sales do not represent transactions that meet the requirements of the definition of market value. Also eliminated from consideration were sales to Wisconsin Public Service and Madison Gas or Electric for similar reasons. The studies are detailed below.

Target areas were defined for each wind turbine farm. The Target Areas are illustrated in Figure 3. The Control Area lies outside the Target Area. The Control Area does not include the western most portion northwestern portion of Section 18 and the western half of Section 8 of the Red River Township. This area is near Highway 57 and Green Bay. This area was excluded because of overall better road access to the City of Green Bay and because of the influence of shore front property and bay view on prices of land and homes when compared to those without views of the bay or quick access to City of Green Bay.

Fig. 3: Target Area of Rosiere and Lincoln Wind Farms.

Small Residential Tract Acreage

A review was made of the selling prices of residential acreage. These tracts are defined as comprised of five acres or less. There were a total of nine sales with in the Target Area and twelve sales within the Control Area. The sales are summarized in Table 2. The average selling price per acre within the Target Area was $6,548 while within the Control Area it was $5,785. These two prices are similar, indicating that there is no difference in the overall price of land within the Target Area versus smaller residential tract sales in the Control Area.

Special mention is made of Sale 9 within the Target Area. This sale is located on Cherry Road approximately 1,900 feet from the nearest operating turbine and has a direct view of the wind farm. This property sold for a price per acre of $23,333. There was an existing old house on the property, which was torn down for a new house. The cost for removal of the existing house is not included in the $23,333 per acre. If Sale 9 is ignored, then the overall price per acre of Target Area is $4,450 per acre.

A statistical comparison was made of the two means to ascertain if there was, in fact, a significant difference between the two indicated prices. This analysis does not include Sale 9. This analysis indicated that the calculated T statistic for the sample was 0.577. This is less than the Standard T of 1.729 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of small residential tracts within the target and control areas.

Table 2: Small Residential Tract Sales.

Sale	Parcel No.	Address	Grantor	Grantee	Sale Price	Size	Book/ Page	Sale Date	$/Ft^2
Target:									
1	31 010 5 021	X	Sprngdl. DF	Chaudoir	$1,800	1.000	341/011	Nov-99	$1,800
2	31 010 14 151	Black Ash	Wery	Miller	$6,500	1.000	420/207	Feb-03	$6,500
3	31 010 22 12	S	Jeanquart	Dufek	$2,400	2.980	336/355	Jul-99	$805
4	31 010 22 14	Cherry	Cravillon	Naze	$5,000	5.000	338/303	Sep-99	$1,000
5	31 010 35 151	P	Mertens	Srnka	$1,500	0.085	346/362	May-00	$17,647
6	31 010 35 151	P	Mertens	Neuzil	$300	0.120	318/895	May-98	$2,500
7	31 010 35 151	P	Mertens	Vogel	$2,000	2.000	337/589	Aug-99	$1,000
8	31 018 12 153	Tamarack	Schlise	Challis	$20,000	4.600	402/782	Sep-02	$4,348
9	31 010 27 092	N7875 Cherry	Fenendael	Pelnar	$21,000	0.900	472/110	Aug-04	$23,333
Average:									$6,548
Average Sales 1 through 8:									$4,450
Control:									
10	31 010 3 061	Fir	Dutil Trust	Hackett	$3,000	5.000	351/130	Sep-00	$600
11	31 010 10 165	Hawk Rd	Nicolet Brd.	Streck	$10,900	1.600	375/146	Sep-01	$6,813
12	31 010 11 15	Hawk Rd	Moreau	Paul	$500	1.000	341/690	Dec-99	$500
13	31 010 19 151	S	Kinnard Fms	Beaurain	$300	0.210	430/225	Apr-03	$1,429
14	31 010 19 014	Martin	Dhuey Trust	Cochart	$2,000	1.400	428/17	Apr-03	$1,429
15	31 010 29 131	Maple Rd	Deprey	Doperalski	$10,000	1.000	333/256	Apr-99	$10,000
16	31 010 29 131	Maple Rd	Deprey Tr.	Petry	$10,000	1.500	342/235	Jan-00	$6,667
17	31 010 29 135	Maple Rd	Martin	Deprey	$12,900	2.000	349/555	Aug-00	$6,450
18	31 010 33 12	K	Strnad	Spitzer	$28,000	4.500	350/173	Sep-00	$6,222
19	31 010 33 061	Maple Rd	Deprey	Moreau	$2,400	2.300	334/457	Jun-99	$1,043
20	31 018 30 163	E0478 Thiry	Pallet	LeGrave	$17,500	1.000	462/636	Apr-04	$17,500
21	31 018 30 166	E0496 Thiry	Nachtwey	LeGrave	$14,000	1.300	461/169	Apr-04	$10,769
Average:									$5,785

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	9	8	$4,450	226,288,635	5318.47
Control:	12	11	$5,785	297,570,905	5201.14
Combined:	21	19		523,859,540	

Variance:	27,571,554.7
Variance of Difference of Means:	5,361,135.64
Standard Deviation:	2,315.41
Calculated T =	0.577
Standard T at 95% 19 Degrees of Freedom:	1.729

Residential Tract Acreage

A review was made of the selling prices of residential tract acreage. These tracts are defined as comprising between five acres and twenty acres. The sales are summarized in Table 3. These sales indicated that the average selling price within the Target Area was $2,494 per acre while within the Control Area it was $1,747. These two prices are close together and would indicate that there is no difference in the overall price of land within the Target Area versus small residential tract sales in the Control Area.

Table 3: Residential Tract Sales.

Parcel No.	Address	Grantor	Grantee	Sale Price	Size	Book/ Page	Sale Date	$/Ft²
Target:								
31 010 22 021	P	Rhoades	Shaw	$76,000	14.040	327/27	Oct-98	$5,413
31 010 35 151	K	Mertens	Jahnke	$15,000	18.100	343/888	Mar-00	$829
31 010 36 13	Chestnut	Salzsieder	Nell	$6,000	6.000	316/642	Apr-98	$1,000
31 010 36 161	SH 54	Salzsieder	Nell	$8,400	7.000	453/230	Nov-03	$1,200
31 010 36 161	SH 54	Salzsieder	Nell	$11,600	12.000	453/232	Nov-03	$967
31 018 24 161	S	Englebert	Johnson	$100,000	18.000	365/845	Jun-01	$5,556
Average:								$2,494
Control:								
31 010 9 15	Hawk Rd	Horak	Alberts	$6,136	9.000	335/675	Jun-99	$682
31 010 20 151	CH "S"	Dhuey	Theys	$2,000	6.000	324/401	Oct-98	$333
31 010 20 06	Spruce Rd	Dhuey	Jandrin	$10,000	12.500	313/817	Feb-98	$800
31 018 3 022	E1531 Cnty Ln.	Laluzerne	Ahlswede	$15,000	10.000	373/219	Oct-01	$1,500
31 018 3 051	County Line	Mork	Jonet	$23,300	17.300	388/236	Mar-02	$1,347
31 018 3 111	X & Rocky Road	Dalebroux	Derenne	$42,000	19.000	444/348	Aug-03	$2,211
31 018 16 16	Town Hall	Dalebroux	Besaw	$27,300	13.000	452/516	Nov-03	$2,100
31 018 19 16	SS	Mertens	Brenneke	$35,000	7.000	357/882	Jan-01	$5,000
Average:								$1,747

Large Tract Acreage

A review was made of the selling prices of large tract acreage. These tracts are defined as comprised of more than twenty acres. They are used for agricultural purposes or very large residential tracts. Sales between family members and related parties as well as those comprising swamp and forested land were not included in the analysis. The agricultural sales are summarized in Table 4. These sales indicated that the average selling price within the Target Area was $1,418 per acre while within the Control Area it was $1,602. These two prices are close together and indicate that there is no significant difference in the overall price of land within the Target Area versus large tract sales in the Control Area.

A statistical comparison was made of the two means to ascertain if there was, in fact, a significant difference between the two indicated prices (see Table 5). This analysis indicated that the calculated T statistic for the sample was 0.881. This is less than the Standard T of 1.678 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of large tracts within the target and control areas.

Table 4: Large Tract Sales.

Sale	Parcel No.	Address	Grantor	Grantee	Sale Price	Acres	Book/ Page	Sale Date	$/Acre
Target:									
1	31 010 6 153	Spruce Rd & C	Herison	Pagel's	$108,000	72.0	394/62	Jun-02	$1,500
2	31 010 7 05	Tamarack Rd	Hurley	Jandrin	$37,500	25.0	469/662	Jul-04	$1,500
3	31 010 21 031	Apple	Kinnard	Peters	$63,800	75.0	335/341	Jun-99	$851
4	31 010 22 04	P	Morse Trust	Sogge	$58,000	40.0	397/709	Aug-02	$1,450
5	31 010 22 06	Partridge	Golapske	Moynihan	$112,500	40.0	442/103	Aug-03	$2,813
6	31 010 27 14	Cherry Rd	Pelnar	Yunk	$29,155	35.0	324/181	Oct-98	$833
7	31 010 27 05	S. Cherry	Duescher	Petersilka	$40,000	36.0	342/652	Jan-00	$1,111
8	31 010 27 091	Cherry	Almonte	Fenendael	$36,000	39.0	355/450	Feb-01	$923
9	31 010 27 08	Cherry	Miller	Zellner	$80,000	40.7	392/639	Jun-02	$1,966
10	31 010 33 08	Hemlock	Vandermause	Maedke	$60,000	41.0	447/625	Sep-03	$1,463
11	31 010 33 03	Hemlock	Annoye	Srnka	$63,000	70.0	318/192	May-98	$900
12	31 010 34 111	Hemlock	Annoye	Strand	$26,000	34.4	316/829	Apr-98	$756
13	31 010 35 12	E4386 K	Mertens	Hoagland	$40,000	40.0	343/352	Feb-00	$1,000
14	31 010 35 12	K	Mertens	Hoagland	$40,000	40.0	431/738	Feb-03	$1,000
15	31 018 23 061	Town Hall	Haske	Watson	$110,000	34.3	472/683	Sep-04	$3,207
Average:									$1,418
Control:									
16	31 010 3 061	X & Fir	Dutil	Pagel's	$45,204	34.7	388/118	Mar-02	$1,303
17	31 010 3 022	Elm	Dutil Trust	DeGrave	$45,200	34.7	373/820	Oct-01	$1,301
18	31 010 3 11	Fir	Huettl	Pagel's	$63,000	35.0	453/937	Dec-03	$1,800
19	31 010 4 05	X	Forsch	Pagel's	$49,600	33.0	462/307	Apr-04	$1,503
20	31 010 4 03	X	Menne	Pagel's	$99,800	66.5	430/516	Apr-03	$1,501
21	31 010 5 13	C	Delfosse	Pagel's	$58,400	39.2	454/163	Dec-03	$1,490
22	31 010 9 15	Fir	Horak	Kinnard	$35,000	50.0	339/233	Oct-99	$700
23	31 010 9 16	N8967 Fir	Kinnard	Pagel's	$50,000	57.7	421/715	Sep-02	$866
24	31 010 9 141	P	Horak	Pagel	$180,500	260.0	317/645	May-98	$694
25	31 010 10 121	Hawk Rd	Pinchart	3 M Tree Fa	$65,000	39.4	375/26	Nov-01	$1,650
26	31 010 11 063	CH P	Horak	Postotnick	$24,000	20.0	320/682	Jul-98	$1,200
27	31 010 11 063	P	Postotnik	Krzewina	$33,000	20.0	347/496	Jun-00	$1,650
28	31 010 11 063	P	Horak	Postotnick	$33,000	20.0	347/495	Jun-00	$1,650
29	31 010 11 032	Black Ash	Massey	Leitzinger	$90,000	60.0	342/146	Jan-00	$1,500
30	31 010 13 04	Hickory	Gostein	Blair	$87,500	40.0	437/129	Jun-03	$2,188
31	31 010 14 04	Black Ash	Tollefson	Parins	$40,000	40.0	400/795	Aug-02	$1,000
32	31 010 14 03	Black Ash	Carr	Destree	$73,500	40.0	439/867	Jul-03	$1,838
33	31 010 14 08	Black Ash	Massey	Destree	$40,000	41.0	338/414	Sep-99	$976
34	31 010 14 111	Cherry & Part	Deer Trail I	Miller	$50,000	72.6	321/902	Aug-98	$688
35	31 010 15 061	Hawk Rd	Mertens	Sautebin	$40,000	40.0	352/831	Dec-00	$1,000
36	31 010 20 101	Spruce	Dhuey Trust	Kinnard	$30,000	20.0	433/377	Jun-03	$1,500
37	31 010 29 131	Pheasant Rd.	Mueller	Pinchart	$108,700	58.7	452/751	Nov-03	$1,852
38	31 010 29 131	Pheasant Rd.	Deprey Tr	Mueller	$104,000	186.6	391/220	May-02	$557
39	31 010 32 011	Maple Rd	Deprey Tr	Massart	$40,000	20.0	342/878	Feb-00	$2,000
40	31 010 32 05	Pheasant Rd.	Frisque	Kinnard	$47,000	21.3	476/574	Nov-04	$2,207
41	31 010 32 10	C	Pinchart	Kinnard	$60,000	40.0	382/721	Jan-02	$1,500
42	31 010 32 011	Pheasant Rd.	Mueller	Anderson	$86,000	40.0	455/397	Dec-03	$2,150
43	31 010 32 06	E2995 Pheasan	Deprey Tr	Mueller	$183,000	100.0	391/219	May-02	$1,830
44	31 010 32 021	Pheasant Rd.	Mueller	Kinnard Fa	$242,000	118.0	455/378	Jan-04	$2,051
45	31 018 3 111	X & Rocky Rd.	Dalebroux	Derenne	$38,000	20.0	444/343	Aug-03	$1,900
46	31 018 20 073	H	Nellis	Bader	$70,000	20.0	369/631	Jul-01	$3,500
47	31 018 20 141	S	Dalebroux	Jacobs Tr.	$235,000	94.0	452/90	Nov-03	$2,500
48	31 018 21 071	A	Dalebroux	Euclide	$124,200	43.8	465/119	Apr-04	$2,836
Average:									$1,602

Table 5: Statistical Analysis of Large Tract Sales.

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	15	14	$1,418	7,521,028	732.95
Control:	33	32	$1,602	13,231,030	643.02
Combined:	48	46		20,752,058	
Variance:					451,131.7
Variance of Difference of Means					43,746.10
Standard Deviation:					209.16
Calculated T =					0.881
Standard T at 95% 46 Degrees of Freedom:					1.678

Single Family Residential Values

A number of homes have sold within the target area surrounding the two operating wind farms in Kewaunee County. A total of seventy-nine improved sales were reviewed. Of these, 33 sales were within the Target Area and 46 sales were within the Control Area. These sales are summarized in Appendix I. Sales between relatives or other related parties, commercial establishments and mobile homes were removed from the analysis as not being truly indicative of values for a single-family residential property. This left a total of 26 sales within the Target Area and 39 sales within the Control Area. The overall average price within the Target Area was $62.19 per square foot and $68.60 per square foot within the Control Area. The two averages are very close indicating that there is no apparent difference between the target and control area prices. A statistical comparison was made of the two means to ascertain if there was a difference between the two indicated prices (see Table 6). This analysis indicated that the calculated T statistic for the sample was 0.688. This is less than the Standard T of 1.671 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of all residences within the target and control areas.

Table 6: Statistical Analysis of All Residential Properties.

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	26	25	$62.19	19,782	28.13
Control:	39	38	$68.60	65,630	41.56
Combined:	65	63		85,412	
Variance:					1,355.7
Variance of Difference of Means:					86.91
Standard Deviation:					9.32
Calculated T =					0.688
Standard T at 95% 63 Degrees of Freedom:					1.671

These homes vary significantly in characteristics such as total size, style, age, amount of associated land, and number of outbuildings. Because of the magnitude of these differences, comparing an overall average sale price of all sales within the Target Area to an average sale price within the Control Area would not be meaningful.

To increase the reliability of the study, certain criteria were applied to the sales. Only houses constructed after 1960 were used because these homes are more similar in style, construction techniques, amenities, condition, and utility than homes constructed before this time frame. Homes located on tracts larger than five acres or those with newer large outbuildings were not used because of the possibility of the extra land and buildings distorting the price per square foot. Bi-level and tri-level homes also were not included in the study because they tend to sell for less per square foot than do one-story and two-story homes and because it is often difficult to accurately estimate the actual amount of living space. Consequently, these types of homes would tend to skew results in the sample.

A total of 19 sales remained in the sample with 6 sales being located within the target area and the remaining 13 within the control area. The sales used are summarized in Table 7. The overall per square foot price range for houses within the target area was from $77.47 to $108.75 with an average of $92.64. In comparison, the overall per square foot price range for houses within the control area was from $68.59 to $122.75 with an average of $91.53 or $1.11 lower than that within the Target Group. A statistical comparison was made of the two means to ascertain if there was, in fact, a significant difference between the two indicated prices. This analysis indicated that the calculated T statistic for the sample was -0.147. This is less than the Standard T of 1.740 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of residences within the target and control areas. Overall, it is concluded that there is no measurable difference between improved residential sales within the Target and Control Area.

Table 7: Sales of Residences Constructed After 1960.

Sale	Parcel No.	Address	Sale Price	Acres	Sale Date	Age	Ft^2	$/$Ft^2$	Sum Of Squares
Target Area:									
17	31 010 27 05	N8015 Cherry	$162,000	5.00	Oct-02	2001	1,850	$87.57	26.0
25	31 018 3 161	E1650 X	$80,000	1.10	Feb-02	1980	1,000	$80.00	160.0
26	31 018 3 162	E1658 X	$121,500	1.50	Sep-02	1998	1,232	$98.62	36.0
27	31 018 13 093	E2225 Fameree	$119,000	1.10	Feb-03	1983	1,536	$77.47	230.0
28	31 018 15 151	E1596 Town Hall	$184,000	5.00	Mar-04	1995	1,692	$108.75	260.0
29	31 018 15 151	E1596 Town Hall	$175,000	5.00	May-02	1995	1,692	$103.43	116.0
Average:								$92.64	828.0
Control Area:									
42	31 010 17 141	N8601 C	$172,000	1.00	May-02	1980	1,569	$109.62	327.0
54	31 010 31 103	N7452 RR&LTL	$150,000	1.29	Mar-04	1988	1,222	$122.75	975.0
55	31 010 32 111	E2962 K	$120,400	2.00	Sep-99	1972	1,544	$77.98	184.0
57	31 010 32 051	E3009 Pheasant	$127,000	2.00	Jul-02	1991	1,361	$93.31	3.0
58	31 010 32 122	E3088 K	$171,000	0.92	Jul-03	1974	1,808	$94.58	9.0
65	31 018 9 093	N9047 A	$118,000	1.79	Jul-01	1995	1,465	$80.55	121.0
67	31 018 18 013	E457 Macco	$175,000	1.00	Jun-02	1987	2,370	$73.84	313.0
68	31 018 18 012	Macco	$137,500	3.00	Jul-01	2001	1,838	$74.81	280.0
69	31 018 19 133	N8207 H	$103,000	1.00	Oct-01	1978	1,104	$93.30	3.0
70	31 018 25 012	E2497 S	$139,900	1.50	Dec-02	1966	1,500	$93.27	3.0
75	31 018 28 092	N7805 A	$179,000	2.70	Sep-03	1977	1,608	$111.32	392.0
76	31 018 32 121	E642 K	$129,000	3.00	Jul-02	1985	1,344	$95.98	20.0
77	31 018 33 012	N7655 A	$207,000	2.90	Jul-02	1976	3,018	$68.59	526.0
Average:								$91.53	3,156.0

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	6	5	$92.64	828.0	12.87
Control:	13	12	$91.53	3,156.0	16.22
Combined:	19	17		3,984.0	

Variance:	234.4
Variance of Difference of Means:	57.09
Standard Deviation:	7.56
Calculated T =	0.147
Standard T at 95% 17 Degrees of Freedom:	1.740

Anecdotal Information

Joe Jerabek, the assessor for Town of Lincoln, provided some anecdotal data. He indicated that construction was continuing in the area and that there was no apparent affect from the wind turbines located in his township. His analysis, based on assessment levels, indicated that the overall percentage level of assessment in the area had declined which would indicate an increase in property value. He also stated that new construction was occurring along Cherry Road, which is approximately 1,750 feet from nearest wind turbine. This was confirmed by a visual inspection of the area.

Special mention is made of two sales between individuals and Wisconsin Public Service. Wisconsin Public Service subsequently removed both properties. Sale 1 is between John C. Kostichka and Wisconsin Public Service on October 10, 2001 and is recorded in Book 371/Page 789. The company paid a total of $86,500 for Kostichka's property. The Lincoln Assessor had the property listed as a 948 square foot single-story house plus an enclosed porch. The construction date was 1955. In addition, there was a 1,200 square foot garage. There was no basement. The house was located on 4.5 acres. The exterior consisted of masonite and some brick. The interior had not been modernized. The assessor stated that the house was somewhat "rambling in design". Overall condition of the house was considered to be fair to average. The overall price paid was $91.24 per square foot. According to the assessor, Kostichka wanted to move to the town of Luxembourg for some time and saw this as an opportunity.

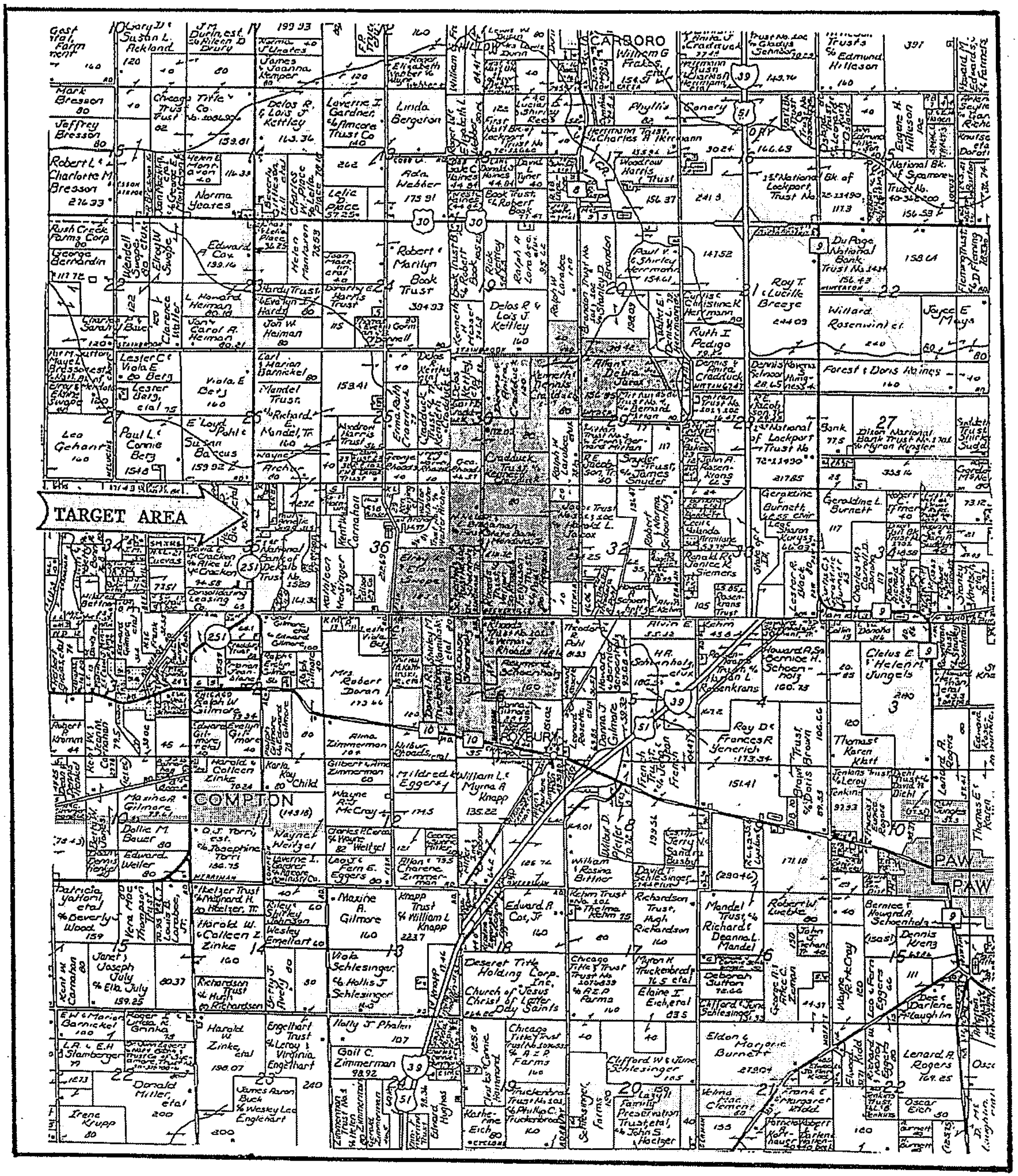
The second property that sold was from Greg Gabriel to Wisconsin Public Service. The price paid on August 30, 2001 was $88,000 and is recorded in Book 369/Page 859. This house was originally constructed in the 1920s as a cheese processing plant and was converted to a house. It is located about 10 feet from the roadway and is located next to a stop sign. The adjoining property was a tavern. The property was a two-story building containing a total of 1,500 square feet. There was no basement. It was located on 0.70 acre tract. The overall price was $58.66 per square foot. According to the assessor, at the time of the sale, Gabriel was divorced and living at a friend's house. The house purchased by Wisconsin Public Service was vacant at the time for this reason.

MENDOTA HILLS WIND FARM, LEE COUNTY, ILLINOIS

The Mendota Hills Wind Farm is operated by Commonwealth Edison and is located in Lee County, Illinois just west of Interstate 39 and south of U.S. Highway 30. This wind farm has 63 wind turbines producing up to 50.4 megawatts of electricity. The design of the turbines is similar to those to be constructed at the subject. The overall height of the tower is 214 feet with a blade length of 83 feet. Construction of this project began in 2003 with the in-service date being November 24, 2003.

Land use in the area is predominately farming with some residential properties located on larger tracts. Commercial uses are generally restricted to Compton. The closest service center is the Village of Paw Paw located about four miles east of the turbines with Mendota (10 miles) and Rochelle (15 miles) providing a greater variety of services. The topography in this area is generally slightly rolling with only limited relief. To the northeast of the wind farm area, the topography has more relief with areas of forested ground, which tends to limit visibility of the turbines from this direction. Land to the north, west, south, and southeast is generally level, gradually falling away from the ridge upon which the wind farm is situated.

A Target Area was established around the Mendota Hill Wind Farm (see Figure 4.) This target area reflects the overall topography of the area as well as tree lines and intervening land uses in the area. It is noted that the wind farm is located at the intersection of four townships (Brooklyn, Viola, Wyoming, and Willow Creek). Wendy Ryerson, the Lee County Supervisor of Assessments, provided a list of sales for all properties within the four townships for the years 2003, 2004, and the first three months of 2005. This time frame was chosen because it corresponds with the period the wind farm was undergoing siting approval and was beginning operations.



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North

Fig. 4: Target Area of Mendota Hills Wind Farm.

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Mendota Hills Agricultural Sales

Agricultural sales are defined as those tracts that comprise 20 acres or more. There were a total of five sales of larger agricultural type tracts that occurred in the Target Area between January of 2003 and March of 2005 (see Table 8). Sales that occurred between related parties (such as family members), as the result of judicial actions or in lieu of foreclosure, or involved governmental units or utilities were eliminated from consideration. Such sales do not represent transactions that meet the requirements of the definition of market value. The Target Area sales were compared to agricultural sales from remaining areas of Viola, Brooklyn, Wyoming and Willow Creek townships. A total of nineteen sales occurred within the Control Area over the same time period.

The sale prices ranged from $3,200 to $5,323 per acre in the Target Area and from $2,613 to $5,700 per acre in the Control Area. The sales indicated an average price per acre within the Target Area of $4,129 while within the Control Area it was $4,224 per acre. A statistical comparison was made of the means for the groups to ascertain if this was a significant difference between the indicated prices. The calculated T statistic for the sample was 0.211. This is less than the Standard T of 1.711 indicating that at a 95 percent confidence interval, there is no significant difference in the mean sales price of agricultural land in the Target and Control areas.

Table 8: Sales of Agricultural Tracts in Mendota Hills Area.

Sale	Parcel	Sale Date	Book/ Page	Size	Sale Price	Grantor	Grantee	$/Ac.
Target:								
1	05 17 02 100 012+	Mar-04	0403-802	62.00	$251,880	BETZ	COMPTON LD	$4,063
2	21 12 17 400 005+	Aug-03	0308-4592	156.50	$686,018	LENHART	REDIEHS	$4,383
3	21 12 28 300 010+	Mar-04	0403-408	118.19	$378,198	SCHOENHOLZ	SECOND BK	$3,200
4	21 12 34 200 003+	Mar-04	0403-4183	62.00	$330,000	SUDDETH	HALICZER	$5,323
5	22 18 05 100 009	Jul-03	0307-1894	25.83	$95,000	METROU	HARDEKOPF	$3,678
Average:								$4,129
Control:								
6	05 17 03 100 002	Jan-05	0501-270	25.50	$140,000	HUGHES	MUETZE	$5,490
7	05 17 05 100 006	Jan-03	0301-5251	72.01	$223,243	QUICK	MUETZE	$3,100
8	05 17 10 100 002	Jun-03	0306-1486	45.17	$180,977	HENKEL	WEILER	$4,007
9	05 17 10 400 003	Sep-04	0409-586	61.83	$200,000	WEILER	KLATT	$3,235
10	05 17 27 300 006	Jun-04	0406-2525	69.71	$325,894	SCHMIDT	CAREY	$4,675
11	05 17 33 100 001+	Feb-04	0402-2822	148.16	$565,000	GRAY	BARNICKEL	$3,813
12	05 17 34 200 002+	Mar-04	0403-4343	80.40	$400,000	HEIMAN	OLD 2nd BK	$4,975
13	05 17 35 100 003	Jan-05	0501-1994	116.00	$580,000	HEIMAN	GANZ	$5,000
14	20 11 05 100 010	Oct-03	0310-5127	77.04	$324,739	BRESSON	DORF	$4,215
15	20 11 27 100 001+	Dec-04	0412-1505	60.00	$294,538	SUTTON	OWEN	$4,909
16	20 11 27 100 001+	Dec-04	0412-1502	60.42	$294,537	SUTTON	COFFMAN	$4,875
17	20 11 28 100 002+	Jun-03	0306-3749	281.86	$1,240,162	LARSON	SIMPSON	$4,400
18	20 11 29 100 001	Jan-03	0301-1234	80.41	$280,000	BUHROW	NOGGLE	$3,482
19	20 11 33 300 004+	Feb-04	0402-1633	111.00	$290,050	SVENSON	YOUSSI	$2,613
20	21 12 09 300 003+	Mar-04	0403-2648	149.76	$636,998	HERRMANN	KHATER	$4,253
21	21 12 13 400 002+	Apr-04	0404-2691	40.00	$228,000	TRT#80	SHIELDS	$5,700
22	21 12 13 400 002+	Apr-04	0404-2686	116.92	$666,444	TRT#80	CASE	$5,700
23	21 12 16 100 003	Mar-04	0403-2636	92.30	$388,684	HERRMANN	MIDWEST BK	$4,211
24	21 12 26 100 002+	Dec-03	0312-695	80.00	$331,900	GUEST	FOSTER	$4,149
25	22 18 29 100 003	Jan-03	0301-6255	40.00	$116,000	ROGERS	HOELZER	$2,900
26	22 18 29 300 002+	Jan-03	0301-4855	117.84	$353,526	PAYNE	VOLINTINE	$3,000
Average:								$4,224

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	5	4	$4,129	2,356,547	767.55
Control:	21	20	$4,224	17,115,050	925.07
Combined:	26	24		19,471,597	

Variance:	811,316.5
Variance of Difference of Means:	200,897.43
Standard Deviation:	448.22
Calculated T =	0.211
Standard T at 95% 24 Degrees of Freedom:	1.711

Small Residential Tract Acreage

A review was made of the selling prices of residential acreage. These tracts are defined as approximately five acres or less. There were a total of eight sales with in the Target Area and twenty-two sales within the Control Area. The sales are summarized in Table 9. The average price of these sales within the Target Area was 11,990 per acre while it $13,001 per acre within the Control Area. A statistical comparison was made of the two means to ascertain if there was, in fact, a significant difference between the two indicated prices. This analysis indicated that the calculated T statistic for the sample was -0.472. This is less than the Standard T of 1.701 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of small residential tracts within the target and control areas.

Special mention is made of sales 1, 2, and 3 within the Target Area. These sales are located within a small eleven lot subdivision that is located approximately one-half mile from the turbines. There is a clear view of the turbines from this location. Further information is provided in the anecdotal section of the report.

Table 9: Small Residential Tract Sales, Mendota Hills.

Sale	Parcel					Sale Date	Book/ Page	Size	Sale Price	Grantor	Grantee	$/Acre
	Target Area:											
1	20	11	35	476	003	Aug-04	0408-2944	2.50	$35,500	FIRT NAT'L BK	GRANGERA	$14,200
2	20	11	35	476	004	Jul-04	0407-3695	2.50	$35,500	CASTLE BK	BERNAL	$14,200
3	20	11	35	477	005	Feb-05	0502-966	2.50	$35,500	CASTLE BK	KOWALSKI	$14,200
4	05	17	11	101	005	Feb-04	0402-2192	2.76	$20,000	JANSEN	SWOPE	$7,246
5	21	12	19	200	004	Jun-03	0306-5974	5.00	$51,900	FIRST ST. BK	SPOHR	$10,380
6	21	12	34	300	016+	Apr-04	0404-4133	5.05	$47,000	COLLIN	BENSON	$9,307
7	05	17	11	184	004	May-04	0405-856	0.32	$7,000	DONAGH	RHOADS	$21,875
8	22	18	07	400	006	Jun-04	0406-734	3.00	$13,500	COX	MUETZE	$4,500
Average:												$11,989
Control Area:												
9	05	17	03	200	009+	Nov-04	0411-2921	2.53	$52,700	SWOPE	MCGINNIS	$20,871
10	05	17	03	400	005+	Jun-03	0306-2038	2.50	$6,000	O'CONNELL	HODDER	$2,400
11	05	17	05	300	006	Apr-04	0404-4576	5.00	$30,000	MAYS	BEARDIN	$6,000
12	05	17	20	400	003	Jun-04	0406-594	1.00	$6,500	BUTLER	VAESSEN	$6,500
13	05	17	36	400	011	Mar-03	0303-1121	5.00	$37,500	PATTERMANN	JOSLIN	$7,500
14	05	17	36	400	009	Aug-04	0408-1615	5.00	$50,000	BUNTON	CARNEY	$10,000
15	05	17	36	400	016	Aug-04	0408-1612	1.00	$28,000	KORDEK	CARNEY	$28,000
16	20	11	05	100	007	Apr-04	0404-3473	1.70	$20,100	BRESSON	ARJES	$11,824
17	20	11	34	200	018	Mar-04	0403-4355	5.00	$60,000	CIOSEK	BERG	$12,000
18	21	12	12	100	004	Jan-05	0501-2305	2.00	$45,000	CASTLE BK	NEWQUIST	$22,500
19	21	12	14	300	007	Jan-05	0501-2975	5.00	$56,000	WACHOWSKI	GEMBECK	$11,200
20	21	12	36	100	005	Apr-03	0304-0596	5.00	$67,500	MENDOTA BK	KRAFFT	$13,500
21	21	12	36	100	012	Jul-04	0407-3286	5.00	$72,500	1st BK MENDOT/	NERI	$14,500
22	21	12	36	100	017	Sep-04	0409-1076	5.14	$64,000	STROYAN	DAVIDSON	$12,444
23	21	12	36	100	012	Sep-04	0409-437	5.15	$72,500	MENDOTA BK	SCRITSMIER	$14,089
24	21	12	36	100	011	Apr-04	0403-673	5.00	$63,000	MENDOTA BK	PAYNE	$12,600
25	22	18	13	100	001+	Mar-03	0303-0283	5.00	$51,000	KERN	GRZESIAKOWSKI	$10,200
26	22	18	13	300	034	Mar-03	0303-1685	2.50	$25,000	KERN	FICKENSCHER	$10,000
27	22	18	24	400	010	Mar-04	0403-4059	1.76	$35,000	TARR	PAOLELLO	$19,886
28	22	18	24	400	013	Aug-04	0408-1000	1.88	$35,000	TARR	BURNETT	$18,617
29	22	18	31	400	011	Dec-03	0312-1969	5.11	$55,400	KIDD	SCARLEY	$10,848
30	22	18	32	100	011	Mar-03	0303-0117	5.12	$40,000	MELMUKA	MITCHELL	$7,813
	Average:											$13,001

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
1:	8	7	$11,989	20,871	54.6
2:	22	21	$13,001	757,205,595	6004.78
Combined:	30	28		757,226,466	

Variance:	27,043,802
Variance of Difference of Means:	4,609,739
Standard Deviation:	2,147.03
Calculated T =	-0.472
Standard T at 95% 28 Degrees of Freedom:	1.701

Single Family Residential Values

A review of all one-story, one and one-half story and two-story houses within Brooklyn, Viola, Willow Creek and Wyoming townships revealed a total of fifteen sales in the Target Area and thirty-eight sales in the Control Area (see Appendix II). Overall, these sales indicated an average price per square foot of $78.84 in the Target Area and $104.46 per square foot in the Control Area. A statistical analysis of the data revealed that this is a significant difference at the 95 percent confidence level.

There are mitigating factors, however, that significantly affect the reliability of this particular sample. A review of the data indicates that of the fifteen sales within the Target Area, twelve were constructed before 1930, two were constructed before 1960, and only one sale was constructed in the 1990s. By contrast, fifteen of the thirty-eight houses in the Control Area were built after 1970, four houses were constructed between 1930 and 1950, and the remaining houses were constructed before 1930. One property was of unknown age.

The overall average is affected by a higher percentage of newer homes within the Control Area sample when compared to the Target Area. Additionally, use of the older residences is unreliable because of unknown factors such as the overall physical condition, the overall utility, and whether the property has been remodeled or repaired. Removal of all sales constructed before 1960 leaves only one sale within the Target seriously eroding any confidence that can be placed in this sample. Finally, the Control Area sales are heavily weighted to Wyoming and Willow Creek townships. These two townships are heavily influenced by the community of Paw Paw (with its greater range of services in comparison to Compton and West Brooklyn) and there has been a greater amount of development within this area than within Brooklyn and Viola townships. This pattern of development precedes the wind farm. This increased development would positively affect prices to some extent in that area. If sales from Willow Creek and Wyoming townships are removed from the sample, then the overall average for the Target Area is $79.62 per square foot while for the Control Area it is $81.03. The calculated T statistic for sales only within Brooklyn and Viola townships is -0.121, which is less than the standard T of 1.703 at 27 Degrees of Freedom indicating that there is no significant difference between the two groups (see Table 10).

No confidence can be placed in the overall value of all houses in this case given the factors of differences in age, the fact that only one improved sale within the Target Area consisted of a house newer than 1960, and the overall development pattern within the four townships.

Table 10: Residential Sales within Brooklyn and Viola Townships.

Sale	Parcel No.	Address	Sale Date	Sale Price	Size	$/Ft^2	Sum of Square
Target Area:							
1	05 17 11 153 002	629 W CHESTNUT	Oct-03	$37,000	1,161	$31.87	$2,280
2	05 17 11 179 004	323 W. CHESTNUT	Oct-04	$40,000	1,425	$28.07	$2,658
5	20 11 14 400 001	1224 IL RTE 251	Jun-03	$138,000	1,272	$108.49	$833
6	05 17 11 179 001	339 CHESTNUT ST.	Jan-03	$72,000	1,684	$42.76	$1,359
7	05 17 11 152 003	630 W. CHESTNUT	Sep-03	$126,000	1,728	$72.92	$45
8	05 17 11 156 004	427 CHESTNUT ST	Oct-03	$87,000	1,380	$63.04	$275
9	05 17 11 185 005	138 CHERRY ST.	Sep-04	$80,000	1,326	$60.33	$372
10	05 17 11 156 008	536 W. CHERRY	Oct-04	$63,500	999	$63.56	$258
11	05 17 02 100 005	885 COMPTON RD	Oct-04	$68,900	480	$143.54	$4,085
12	05 17 11 156 010	518 W CHERRY ST	Apr-03	$87,500	927	$94.39	$218
13	05 17 11 252 004	222 MAPLE ST	Dec-04	$150,000	1,852	$80.99	$2
14	05 17 11 158 009	444 W. MAIN ST.	Mar-05	$109,900	1,402	$78.39	$2
15	20 11 35 400 006	2874 BEEMERVILLE	Jul-03	$367,000	2,201	$166.74	$7,589
Average:						$79.62	$19,976
Control Area:							
16	20 11 10 400 006	1310 MELUGINS GROVE	Apr-04	$179,000	1,952	$91.70	$114
17	05 17 16 300 004	2612 SHADY OAKS RD	Apr-03	$131,000	1,208	$108.44	$752
19	05 17 08 153 011	2524 JOHNSON ST	Aug-04	$61,800	948	$65.19	$251
20	05 17 08 305 009	741 THIRD ST	Feb-04	$63,500	868	$73.16	$62
21	05 17 35 100 002	613 CHURCH RD	May-03	$115,000	1,458	$78.88	$5
25	05 17 08 304 008	745 SECOND ST.	Dec-04	$59,000	1,161	$50.82	$912
26	05 17 08 154 005	761 4TH ST	Mar-03	$68,000	724	$93.92	$166
27	05 17 34 400 005	2774 WELLAND RD	Apr-03	$93,000	1,104	$84.24	$10
29	05 17 08 304 003	2505 WOOD ST	Aug-04	$105,000	1,812	$57.95	$532
32	05 17 08 305 006	742 2ND STREET	Jan-03	$103,000	1,876	$54.90	$683
34	05 17 08 305 002	2515 WOOD ST.	Apr-04	$80,000	912	$87.72	$45
36	20 11 34 400 006	901 MELUGENS GROVE	Aug-03	$228,000	2,000	$114.00	$1,087
39	05 17 22 300 001	546 CARNAHAN RD	Jan-05	$110,000	1,296	$84.88	$15
41	05 17 08 152 012	2512 JOHNSON ST.	Feb-05	$123,000	2,232	$55.11	$672
42	20 11 05 100 003	2509 HERMAN RD	Apr-04	$142,900	1,404	$101.78	$431
53	05 17 05 100 008	2512 SHAW RD	Jun-04	$153,500	1,638	$93.71	$161
Average:						$81.03	$5,898

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
1:	13	12	$79.62	19,976	40.8
2:	16	15	$81.03	5,898	19.83
Combined:	29	27		25,874	
Variance:					958.3
Variance of Difference of Means:					133.61
Standard Deviation:					11.56
Calculated T =					-0.121
Standard T at 95% 27 Degrees of Freedom:					1.703

Anecdotal Information

Discussion with the Wendy Ryerson, the Supervisor of Assessments for Lee County, indicated that she did not notice any difference in the values due to the Mendota Hills Wind Farm. A drive in the area revealed that there is a small subdivision located just north of Beemerville Road and about one-quarter mile east of Highway 251. The Meadow Brook Subdivision has eleven lots each comprising about two and one-half acres. One house was completed prior to the development of the wind farm. The real estate agent for the subdivision, Lucy Nicholson, stated that only one lot (8) remains to be sold. Four lots sold previously for prices that range between $32,000 to $37,000. There are five lots with pending sales that are scheduled to close by the end of May 2005. Prices for these five lots were between $44,900 and $47,900 depending upon location within the subdivision. Ms. Nicholson stated that they received full asking price for all of the lots that sold. One lot has a new house that is for sale. According to Ms Nicholson, the asking price is $245,000. There are 2,506 square feet above grade with a built-in two-car garage. There is one other house currently under construction by the lot owner. This subdivision is located about one-half mile west of property with wind turbines and house will have a clear view of the wind farm.

This indicates that development is continuing in close proximity to the wind farm. Also of note, this is the only subdivision being developed in the rural area between Compton on the west and Paw Paw on the east. Elmer Rhoads, a farmer who participates in the Mendota Hills project stated that his neighbor just to the north prefers the wind turbines over subdivision development in the area.

MENDOTA HILLS WIND FARM, UPDATE

The same Target and Control areas used around the initial study were again used for the update. A Target Area was established around the Mendota Hill Wind Farm (see Figure 3.) Wendy Ryerson, the Lee County Supervisor of Assessments, provided a list of sales for all properties within the four townships for the year 2005 and the first six months of 2006.

Mendota Hills Agricultural Sales

Agricultural sales are defined as those tracts that comprise 20 acres or more. There were a total of six sales of larger agricultural type tracts that occurred in the Target Area between January of 2005 and June of 2006 (see Table 11). The above sales do not include sales that occurred between related parties (such as family members), as the result of judicial actions or in lieu of foreclosure, or involved governmental units or utilities. Such sales do not represent transactions that meet the requirements of the definition of market value. The Target Area sales were compared to agricultural sales from remaining areas of Viola, Brooklyn, Wyoming and Willow Creek townships. A total of fourteen sales occurred within the Control Area over the same time period.

The sale prices ranged from $3,999 to $8,627 per acre in the Target Area and from $4,736 to $9,971 per acre in the Control Area. The sales indicated an average price per acre within the Target Area of $6,150 while within the Control Area it was $6,220 per acre. A statistical comparison was made of the means for the groups to ascertain if this was a significant difference between the indicated prices. The calculated T statistic for the sample was 0.087. This is less than the Standard T of 1.734 indicating that at a 95 percent confidence interval, there is no significant difference in the mean sales price of agricultural land in the Target and Control areas.

Table 11: Sales of Agricultural Tracts in Mendota Hills Area.

	Parcel Number	Sale Date	Book/ Page	Size	Sale Price	Grantor	Grantee	$/Ac.
Target:								
1	05 17 02 100 015	Jun-05	0506-1393	25.39	$101,544	BETZ	GIBSON,LLC	$3,999
2	05 17 03 300 005+	May-06	0605-1674	59.60	$325,000	KROMM	MUETZE	$5,453
3	21 12 17 300 011+	Jan-06	0602-431	22.95	$198,000	HERRMANN	ESPE	$8,627
4	22 18 04 300 002+	Mar-06	0603-3383	117.10	$591,330	ROSENKRANS	CRAIG	$5,050
5	22 18 04 400 002+	Mar-06	0603-3221	203.67	$1,405,323	BROWN	WYOMING FARMS	$6,900
6	22 18 16 100 004	Mar-06	0603-3060	291.59	$2,011,937	MANDEL	CRAIG	$6,900
Average:								$6,155
Minimum:								$3,999
Maximum:								$8,627
Control:								
7	05 17 09 300 003	Jun-05	0507-538	81.98	$405,820	CARNAHAN	JKB SMART	$4,950
8	05 17 10 300 006	May-05	0506-637	77.93	$382,283	CARNAHAN	PARAMOUNT	$4,905
9	05 17 20 400 005	Apr-05	0504-3546	119.93	$568,000	BUTLER	GLEIM	$4,736
10	05 17 32 200 005+	Mar-06	0603-94	370.30	$2,056,010	CONKEY	BEETZ	$5,552
11	05 17 35 100 003	Mar-06	0603-1192	116.00	$622,532	GANZ	OLD 2nd NAT'L	$5,367
12	20 11 35 300 001	Aug-06	0608-3468	94.58	$600,000	MCCRACKEN	MUETZE	$6,344
13	21 12 11 400 004	Aug-06	0608-1142	61.08	$506,600	MOULTON	HALICZER	$8,295
14	21 12 13 400 007	Dec-05	0601-935	116.92	$763,518	CASE	FIRST MIDWEST	$6,530
15	21 12 13 400 006	Dec-05	0601-939	40.00	$280,000	SHIELDS	FIRST MIDWEST	$7,000
16	21 12 16 200 004	Sep-06	0609-2949	54.00	$332,999	NAT'L BK	PAIK FAMILY	$6,167
17	22 18 03 200 018+	May-05	0506-150	25.07	$250,000	HEIMAN	SCRITSMIER	$9,971
18	22 18 14 400 012	May-05	0506-1188	35.80	$207,976	NORTH STAR	TRESTLE	$5,809
19	22 18 24 400 014	Jun-06	0607-589	106.34	$701,844	TARR	AGVEST	$6,600
20	22 18 31 100 012	Apr-05	0504-2584	112.69	$546,551	SCHEIDENHELM	MUETZE	$4,850
Average:								$6,220
Minimum:								$4,736
Maximum:								$9,971

Sample:	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	6	5	$6,155	13,583,604	1648.25
Control:	14	13	$6,220	28,005,009	1467.73
Combined:	20	18		41,588,613	
Variance:					2310478.5
Variance of Difference of Means:					550113.9
Standard Deviation:					741.70
Calculated T =					-0.087
Standard T at 95% 18 Degrees of Freedom:					1.734

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Small Residential Tract Acreage

A review was made of the selling prices of residential acreage. These tracts are defined as approximately five acres or less. There were a total of seven sales with in the Target Area and seven sales within the Control Area. The sales are summarized in Table 12. The average price of these sales within the Target Area was $16,096 per acre while it $14,952 per acre within the Control Area. A statistical comparison was made of the two means to ascertain if there was, in fact, a significant difference between the two indicated prices. This analysis indicated that the calculated T statistic for the sample was 0.549. This is less than the Standard T of 1.782 indicating that at the 95% confidence interval, there is no significant difference in the mean sale price per square foot of small residential tracts within the target and control areas.

Special mention is made of sales 4, 5, 6, and 7 within the Target Area. These sales are located within an eleven lot subdivision that is located approximately one-half mile from the turbines. There is a clear view of the turbines from this location. Further information is provided in the anecdotal section of the report.

Table 12: Small Residential Tract Sales, Mendota Hills.

Parcel Number	Address	Lot Size	Sale Price	$/Ac.	Sum of Squares
Target:					
1 21 12 19 200 007	LOT D CRESTRIDGE	5.00	$75,000	$15,000	1,201,816
2 20 11 35 200 029+	966 IL STATE RTE 251	5.00	$106,000	$21,200	26,048,022
3 20 11 35 200 026+	966 IL STATE RTE 251	5.00	$100,000	$20,000	15,239,079
4 20 11 35 476 001	MEADOWBROOK SUB.	3.36	$46,000	$13,690	5,787,862
5 20 11 35 477 001	MEADOWBROOK SUB.	3.67	$47,900	$13,052	9,268,996
6 20 11 35 477 002	MEADOWBROOK SUB.	3.47	$47,900	$13,804	5,254,360
7 20 11 35 477 003	920 BROOK MEADOW DR	2.819	$44,900	$15,928	28,439
Average:				$16,096	62,828,574
Minimum:				$13,052	
Maximum:				$21,200	
Control:					
8 20 11 05 100 007	HERMAN RD	1.70	$40,500	$23,824	78,702,245
9 05 17 05 300 018	838 BROOKLYN RD	5.00	$45,000	$9,000	35,427,504
10 22 18 03 200 022	DREDGE RD	5.00	$65,000	$13,000	3,810,698
11 22 18 03 200 020	DREDGE RD	5.00	$72,500	$14,500	204,395
12 22 18 03 200 019	DREDGE RD	5.00	$70,000	$14,000	906,496
13 22 18 03 200 021	DREDGE RD	5.00	$74,500	$14,900	2,714
14 22 18 10 301 019	CHICAGO RD	3.40	$52,500	$15,441	239,195
Average:				$14,952	119,293,247
Minimum:				$9,000	
Maximum:				$23,824	

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	7	6	$16,096	62,828,574	3235.96
Control:	7	6	$14,952	119,293,247	4458.95
Combined:	14	12		182,121,821	
Variance:					15,176,818
Variance of Difference of Means:					4,336,234
Standard Deviation:					2,082.36
Calculated T =					0.549
Standard T at 95% 12 Degrees of Freedom:					1.782

Single Family Residential Values

A review of all one-story, one and one-half story and two-story house sales within Brooklyn, Viola, Willow Creek and Wyoming townships between January of 2005 and June of 2006. Sales that were between relatives, as a result of judicial actions, or involving banks were not included in this review. These types of sales do not meet the definition of market value. There were a total of thirteen sales in the Target Area and twenty-two sales in the Control Area (see Table 13). Overall, these sales indicated an average price per square foot of $86.37 in the Target Area and $91.59 per square foot in the Control Area. A statistical analysis of the data revealed that this is a significant difference at the 95 percent confidence level.

Table 13: Residential Sales, January 2005 through June 2006.

	Parcel Number	Address	Sale Date	Price	Sq. Ft.	Age	$/Ft²
1	05 17 11 151 006	414 Hillcrest Ave.	Jun-06	$110,000	1,360	1958	$80.88
2	05 17 11 156 008	536 Cherry	May-05	$114,900	978	1906	$117.48
3	05 17 11 181 001	232 W Chestnut St.	Aug-05	$139,900	2,112	1886	$66.24
4	05 17 11 183 004	223 W Cherry St.	May-05	$74,000	1,044	1911	$70.88
5	05 17 11 183 005	215 W Cherry St.	Jul-05	$88,000	1,592	1911	$55.28
6	05 17 11 184 002	136 Chestnut	Jan-06	$60,000	1,344	1940	$44.64
7	05 17 11 185 004	109 Chestnut	Apr-05	$58,700	780	1891	$75.26
8	05 17 11 252 004	222 Maple St.	Mar-06	$152,000	1,852	1955	$82.07
9	20 11 13 400 004+	1202 Fisk	Jun-05	$104,900	1,568	1998	$66.90
10	20 11 35 477 004	914 Brook Meadow	Jun-05	$225,000	2,508	2003	$89.71
11	21 12 17 301 001	3103 Cobb Ln.	Aug-06	$554,148	3,252	2005	$170.40
12	21 12 20 200 004	1191 German Rd.	Dec-05	$230,000	2,490	1891	$92.37
13	21 12 20 300 010	Steward Rd.	Apr-06	$189,000	1,708	1861	$110.66
Average:					1,738		$86.37
Control:							
14	20 11 01 400 005	1403 Townline	Dec-05	$162,000	1,848	1910	$87.66
15	22 18 20 400 006	3196 Cyclone	Apr-05	$172,500	1,542	1881	$111.87
16	05 17 08 302 004	2523 Johnson	Apr-05	$38,000	2,000	1946	$19.00
17	05 17 08 305 003	2517 Wood	May-06	$66,000	1,376	1901	$47.97
18	05 17 16 300 004	2612 Shady Oaks	Sep-06	$92,000	1,208	1860	$76.16
19	20 11 01 400 007	1435 Townline	Mar-06	$300,000	2,280	1995	$131.58
20	20 11 05 100 003	2509 Hermon	Nov-05	$163,000	1,404	1993	$116.10
21	21 12 01 426 010	211 Hardanger	Feb-06	$141,645	1,412	1891	$100.32
22	21 12 01 427 004	151 Hardanger	Aug-05	$135,000	2,064	1889	$65.41
23	21 12 01 428 008	210 Hardanger	Jun-05	$59,000	1,112	1861	$53.06
24	21 12 01 428 002	280 W. Hardanger	Oct-05	$165,500	1,620	1966	$102.16
25	21 12 01 430 003	101 S. Skole	Jul-05	$140,000	1,960	1911	$71.43
26	21 12 01 430 002	210 W Kirke	Apr-06	$115,000	1,360	1891	$84.56
27	21 12 01 431 008	141 S Viking View	Jun-06	$90,000	2,912	1901	$30.91
28	21 12 01 432 014	321 S Viking View	Sep-05	$140,000	1,560	1967	$89.74
29	21 12 12 400 004	1347 County Line	Aug-06	$175,000	1,853	1891	$94.44
30	21 12 23 400 002	1125 Woodlawn	Apr-05	$439,000	2,760	1977	$159.06
31	22 18 10 301 019	3315 Chicago	Jul-05	$179,000	1,692	1901	$105.79
32	22 18 11 352 003	225 Chapman	Jul-06	$87,000	1,004	1861	$86.65
33	22 18 13 300 029+	648 Ogee	Dec-05	$290,000	1,768	1997	$164.03
34	22 18 15 229 006	267 Brookside	Jun-06	$130,000	1,310	1990	$99.24
35	22 18 36 300 003	324 Wixom Pit	May-05	$144,000	1,222	1861	$117.84
Average:					1,694		$91.59

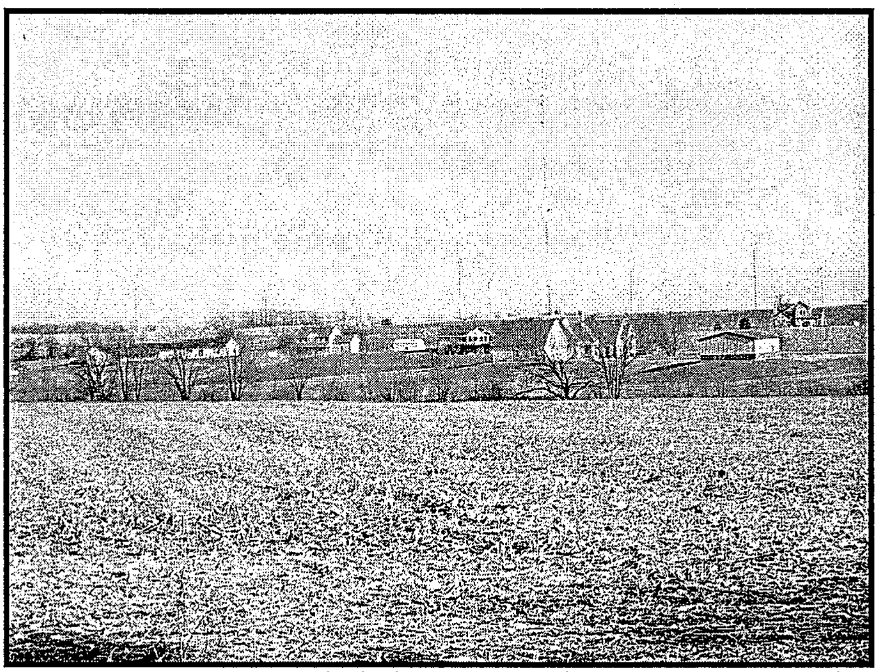
Table 13: Continued On Next Page

Table 13: Continued.

Sample	Sample Size	Degrees Of Freedom	Sample Mean	Sum Of Squares	Standard Deviation
Target:	13	12	$86.37	12,570	32.37
Control:	22	21	$91.59	27,314	36.06
Combined:	35	33		39,884	
Variance:					1,208.6
Variance of Difference of Means:					147.91
Standard Deviation:					12.16
Calculated T =					-0.429
Standard T at 95% 33 Degrees of Freedom:					1.611

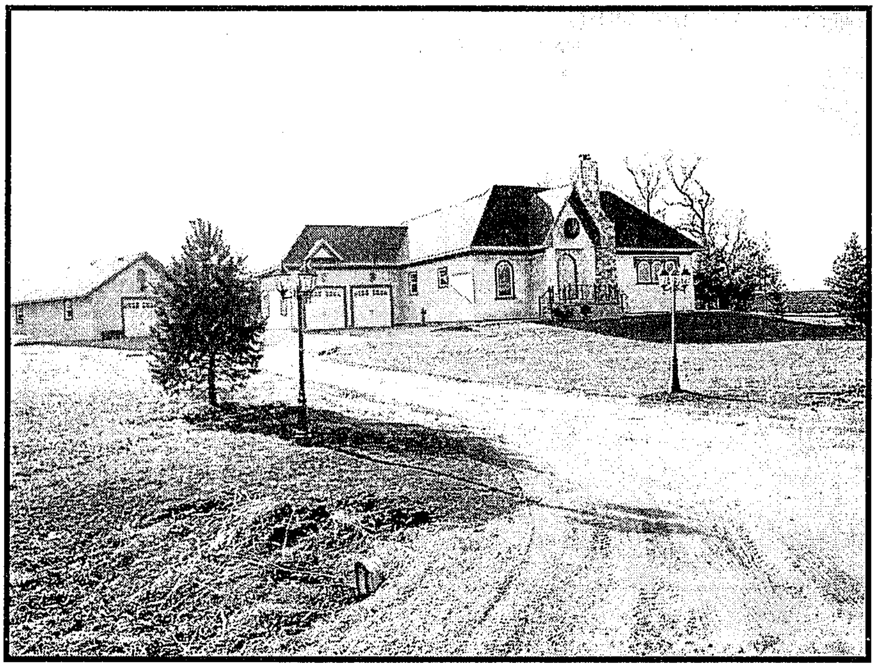
Anecdotal Information

A drive in the area revealed that there is a small subdivision located just north of Beemerville Road and about one-quarter mile east of Highway 251. The Meadow Brook Subdivision has eleven lots each comprising about two and one-half acres. One lot was sold and one house completed prior to the development of the wind farm. This lot sold for a reported price of $30,000. Subsequent to the development of the Mendota Hills Wind Farm, the remaining lots have been sold with prices ranging from $35,000 to $47,900 per lot. There have been an additional eight homes constructed on these lots. Additionally, according to the zoning administrator for Lee County, Chris Henkel, the County Board has just approved plans for a new 100 lot subdivision just to the west of the Meadow Brook Subdivision. The developer is the same person who developed the Meadow Brook Subdivision.

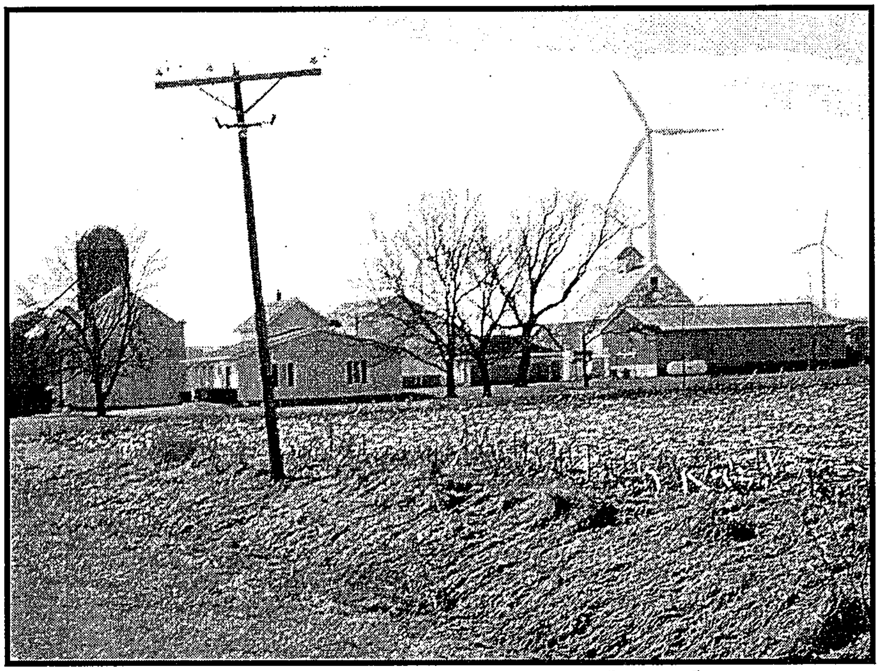


View of Meadow Brook Subdivision from Highway 251 Roadside Park.

Besides the activity within the Meadow Brook Subdivision, there was also a new house constructed in 2006 on Cobb Lane that sold for $554,148. This house was constructed after the installation of the wind farm and has a direct view. The location is about one mile to one and one half miles from the nearest turbines. Additionally a house constructed in 1989 located no a larger tract was sold for $534,000 in March of 2006. This property is located about one-half miles from the nearest turbines. Finally, thee was an older farm house with some outbuildings that sold for $189,000 in April 0f 2006. This property is located on Steward Road about one-half miles north of the nearest turbine.



Property Located on Cobb Lane.



Property Located on Steward Road.

CONCLUSION

The subject property is located near the communities of Carlock and Hudson in central Illinois. The topography of the area is level to slightly rolling. The current land use of properties within the project area is primarily agricultural uses with some residential. Visibility is generally limited by distance, terrain, intermediate natural vegetation, and intervening land uses.

Since this is a proposed project, it was necessary to use data from other operating wind farms. These included Rosiere Wind Farm and Lincoln Wind Farm in Kewaunee County, Wisconsin and the Mendota Hills Wind Farm in Lee County Illinois. A review was made of the selling prices for single-family residential properties between 1998 and 2004 around the Lincoln Wind Farm and Rosiere Wind Farm in Kewaunee County, Wisconsin. A review of the average price per square foot indicated that there was no significant difference between the price per square foot for residences within the Target Area when compared to those within the Control Area. Similarly, analysis of vacant agricultural land and small and medium size residential tracts indicated that there was no significant difference in the price per acre for these types of properties.

An analysis of the Mendota Hills Wind Farm in Lee County, Illinois indicated that there was no significant difference paid for agricultural land or small residential tracts near the wind farm in comparison to similar tracts located some distance from the wind farm. An analysis of improved residential properties was attempted. The data derived from all sales indicated that there was a difference in the price paid per square foot. A closer review of the data indicated that the sales within the Target Area were heavily weighted to older houses and only one property transaction in the Target Area had a residence constructed after 1960. By contrast, the sales in the Control Area were more heavily weighted to newer homes with a total of fifteen sales out of thirty-eight built after 1960. Since there was only a single house sale in the Target Area with a construction date after 1960, as well as the development pattern of the area, it was concluded that there was insufficient data to do an analysis of residential prices. Anecdotal data indicated that there is a small eleven lot subdivision (Meadow Brook) with a direct view of the turbines located about one-half mile west of the wind farm. According to the real estate agent, four lots have sold after the construction of the wind farm with an additional five lots under contract and scheduled to close by end of May 2005. Initial asking prices were $32,000 to $37,000 for the lots but the latest sales are in the $44,900 to $47,900 price range. All lots sold at full asking price according to the agent. Based upon the sales of agricultural land, small residential tracts as well as the anecdotal data, the Mendota Hills Wind Farm has not affected prices in the Target Area or development within that area.

A follow-up study was also completed of the Mendota Hills Wind Farm. This second study reviewed sales between January 2005 and June of 2006. The update indicated that there was no significant difference paid for agricultural land, small residential tracts, or residential properties near the wind farm in comparison to similar tracts located some distance from the wind farm. The follow-up investigation also indicated that prices for the properties types studied had increased in both the target and control areas and that sales activity was continuing. This update also revealed that nine of the eleven lots within the Meadow Brook Subdivision now have houses constructed on the lots and that the developer of this subdivision has received zoning approval from Lee County to develop a 100 lot subdivision just to the west of the Meadow Brook Subdivision.

Therefore, after reviewing the available data, it is my opinion that as of January 5, 2007 the proposed White Oak Wind Farm is located so as to minimize any effect on the value of the surrounding property.

CERTIFICATE OF CONSULTING REPORT

I certify to the best of my knowledge and belief, that . . .

1. the facts and conclusions reached in this report are true and correct.

2. the report analyses, opinions, and conclusions are limited only by the assumptions and limiting conditions, and are my personal, impartial, unbiased professional analyses, opinions, and conclusions.

3. I have no present or prospective interest in the property that is the subject of this report, and I have no personal interest or bias with respect to the parties involved.

4. my compensation is not contingent on an action or event resulting from the analyses, opinions, or conclusions in, or the use of, this report.

5. my analyses, opinions, and conclusions were developed, and this report has been prepared, in conformity with the Uniform Standards Professional Appraisal Practice.

6. the use of this report is subject to the requirements of the Appraisal Institute and the International Association of Assessing Officers relating to review by their duly authorized representatives.

7. Peter J. Poletti is currently certified under the voluntary continuing education program of the Appraisal Institute and the International Association of Assessing Officers.

8. my engagement in the assignment was not contingent upon developing or reporting predetermined results.

9. my compensation for completing this assignment is not contingent upon the development or reporting of a predetermined value or direction in value that favors the cause of the client, the amount of value, the attainment of a stipulated result, or the occurrence of a subsequent event directly related to the intended use of this consulting assignment.

10. Peter J. Poletti of Poletti and Associates, Inc. has made a personal inspection of the property that is the subject of this report.

11. the consulting assignment was not based on a requested minimum valuation, a specific valuation or the approval of a loan.

12. the reported analyses, opinions, and conclusions were developed, and this report prepared, in conformity with the requirements of the Code of Professional Ethics and the Standards of Professional Practice of the Appraisal Institute and the International Association of Assessing Officers.

13. I have the necessary experience and education and am competent to undertake this consulting assignment.

14. as of the date of this report, Peter J. Poletti has completed the requirements of the continuing education program of the Appraisal Institute and the International Association of Assessing Officers.

15. the departure rule of the Uniform Standards of the Appraisal Foundation and Appraisal Institute was not used.

16. no one provided significant real property appraisal or appraisal consulting assistance to the person signing this certification.

Peter J. Poletti, Jr., Ph.D.; MAI
President
Illinois Certified General Real Estate Appraiser
153.0000415 Exp. 09/07

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Appendices

Appendix I: All Residential Sales within the Lincoln Town Plat.

Appendix I: All Residential Sales within the Lincoln Town Plat (1998-2004) and Red River Town Plat 2001-2004).

Sale	Parcel No.			Address	Grantor	Grantee	Sale Price	Acres	Book/ Page	Sale Date	Age	Ft^2	$/$Ft^2$	Comments
Target Area:														
1	31	010	5 054	E3045 X	Sisel	Bardouche	$15,000	6.75	313/26	Jan-98	1880s			Tavern and Dance Hall
2	31	010	5 052	E3019 X	Vlies	Guilette	$45,000	3.60	318/613	May-98				Old Cheese Factory
3	31	010	14 153	N8501 Black Ash	Deprey Est	Miller	$49,000	1.00	349/939	Sep-00	1920	1,179	$41.56	
4	31	010	18 122	E2690 Martin	Vandervest	Wery	$54,900	0.58	329/127	Sep-98	1900	768	$71.48	
5	31	010	18 122	E2690 Martin	Wery	Giradi	$73,100	0.59	373/359	Sep-01	1900	768	$95.18	
6	31	010	19 052	N8439 Tamarack	DuBois	Ives	$37,000	0.52	316/575	Apr-98	1900	924	$40.04	Lost to Bank
7	31	010	19 114	E2570 S	Duerst	Nelson	$46,300	0.29	317/965	May-98	1921	1,314	$35.24	
8	31	010	19 123	E2688 S	Jacobs	French	$100,000	0.30	401/561	Sep-02	1955	2,460	$40.65	
9	31	010	19 153	W2798 S	Beaurain	Fadroski	$114,900	0.44	444/943	Aug-03	1930			Old Elementary School
10	31	010	19 126	E2656 S	Mauer	Garcia	$75,000	0.30	457/33	Jan-04	1940	1,632	$45.96	
11	31	010	20 164	N8111 C	Challe	Malott	$62,700	0.22	379/141	Dec-01	1952	896	$69.98	
12	31	010	20 112	E2910 S	Katers	Mumper	$154,500	2.80	463/723	Apr-04	1900	1,768	$87.39	
13	31	010	22 121	E3890 Ctn Rd S	Jeanquart	Dufek	$59,900	1.00	322/198	Aug-98	1987			Double Wide
14	31	010	23 044	N8308 Black Ash	Kalk	Sunqvist	$110,000	8.30	457/574	Jan-04	1984	1,680	$65.48	
15	31	010	26 062	N8094 Cedar	Wehausen	Raduenz	$82,500	0.50	464/362	Apr-04	1951	2,457	$33.58	
16	31	010	27 13	N7855 Cedar	Pelnar	Lohrey	$84,000	4.90	398/367	Aug-02	1900	1,456	$57.69	
17	31	010	27 05	N8015 Cherry	Five Star Mo	Hoesly	$162,000	5.00	402/965	Oct-02	2001	1,850	$87.57	
18	31	010	28 154	E3588 Pheasant	Johnson	May	$108,000	3.90	436/356	Jun-03	1900	1,728	$62.50	
19	31	010	34 114	E3764 K	Massart	Paul	$45,000	1.70	346/256	May-00				Mobile Home
20	31	010	34 011	E4097 Pheasant	Heraly	El-Na Farms	$30,000	1.00	470/789	Aug-04	1900	1,410	$21.28	
21	31	010	35 156	N7343 P	Bezecny	Laurant	$68,000	0.30	345/306	Apr-00	1900	1,944	$34.98	
22	31	010	36 041	N7501 Chestnut	Marquardt	Vania	$54,000	5.00	324/980	Nov-98	1898	1,688	$31.99	
23	31	010	36 131	N7497 Chestnut	Salzsieder	Teich	$35,000	6.99	335/234	Jun-99				Mobile Home
24	31	010	36 021.	Pheasant	Korithoski	Rankin	$23,500	5.86	338/527	Sep-99				Barn
25	31	018	3 161.	E1650 X	Ferron	Derenne	$80,000	1.10	385/950	Feb-02	1980	1,000	$80.00	
26	31	018	3 162	E1658 X	Delise	Phillips	$121,500	1.50	404/598	Sep-02	1998	1,232	$98.62	
27	31	018	13 093	E2225 Fameree	Brink	Knudson	$119,000	1.10	423/368	Feb-03	1983	1,536	$77.47	
28	31	018	15 151	E1596 Town Hall	Speth	Lemens	$184,000	5.00	461/212	Mar-04	1995	1,692	$108.75	
29	31	018	15 151	E1596 Town Hall	Dorner	Speth	$175,000	5.00	390/844	May-02	1995	1,692	$103.43	Sold for $220,000 in 1999 but kept 35 acres.
30	31	018	23 072	E1796 LeCaptain	Frisque	Strebel	$80,500	5.00	367/726	Aug-01	1900	2,184	$36.86	
31	31	018	24 162	E2498 S	Englebert	Johnson	$65,000	1.00	365/843	Jun-01	Family Trust			
32	31	018	24 15	E2322 S	Baldwin	Ball	$127,000	5.40	454/397	Nov-03	1920	1,612	$78.78	
33	31	018	25 051	E2273 S	Sconzert	Charles	$81,000	1.40	369/846	Aug-01	1926	1,680	$48.21	
Average:													$62.19	

Appendix I: Continued on Next Page

Appendix I: Continued

Sale	Parcel No.	Address	Grantor	Grantee	Sale Price	Acres	Book/ Page	Sale Date	Age	Ft^2	$\$/Ft^2$	Comments
Control Area:												
34	31 010 3 062	E3705 X	Flauger	Galiano	$100,200	0.75	367x567	Jul-01	1875	2,506	$39.98	
35	31 010 4 133	N9449 Fir	Cowan	Kinjerski	$74,500	1.15	367/939	Aug-01	1870	924	$80.63	
36	31 010 4 121	E3512 Cardinal	Pagel's	Niles	$175,000	4.90	394/327	Jul-02				Not Arm's Length Partners
37	31 010 4 133	N9449 Fir	Kinjerski	Townsend	$85,000	1.10	452/417	Nov-03	1870	1,848	$46.00	
38	31 010 10 162	E4076 Hawk	Herison	Larkin	$104,000	1.19	392/309	Jun-02	1980	1,716	$60.61	
39	31 010 14 112	E4144 Partridge	Cravillon	Pierre	$33,000	8.50	368/49	Aug-01	1900s			Tore House down and put in DW
40	31 010 16 102	N8654 C	Kroening	DeWitt	$32,600	0.81	345/175	Apr-00				Bgt. M.H. & Convt. to house
41	31 010 17 162	N8515 C	Shaw	LaFave	$63,600	0.84	345/650	Apr-00	1900	1,538	$41.35	
42	31 010 17 141	N8601 C	Bertrand	Schartner	$172,000	1.00	392/523	May-02	1980	1,569	$109.62	
43	31 010 17 132	N8653 C	Owen	Mencheski	$85,000	0.70	401/748	Sep-02	1900	1,586	$53.59	
44	31 010 21 114	E3324 S	Nowak	Deprey	$35,000	0.24	317/194	Apr-98	1940	840	$41.67	
45	31 010 21 114	E3324 S	Deprey	Petri	$50,000	0.24	400/89	Sep-02	1940	840	$59.52	
46	31 010 28 021	Apple	Theis	Kinnard	$60,000	5.30	473/791	Sep-04				Bunch of Ag. Buildings
47	31 010 29 011	E3291 S	Bernetzke	Nachiwey	$80,000	1.00	338/237	Aug-99	1920	2,028	$39.45	
48	31 010 29 062	E2919 S	Kinnard	Delebreau	$55,000	5.00	337/944	Aug-99	1900	2,083	$26.40	
49	31 010 29 011	E3291 S	Nachtwey	Schema	$57,500	1.52	353/890	May-00	1920	2,028	$28.35	
50	31 010 29 062	E2919 S	Delebreau	McGarry	$139,000	5.00	376/763	Nov-01	1900	2,083	$66.73	
51	31 010 30 012	E2881 S	Jandrin	Alsteen	$49,000	5.00	351/463	Oct-00	1900	1,248	$39.26	
52	31 010 31 02	E2745 Pheasant	Kinnard	Giese	$100,000	5.00	327/810	Sep-98	1900	1,636	$61.12	
53	31 010 31 02	E2745 Pheasant	Frisque	Kinnard	$100,000	5.00	327/808	Sep-98	1900	1,636	$61.12	
54	31 010 31 103	N7452 RR&LTL	Jorgensen	Anderson	$150,000	1.29	460/889	Mar-04	1988	1,222	$122.75	
55	31 010 32 111	E2962 K	Baeb	Maedke	$120,400	2.00	338/201	Sep-99	1972	1,544	$77.98	
56	31 010 32 022	E3191 Pheasant	Deprey Est	Uecker	$33,000	0.77	348/978	Aug-00	1900	1,436	$22.98	
57	31 010 32 051	E3009 Pheasant	Frisque	Anderson	$127,000	2.00	395/261	Jul-02	1991	1,361	$93.31	
58	31 010 32 122	E3088 K	Boucher	Guilette	$171,000	0.92	443/219	Jul-03	1974	1,808	$94.58	
59	31 018 3 021	E1531 Cnty Ln	Ahlswede	Meyer	$45,000	2.00	368/493	Aug-01				Mobile Home with 3 car garage
60	31 018 3 02	E1525 Cnty Ln	Jonet	Derenne	$110,000	7.80	471/498	Aug-04	1920	1,500	$73.33	
61	31 018 4 154	X	Budzban	Jonet	$10,000	0.35	479/692	Dec-04				No Measurments
62	31 018 8 114	E510 Macco	Keller	Tebon	$131,900	1.15	468/319	Jun-04	1920	1,680	$78.51	1920 Rem 1980
63	31 018 8 102	E589 Borley	Tillmann	Beauparlant	$248,000	5.00	448/15	Aug-03	1992			Remodel
64	31 018 9 023	E1121 X	Englebert	Borley	$99,000	0.61	393/328	Mar-02	1935	1,496	$66.18	
65	31 018 9 093	N9047 A	Jeanquart	McFarlin	$118,000	1.79	368/839	Jul-01	1995	1,465	$80.55	
66	31 018 10 112	E1406 Macco	Dequaine	Neuser	$105,000	1.00	433/807	May-03	1920	1,450	$72.41	
67	31 018 18 013	E457 Macco	Spiegelhoff	Nicholson	$175,000	1.00	393/452	Jun-02	1987	2,370	$73.84	
68	31 018 18 012	Macco	Maloney	Wahlen	$137,500	3.00	369/254	Jul-01	2001	1,838	$74.81	
69	31 018 19 133	N8207 H	Woosencraft	Devos	$103,000	1.00	372/515	Oct-01	1978	1,104	$93.30	1995 $72,000 on 2/23/95

Appendix I: Continued on Next Page.

Appendix I: Continued

Sale	Parcel No.			Address	Grantor	Grantee	Sale Price	Acres	Book/ Page	Sale Date	Age	Ft^2	$/$Ft^2$	Comments
70	31	018	25 012	E2497 S	Englebert	Thiry	$139,900	1.50	413/852	Dec-02	1966	1,500	$93.27	
71	31	018	25 12	E1840 K	Joniaux	Assoc. Tr.	$142,000	5.00	479/481	Dec-04	1920	2,016	$70.44	
72	31	018	25 051	E2273 S	Sconzert	Charles	$81,000	1.40	369/846	Aug-01	1926	1,680	$48.21	
73	31	018	26 021	E1931 S	Massey	Daul	$52,000	0.10	447/641	Sep-03	1920	1,600	$32.50	Poor Condition
74	31	018	27 112	E1392 Thiry Dae	Stuckart	LeGrave	$73,000	0.50	421/275	Feb-03	1917	1,120	$65.18	
75	31	018	28 092	N7805 A	Soquet	Thiry	$179,000	2.70	448/48	Sep-03	1977	1,608	$111.32	
76	31	018	32 121	E642 K	Prevost	Dunks	$129,000	3.00	395/226	Jul-02	1985	1,344	$95.98	
77	31	018	33 012	N7655 A	Dalebroux	Besaw	$207,000	2.90	395/877	Jul-02	1976	3,018	$68.59	
78	31	018	34 11	N7396 A	Smith	Monfort	$226,000	6.00	450/220	Sep-03	1995	1,786	$126.54	
79	31	018	34 065	E1347 Thiry Dae	Dalebroux	Langteau	$168,500	7.00	395/821	Jul-02	1918	2,020	$83.42	Downtown Thiry Daems
Average:													$68.60	

Appendix II: Residential Sales, Mendota Hills Wind Farm; 2003-March 2005 .

Appendix II: Residential Sales Mendota Hills Wind Farm, 2003 through March 2005.

Sale	Parcel No.	Address	Sale Date	Book/ Page	Sale Price	Grantor	Grantee	Style	Age	Size	$/Ft^2
Target Area:											
1	05 17 11 153 002	629 W CHESTNUT	Oct-03	0310-2282	$37,000	ESTES	LIPE	1.5	1861	1,161	$31.87
2	05 17 11 179 004	323 W. CHESTNUT	Oct-04	0410-2816	$40,000	REED	HOVIOUS	1.5	1880	1,425	$28.07
3	21 12 29 300 002	1019 STEWARD RD	May-03	0305-3823	$40,000	HOULE-WARD	REYNS	2	1891	1,408	$28.41
4	21 12 34 300 014+	91143 PAW PAW	Mar-05	0503-3432	$187,000	ZAYLIK	PACHERO	2	1891	1,571	$119.03
5	20 11 14 400 001	1224 IL RTE 251	Jun-03	0306-0490	$138,000	GITTLESON	KOWALSKI	2	1899	1,272	$108.49
6	05 17 11 179 001	339 CHESTNUT ST.	Jan-03	0301-5361	$72,000	WHITE	FLYNN	2	1900	1,684	$42.76
7	05 17 11 152 003	630 W. CHESTNUT	Sep-03	0309-6208	$126,000	EDDY	MORATH,SR.	1.5	1901	1,728	$72.92
8	05 17 11 156 004	427 CHESTNUT ST	Oct-03	0310-3369	$87,000	HESIK	ROURKE,JR.	1.5	1901	1,380	$63.04
9	05 17 11 185 005	138 CHERRY ST.	Sep-04	0409-2268	$80,000	HAMMOND	ALEXANDER	1.5	1901	1,326	$60.33
10	05 17 11 156 008	536 W. CHERRY	Oct-04	0410-67	$63,500	JOHNSON	FITZPATRICK	1.5	1906	999	$63.56
11	05 17 02 100 005	885 COMPTON RD	Oct-04	0410-138	$68,900	BOYSEN	GELLINGS	1	1925	480	$143.54
12	05 17 11 156 010	518 W CHERRY ST	Apr-03	0304-0657	$87,500	ALLEN	BECKMAN	1	1928	927	$94.39
13	05 17 11 252 004	222 MAPLE ST	Dec-04	0412-2193	$150,000	CLARK	CUMMINGS	1	1955	1,852	$80.99
14	05 17 11 158 009	444 W. MAIN ST.	Mar-05	0503-3896	$109,900	MILLER	MICHAELS	1	1959	1,402	$78.39
15	20 11 35 400 006	2874 BEEMERVILLE	Jul-03	0307-5158	$367,000	FINKBONER	DGNB TRT	1	1997	2,201	$166.74
Average:											$78.84
Control Area:											
16	20 11 10 400 006	1310 MELUGINS GROVE	Apr-04	0404-257	$179,000	LYONS	OVERTON	2	1849	1,952	$91.70
17	05 17 16 300 004	2612 SHADY OAKS RD	Apr-03	0304-3123	$131,000	SMITH	PAPIECH	1.5	1860	1,208	$108.44
18	22 18 23 300 004	3448 CYCLONE RD	Mar-03	0303-4251	$105,900	MUNYON	PIPPENGER	2	1861	1,456	$72.73
19	05 17 08 153 011	2524 JOHNSON ST	Aug-04	0408-3017	$61,800	COPELAND	LAMPSON	1.5	1876	948	$65.19
20	05 17 08 305 009	741 THIRD ST	Feb-04	0402-2290	$63,500	ECKHARDT	ROSALES	1.5	1881	868	$73.16
21	05 17 35 100 002	613 CHURCH RD	May-03	0305-5466	$115,000	MERKEL	PARPART	1.5	1881	1,458	$78.88
22	21 12 14 100 004	3435 WILLOW CREEK	Jun-03	0306-4798	$118,000	SWIATEK	BRYDUN	2	1881	884	$133.48
23	22 18 31 100 008	3021 COTTAGE HILL	Mar-05	0503-3062	$182,000	RUSS	CURTIS	1.5	1881	1,239	$146.89
24	21 12 15 200 002	3385 WILLOW CREEK	Mar-03	0303-0263	$180,000	MCCOY	CARVER	2	1886	2,840	$63.38
25	05 17 08 304 008	745 SECOND ST.	Dec-04	0412-443	$59,000	WILSON	CALDERON	1.5	1891	1,161	$50.82
26	05 17 08 154 005	761 4TH ST	Mar-03	0303-0239	$68,000	STEWART	ELSINGER	1	1891	724	$93.92
27	05 17 34 400 005	2774 WELLAND RD	Apr-03	0304-3095	$93,000	BATHA	CRUMPTON	1.5	1891	1,104	$84.24
28	22 18 22 200 006+	558 EARLVILLE RD	Jan-03	0301-4140	$145,000	HODGE	IKELER	2	1891	1,280	$113.28
29	05 17 08 304 003	2505 WOOD ST	Aug-04	0408-0067	$105,000	JANIAK	BULLOCK	2	1896	1,812	$57.95
30	22 18 34 200 003	385 EARLVILLE RD	Aug-04	0408-372	$280,000	RAGO	DIEHL	2	1896	2,142	$130.72
31	22 18 30 200 003	3095 CYCLONE RD	Dec-04	0412-2443	$169,900	SUMMERHILL	RAINBOLT	2	1904	2,048	$82.96
32	05 17 08 305 006	742 2ND STREET	Jan-03	0301-6333	$103,000	DELHOTAL	STEWART	2	1908	1,876	$54.90
33	22 18 32 100 017	395 ANGLING RD	Mar-05	0503-3082	$119,000	BMV PROP.	HERENDEEN	1	1911	680	$175.00

Appendix II: Continued on Next Page.

Appendix II: Continued.

Sale	Parcel No.	Address	Sale Date	Book/ Page	Sale Price	Grantor	Grantee	Style	Age	Size	$/Ft^2
34	05 17 08 305 002	2515 WOOD ST.	Apr-04	0404-2618	$80,000	JONES	SARVER	1	1937	912	$87.72
35	21 12 14 300 012	1218 LOCUST RD	Jan-05	0501-2972	$169,000	WACHOWSKI	GEMBECK	1	1939	1,040	$162.50
36	20 11 34 400 006	901 MELUGENS GROVE	Aug-03	0308-1376	$228,000	KIDD	RAJAN	1	1945	2,000	$114.00
37	21 12 04 100 002	1490 GERMAN RD	Aug-04	0408-1829	$85,000	FIRLIT	CHALLAND	2	1950	2,144	$39.65
38	22 18 13 300 003	603 OGEE RD	Apr-04	0404-4932	$285,000	ANDERSON	MILLER	1	1974	1,920	$148.44
39	05 17 22 300 001	546 CARNAHAN RD	Jan-05	0501-2212	$110,000	COLEY	SARABIA	1	1977	1,296	$84.88
40	21 12 12 200 003	1353 COUNTY LINE	Nov-03	0311-554	$185,000	VALLEJO	BOZAETH	1.5	1978	1,338	$138.27
41	05 17 08 152 012	2512 JOHNSON ST.	Feb-05	0502-299	$123,000	MONTAVON	SUTTON	2	1985	2,232	$55.11
42	20 11 05 100 003	2509 HERMAN RD	Apr-04	0404-3469	$142,900	BRESSON	ARJES	1	1993	1,404	$101.78
43	21 12 35 200 005	955 WOODLAWN	Jul-03	0307-0281	$265,000	SWAN	LAROSA	1.5	1994	1,918	$138.16
44	21 12 15 200 023	1279 LOCUST RD	Mar-03	0303-4834	$270,000	WITTE	OLIN	1	1996	2,156	$125.23
45	22 18 13 300 029+	648 OGEE	Nov-03	0311-3087	$225,000	FICKENSCHER	ROJAS	1	1997	1,768	$127.26
46	21 12 11 400 019	1339 WOODLAWN RD	Sep-03	0309-178	$230,000	HOWELL	BARNHILL	1	1998	1,701	$135.21
47	21 12 11 400 017	1349 WOODLAWN RD	May-03	0305-2810	$207,500	HOWELL	WISKARI	1	1998	1,809	$114.70
48	22 18 12 300 007	711 O'GEE RD	Aug-04	0408-1618	$185,000	GROEVENGOED	CARABAL	1	1998	1,352	$136.83
49	21 12 15 200 020+	1295 LOCUST RD	May-04	0405-4036	$300,000	HAGAN	LOWE	1	2001	2,672	$112.28
50	22 18 03 200 004+	860 PAW PAW RD	May-04	0405-292	$185,000	WISKUR	POGREBA	1	2002	1,148	$161.15
51	22 18 31 300 021	3011 HONEYSUCKLE	Mar-05	0503-68	$355,000	ABBOTT	BRANDT	2	2002	3,655	$97.13
52	22 18 27 200 007	489 EARLVILLE RD	Nov-04	0411-463	$165,000	SCHLAFKE	FROMHERTZ	2	2003	1,400	$117.86
53	05 17 05 100 008	2512 SHAW RD	Jun-04	0406-2245	$153,500	HLAVIN	KAPINSKI	2	N/A	1,638	$93.71
Average:											$104.46
Average Price Target Area Post 1960 Contruction:											$166.74
Average Price Control Area Post 1960 Contruction:											$119.62

Section 4

SCIENTIFIC REPORTS: Health

Document List

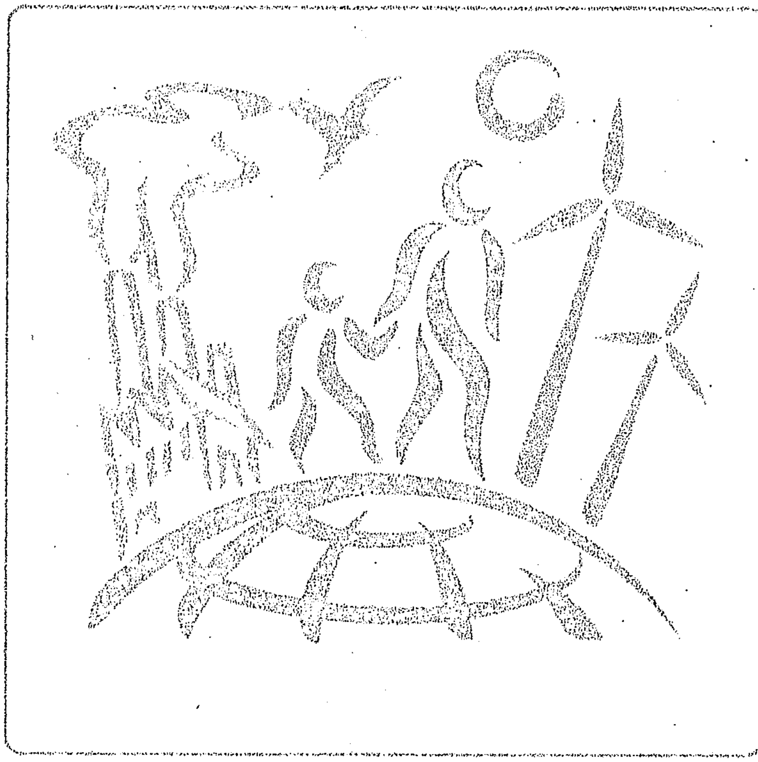
- Excerpt: World Health Organization. *Energy, Sustainable Development and Health.* June 2004.
- Springfield-Sangamon County Regional Planning Commission. *The Effects of Wind Turbine Sound on Health.* January 2010.
- Hessler, George and Hessler Associates. *A Note on the Debate about Health Effects from Low Frequency Noise (LFN) from Modern Large Wind Turbines.* April 2011.
- AWEA and CanWEA. *Wind Turbine Sound and Health Effects: An Expert Panel Review.* December 2009.
- Epilepsy Action, British Epilepsy Association. *Wind turbines.* April 2008.
- Epilepsy Action, British Epilepsy Association. *Photosensitive epilepsy.* August, 2007

WORLD HEALTH ORGANIZATION
EUROPE

Fourth Ministerial Conference on Environment and Health

Budapest, Hungary, 23–25 June 2004

The future for our children



Energy, sustainable development and health

Background document

EUR/04/5046267/BD/8

3 June 2004

UNEDITED DRAFT
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Page

Abstract

Europe faces considerable challenges in restructuring its energy sector to reconcile environmental, social and economic objectives – the three pillars of sustainable development. This document reviews trends in energy availability and demand, access to electricity and heating, and the effects on health of electric power generation, transmission and distribution.

Some parts of Europe still have problems with the affordability of commercial energy and with improving the efficiency of energy use. Such unmet demand may lead to increased use of domestic solid fuel with associated health effects. The various forms of electric power generation are associated with different health effects on workers in industries involved in energy production and in the general population. These effects may arise during the different phases of fuel extraction (mining, drilling), power generation and waste disposal. While some occur after a very short time, others (such as those associated with chronic exposure to airborne pollutants) may occur after a period of some years. No form of power generation is entirely free of effects on health, but there are clear contrasts in the type and magnitude of health burdens associated with each.

Although many factors influence energy policies, health considerations would favour a substantial increase in the contribution from renewable sources, especially those based on non-combustion processes.

Overall, progress has been made over the past decade in reducing the health burdens of energy generation, transport and distribution. Nevertheless, energy consumption is still one of the key pressures on health within Europe, and further policies and actions are needed to reduce health risks in the future.

Acknowledgement

The process of developing this document was started in 2003, as a request of the European Environment and Health committee, as an input into the Budapest 4th Ministerial Conference on Environment and Health.

The document was prepared by Bettina Menne from the WHO Regional Office for Europe and Anil Markandya, from the World Bank and Bath University. The development of the framework, the writing process and first review process was coordinated by the WHO Regional Office for Europe, Global Change and Health Programme. The document still needs further in depth development and expert review.

The editors would like to thank Aphrodite Mourelatou from the European Environment Agency for the coordination of the writing of the chapter on Energy availability, demand and trends in Europe. Peter Taylor, Paul Watkiss, Claire Handley and Daniel Waller, from AEA Technology, United Kingdom were the actual writers of the chapter. Large parts of this chapter are based on the energy chapter of the EEA's recent "Kiev report", which was prepared by George Marsh (also from AEA Technology).

The chapter on Access to electricity and heating was prepared by Bettina Menne, Anil Markandya and Tom Kosatsky with contributions from Boris Revich, Russian Academy of Sciences, Moscow, the Russian Federation; Mike Ahern and Paul Wilkinson, London School of Hygiene and Tropical Medicine, United Kingdom; Giorgio Tamburlini, Burlo Garofano, Trieste, Italy; Matthias Braubach and Xavier Bonnefoy from the WHO Regional Office for Europe.

The chapter on Exposure and Health Impacts of Electric Power Generation, Transmission and Distribution was prepared by Mike Ahern and Paul Wilkinson from the London School of Hygiene and Tropical Medicine and Alistair Hunt, from the Bath University, United Kingdom. Kristie L Ebi from Exponent, United States wrote the session on Electro magnetic waves.

Chapter 5 was prepared by Anil Markandya, Bettina Menne and Michael Joffe. Michael Joffe is from Imperial College London, United Kingdom.

The editors and authors would like to thank the following reviewers for their useful comments provided. The reviewers are Michal Krzyzanowski, Juergen Schneider, Marco Martuzzi and Michele Faberi from the WHO Regional Office for Europe; Professor Mark McCarthy, University College London, United Kingdom and Colin Buttler, Australian National University, Canberra, Australia.

Note from the editors: we plan to hold a meeting to review this document and to develop further recommendations. This document is English unedited. It is planned to be published as: Menne and Markandya. 2004. Energy, sustainable development and health. World Health Organization, Regional Office for Europe. Global change and health series. For comments please contact: Dr Bettina Menne (bme@who.it).

Chapter 1: Introduction

Author: Anil Markandya

With the onset of industrialization, rapid technological change and the advance of economic development, the people of the industrialized world have seen a remarkable rise in their living standards and improvement of health status.

Carefully reconstructed data for Western Europe show, for example, that twelve Western European countries had a per capita income of $1,230 in 1820; by 1992, this had risen to $17,400 (Maddision, 1995) [1], implying a sustained annual growth rate of 1.6 percent for 172 years, something that was unprecedented in the history of the world. In parallel to this we observe an increase of life expectancy in Europe from around 40 years at the beginning of the 19th Century in Europe to nearly 80 years for a child born today (Woods, 2000). The increase of life expectancy is not linear with economic growth. In general once the per capita income has exceeded 7,500 USD, life expectancy is expected to rise more slowly.

Needless to say, neither the improvement of health status nor the economic growth would have been possible without an increase in the supply of energy, both as an input in production as well as an end-use commodity in its own right. Energy data only go back on a consistent basis to 1850. Since then and up to 1990 (i.e. 140 years) energy use in Western Europe has gone up 4.7 times while GDP has gone up 21.5 times (Gruebler, 1997)[2]. The implied increase in energy 'efficiency' – the amount of output one gets from a given input of energy – has been quite steady over the whole period. Each unit of energy now produces more than 4.5 times as much output as it did in 1850.

Both population growth as well as economic growth has led to increased well-being, but also increased energy consumption. What have been the health implications of this increase in energy consumption?

Overall, there is little doubt that the impact has been positive. This is particularly so because of the shift away from non-commercial fuels, such as wood, and towards commercial energy, particularly electricity, which we have seen as part of the development process. Our present concern with the health implications of burning fossil fuels should not blind us to the fact that, compared to the situation that existed in the 19th Century, the positive health impacts of 'modern' energy use (cleaner air in the home, adequate heating in winter, reduced risk of fires, less health hazards associated with animal waste, more efficient and cleaner medical services) might out weigh the negative impacts that are so much the focus of our attention today.

As we look to the future, we must recognize the important contribution increased access to commercial energy can make to improved health and to the reduction of poverty throughout the world. Indeed this recognition is among the key objectives of sustainable development, as

[1] The countries are: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Sweden, Switzerland and the United Kingdom.

[2] Based on detailed data for France, Germany and the UK. Data are from A. Grübler et al and J-M Martin.

articulated at the World Summit on Sustainable Development in Johannesburg in September of 2000.

Box 1 The Millennium development Goals[4]

In September 2000, 147 heads of state and government and 189 nations in total committed themselves to making the right to development a reality for everyone. The objective of the declaration is to promote "a comprehensive approach and coordinated strategy, tackling many problems simultaneously across a broad front". To help trace progress, a set of time-bound and measurable goals and targets for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women were defined.

At that conference the international community committed itself to eight Millennium Development Goals (MDGs)[5]. To a lesser or greater degree, development of, and access to, commercial energy is necessary for meeting all these goals. It is particularly relevant to the health and poverty-related goals. A recent World Bank study looked at demographic and health data from over 60 low-income countries and investigated the determinants of health outcomes using cross-country data between 1985 and 1999 (Wang, 2003). It found that in urban areas, linking households to electricity is the only key factor that reduces both the infant mortality rate (IMR) and the under five-mortality rate (U5MR), and that this effect is large, significant and independent of incomes. In rural areas, improving female secondary education is crucial for reducing IMR, while expanding vaccination coverage reduces U5MR.

The MDGs contain not only the goals listed above, but also a number of targets for these goals, and indicators that should be monitored as part of the program. Goal 7 is to ensure environmental sustainability, with the target to integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. The energy indicators that will be monitored under the MDG implementation program are:

- Energy use (kg oil equivalent) per $1 GDP (PPP) (IEA, World Bank);
- Carbon dioxide emissions per capita (UNFCCC, UNSD) and consumption of ozone-depleting CFCs (ODP tons) (UNEP-Ozone Secretariat); and
- Proportion of population using solid fuels (WHO).

A reduction in each of these indicators will have beneficial health impacts. That is a major reason for preparing this report, which takes stock of our knowledge of the links between energy sustainable development and health and addresses a number of high profile concerns.

The substantive part of the report begins (in Chapter 2) by providing important background information relevant to understanding energy and health linkages, such as the key trends in energy demand and use in different parts of Europe, the outlook for the future and the main problems that need to be addressed at the national and international level.

[4] http://www.who.int/indoorair/mdg/en/; accessed 10 May, 2004
[5] http://www.un.org/millenniumgoals/, accessed 10 May, 2004

The rest of the report addresses a number of major concerns. The first of these concerns is of social nature – the accessibility of commercial energy. Although we have no shortage of energy in most countries of Europe, there is concern about energy prices, energy efficiency in houses and frequency of energy-related local accidents. There are individuals, families and households who cannot afford enough for their basic needs and there is energy poverty in the midst of plenty. How serious a problem this is and what are the links with health[6]? What could be effective measures? Chapter three deals with access to electricity and heating. It also addresses the problems of indoor air pollution arising from the use of solid fuel in the home. In general these are less serious in Europe than they are in tropical countries, but there are some communities, especially in the Former Soviet Union, that are increasingly burning solid fuels to meet their energy needs. This has health implications, which need to be studied and the scale of the present problem evaluated.

The second major concern arises from emissions from commercial fuels used for heat, electricity and transport, especially small particles. To assist our understanding of the diversity and complexity of the health impacts of energy generation, transmission and distribution, we have, adopted the Life Cycle approach, where each stage of the activity (production, transportation, consumption, disposal of waste etc.) are analysed for their health impacts. We consider which stages of the cycle are the most relevant from this perspective for each of the energy-generating resources and hence identify the numerous pathways through which the health impacts occur. This is followed by a review of recent studies, such as ExternE, that assess the potentially damaging and spatially and temporally far-reaching effects of burning coal, oil, gas and other fossil fuels. The implied costs of their use have been estimated and the implications for energy policy, which are still being worked out, are discussed. One important fact is that, of all the impacts of using such fuels, the most important ones relate to health. All this is dealt with in chapter 4.

The health issues arising from the present pattern use of energy need to be seen in a longer-term perspective as well. We started by stressing the importance of increased commercial energy supplies for economic development and, *pari passu,* improved human health. Of course, as we note in Chapters 3-4, new problems are coming to the forefront from the massive expansion in the use of energy, especially fossil fuels and these need to be addressed. In the short to medium term we can address them by adopting cleaner versions of existing large-scale energy production technologies. But in the longer term we will need to switch much more to renewable sources that are much less damaging to health and increase energy security. The reason is that the planet will not be able to sustain energy use at the present levels of the industrialized countries once the developing countries have also reached similar levels of GDP *per capita*. This is most clearly brought out in the debate on climate change, where it is recognized that both developing and developed countries have to reduce emissions of carbon into the atmosphere. Presently developed countries emit around 4.3 tons of carbon per person, the countries of Eastern Europe and the Former Soviet Union emit 2.2 tons per person and the developing countries emit half of that -- 1.1 tons. If climate is eventually to be stabilized (and no one seriously doubts that it must) the target emissions *per capita* in 2100 must be around 0.3 tons per person, which is less than one-third of what developing countries are emitting today. The target can only be achieved with a 'renewable transition' – i.e. a whole-scale shift out of using fossil fuels and a shift to renewable sources of energy.

[6] See, for example, The World Bank. *Coping with the Cold*, Technical Paper, No 529, Washington DC, 2002.

The report concludes (chapter 5), by bringing together the main findings and makes some recommendations for follow-up action, to fill the gaps in knowledge that have been revealed and to direct policy-makers on areas that the literature has identified as critical for the protection of human health.

Wind power

Wind energy was widely used prior to the industrial revolution, but was then displaced by fossil fuels because of differences in costs and reliability (Turkenburg 2000). We have not included a figure of the wind fuel cycle here, but the main stages are: building and manufacturing, normal operation during the turbine's lifetime, decommissioning. In the turbine construction phase there are some pollutant emissions, but these have been considered to be negligible when compared with other fuel cycles (CIEMAT 1998). Most wind farms are considered to have very low impacts, and these are caused mostly at the local scale – noise pollution may be a problem if turbines are situated close to centres of population. A wind turbine produces no emissions, so in the context of global climate change the potential to reduce CO_2 emissions depends on the fuel mix of the fossil-fuelled plants the wind turbine is working with (Turkenburg 2000). One study (BTM Consult 1999), cited in (Turkenburg 2000), suggested that by the year 2025 wind energy could prevent the emission of 1.4 – 2.5 gigatonnes of CO_2 per annum. The ExternE Project considered wind energy to have the lowest level of impacts (health and environmental), of all the fuel cycles considered (CIEMAT 1998). For example, in Germany, the health impacts are 10% of those from coal per terawatt hour of electricity production. Clearly, these up-stream processes are dominant since no pollutants are emitted during power generation. Within the ExternE comparison, health effects from wind energy are negligible, however issues such as sleep disturbance, school absenteeism, eventually resulting from noise in vicinity, could not be evaluated.

Waste incineration

While it could be argued that waste incineration differs from the other fuel cycles described here, the fuel – waste materials – is readily available, and does not require extraction, as in the case of the fossil fuels. The waste incineration cycle, illustrated in Figure 4.10, consists of waste collection, and transport to the municipal solid waste (MSW) plant, where it is usually separated into recycling, composting, and incineration flows, and the most important burdens associated with this fuel cycle are the atmospheric emissions generated in the power generation stage (CIEMAT 1998). The key health impacts from the waste fuel cycle inevitably arise in the combustion process itself. As well as generating many of the classic air pollutants of combustion (PM, NOx, SOx, CO), waste incineration plants also emit dioxins and furans, metals such as lead, mercury, cadmium, arsenic, chromium, nickel, volatile organic compounds and polycyclic aromatic compounds. Exposure to incineration emissions is a complex process as it combines direct exposure to air pollutants with long-term exposure to dioxins and furans through ingestion. It is the latter, which are of most concern, given their very high toxicity.

Although there is clearly potential for waste incinerators to cause significant adverse health effects, the literature on the actual impacts of incinerators appears equivocal. The UK Royal Commission on Environmental Pollution concluded that although the pollutants produced by incinerators can cause acute and chronic toxicity in humans, the concentrations produced by incinerators are below levels likely to cause significant harm. However, the report also highlights that some concern still remains over emissions of heavy metals from solid waste incineration and highlights site-specific risk assessments that could be carried out to assess the risks of adverse health.

Information Brief

SSC RPC Springfield-Sangamon County Regional Planning Commission

January 6, 2010

Key Findings:

The SSCRPC finds that while some living near wind farms may find the sound generated by such facilities to be an annoyance – and this annoyance may have certain effects and be related to negative opinions concerning wind energy facilities – there is no current reliable empirical evidence that the sounds generated have adverse health effects. This includes the effects reported as coming from low-frequency and infrasound.

While there may be other policy reasons for changing site location and setback requirements, the SSCRPC does not find that this should be necessitated by public health concerns.

The Springfield-Sangamon County Regional Planning Commission

Room 212
200 South 9th Street
Springfield, Illinois 62701

Phone: 217.535.3110
Fax: 217.535.3110
Email:
sscrpc@co.sangamon.il.us

www.sscrpc.com

The Effects of Wind Turbine Sound on Health

A Brief Consideration of the Literature

Issues related to sound generated by wind energy turbines have led to some debate regarding the appropriateness of wind energy facility site location and setback requirements, with opponents of wind farms arguing that certain sounds generated by the facilities may cause health problems for those who live nearby necessitating greater setback distances.

Because of the importance of public health and safety to wind energy facility regulation, the Springfield-Sangamon County Regional Planning Commission (SSCRPC) conducted a brief review of the available and noteworthy literature on the subject of wind turbine sound. Particular attention was given to low-frequency and infrasound generated by wind turbines as this sound is often the focus of those arguing for additional regulation and greater setback distances. As is the practice of the SSCRPC in conducting such reviews, preference was given to published scholarly studies that were subject to peer review or that provide sufficient methodological information to allow for peer review.

While a great amount of empirical work has been done on the effects of sound on human health, which is applicable to the issue of wind turbine generated sound, scholarly work specifically regarding the sound created by wind turbines appears to still be limited.

However, and consistent with other reviews of the literature, the SSCRPC found that while some living near wind farms may find the sound generated by such facilities to be an annoyance, there is no reliable empirical evidence at this time that the sounds generated by wind energy facilities – including low-frequency and infrasound – are a threat to public health.

The following pages outline the information reviewed.

Wind Energy Facilities and Sound

There is no question that wind turbines generate sound. This sound is generally created in two ways; as mechanical sound, created by the equipment internal to the turbine, or as aerodynamic sound, created by air moving past the rotor blades (Rogers, et al., 2006, pp. 10-13; Colby, et al., 2009, pp. 3-1 – 3-12). To understand the implications of sound generated by wind energy facilities, it is important to understand a bit about how sound is measured and the types of sound created by wind turbines.

Sound is most often considered in two ways: the sound's magnitude, volume or *pressure*, which is measured in decibels (dB), and the sound's pitch, tone or *frequency*, which is measured in hertz (Hz). Since both sound pressure and frequency have an effect on the perception of a sound, they are often brought together in a scaled set of measures (see Colby, et al., 2009, pp. 3-2 – 3-3, and C-1). For example, a pneumatic drill at 50 ft. distance is said to have an "A-Weighted Sound Level" of 80 dB, and is considered "annoying", while light auto traffic is measured at 50 dB under the same system and is considered "quiet".

The sound pressure of a modern wind turbine is normally in the range of 35 to 45 dB at a distance of about 1000 feet, which is comparable to the sound level in a typical home (50-60 dB) and less than that found in a typical office environment (60-70 dB). One acoustic consultant compared the sound level of a wind turbine at 50-100 meters (about 165 ft. to 330 ft.) to the sound of a flowing stream (Hayes McKenzie, 2000).

While the human ear can detect a very wide range of sound levels (magnitude, pressure or loudness) and sound frequencies (pitch or tone), typically the frequencies of sound that can be heard range from about 20 hertz to 20,000 hertz (Rogers, et al., 2006, p. 4). Hertz (Hz) is a measure of the sound's oscillations per second. Understanding the difference between sound *pressure* (measured in decibels) and sound *frequency* (measured in hertz) is particularly relevant to the debate concerning wind turbines because of the contentions made about low-frequency sound and infrasonic or "infrasound".

Low-frequency sound is generally near the bottom of human perception, at frequencies between 10 and 100 Hz. Low-frequency sounds are not uncommon and are usually present in the environment as background noise. What is called infrasound overlaps with low-frequency sound frequencies, and is generally described as existing at frequencies below 20 Hz but can occasionally be perceived at frequencies as low as 2 Hz. Infrasound is "always present in the environment and stems from many sources including ambient air turbulence, ventilation units, waves on the seashore, distant explosions, traffic, aircraft, and other machinery" (Rogers, et al., p. 8). Infrasound and low-frequency sound can be perceived as a mixture of auditory and tactile sensations, with the primary human response to infrasound being "annoyance" (Rogers, et al., p. 9; see also, Pedersen and Waye, 2007, and van den Berg, 2004).

The Wind and Hydropower Technologies Program of the U.S. Department of Energy (2009) notes four types of sound associated with wind turbines that can differ in both sound pressure and sound frequency:

- **Broadband Sound:** Made up of a combination of sound waves with different frequencies. Broadband sound has no distinct pitch and can be described as a humming, whooshing, or swishing sound. Broadband sound does not start or end abruptly. It has frequencies higher than 100 Hz and is typically caused by the interaction of the turbine blades with atmospheric turbulence. Low-frequency sound (20 Hz to 100 Hz) usually occurs only when the turbine blades are located on the downwind side of the turbine tower. The blades experience airflow deficiencies because the airflow is partially blocked by the tower. Low-frequency sound can often be felt before it is clearly heard.

- **Infrasonic Sound:** As noted above, infrasound exists at frequencies of less than 20 Hz and is always present in the environment. Infrasonic sound can propagate further than higher, more audible frequencies, but it also has higher levels of dissipation and blends in with ambient noise. Though infrasound is barely audible, it can cause structural vibration, such as window rattling.

- **Impulsive Sound:** Is generated when disturbed airflow interacts with turbine blades or when multiple turbines making swishing noises synchronize in stable winds. Impulsive sounds are characterized by thumping sounds that can vary in amplitude over time. As with low-frequency sound, impulsive sound from a single turbine tends to occur in downwind turbines as a result of air flowing around the tower to reach the blades.

- **Tonal Sound:** Can be caused by the rotation of shafts, generators, and gears operating at natural frequency; unstable airflow over holes or slits; or non-aerodynamic instabilities interacting with the blade surface. Tonal sounds can have a distinct pitch, like a musical note, and do not start or end abruptly.

Wind Turbine Sound and Health

While the sound generated by wind turbines may be considered "noise" by some and be a nuisance, more troubling is the contention by wind farm opponents that the sound generated by the turbines, particularly low-frequency sounds and infrasound, may have detrimental effects on human health and therefore necessitate greater separation from human habitation. As sometimes reported, these effects have even been termed "wind turbine syndrome" and "vibroacoustic disease" by their advocates (for example, Nina Pierpoint and Mariana Alves-Pereira, respectively). Because of this concern, the SSCRPC specifically sought information concerning the effect that the sounds made by wind turbines might have on human health.

The infrasound generated by wind turbines is affected by a number of variables (see Rogers, et al., pp. 16-20, and Wagner, et al., 1996), but one of some importance – and alluded to in the section above – relates to the design of the turbines. Some early wind turbines had "downwind" rotors that generated significant levels of infrasound. This downwind design is rarely used in modern "utility-scale" wind power turbines (Rogers, et al., p.13). Modern "upwind" rotors emit broadband sound emissions, including low-frequency sound and some infrasound, but the "swishing" sound of the turbine often suggested as a product of low-frequency or infrasound is merely the "amplitude modulation at blade passing frequencies of higher frequency blade tip turbulence" and does not contain low frequencies. (Rogers, et al., p. 13).

The effect of low-frequency and infrasound on human health is an issue that has been debated by both wind farm opponents and proponents. While there is a very large literature dealing with the effects of sound on the human body, and it is often discussed in the occupational health literature, the SSCRPC found less peer-reviewed scholarly work specific to wind turbines; particularly as it relates to detrimental effects. This may largely be due to there being general concurrence that, as previous studies of low-frequency and infrasound indicate, the sound generated by wind turbines does not present a hazard.

One of the most cited reports that considered the relevance of wind turbine sound to human health is that by Leventhall (2006a), who found no reliable evidence that infrasound levels below the hearing threshold had an adverse effect on the human body (p. 30) and was of "no consequence" (p. 34). This was also noted by Rogers and colleagues (p. 10) in regard to both "physiological or psychological effects".

Leventhall writes:

> It has been shown...that there is insignificant infrasound from wind turbines and that there is normally little low frequency noise. Turbulent air inflow conditions cause enhanced levels of low frequency noise, which may be disturbing, but the overriding noise from wind turbines is the fluctuating audible swish, mistakenly referred to as "infrasound" or "low frequency noise". Objectors' uninformed and mistaken use of these terms ..., which have acquired a number of anxiety-producing connotations, has led to unnecessary fears and to unnecessary costs, such as for re-measuring what was already known, in order to assuage complaints. (2006a, p. 35).

There is additional support for Leventhall's finding.

Consider first that if low-frequency sound emitted by wind turbines is harmful to health, city dwelling would be impossible due to the similar levels of ambient low-frequency sound normally present in urban environments (Colby, et al., p. 4-1). This is but one of the reasons why acoustic experts find that low-frequency sound from wind turbines is of no consequence to health (see, for example, Jakobsen, 2004).

But even if the research were to indicate a relationship, the effect would most likely be insignificant because, as Leventhall notes, only low levels of infrasound and low-frequency sound have been found by other studies of wind turbines (Jakobsen, 2004; van den Berg, 2004). As a general rule, higher frequency sounds present a greater risk of adverse effect than do lower frequency ones (Colby et al., pp. 3-12 – 3-14).

The most complete review of the literature (Colby, et al., 2009) concerning the effect of wind turbine sound on health was recently provided by an eight-member expert panel brought together by the American Wind Energy Association and the Canadian Wind Energy Association. This review, published in December 2009, assessed the contentions of those suggesting that wind turbines have a detrimental affect on health. Although the work might be considered suspect by some due to the sponsoring organizations, the SSCRPC found the work to be well-researched, complete, scholarly and informative.

After reviewing the extant peer-reviewed literature on wind turbine sound and possible health effects (drawing from the research listed in *PubMed* as well as other sources), the panel reached agreement on three key points which are fundamental to their analysis (Colby, et al., p. 5-1):

- *There is nothing unique about the sounds and vibrations emitted by wind turbines.* That is, the accumulated knowledge about sound and its affect on human health is as applicable to the consideration of sound generated by wind turbines as it is to any other sound source.

- *The body of accumulated knowledge about sound and health is substantial.* While the body of knowledge specifically related to sounds generated by wind turbines may be more limited, a great amount of work has been done concerning sound and health more generally, as well as under specific conditions. This work is accessible by those studying the effect of wind turbine generated sound on human health and is relevant in assessing any health risks. The SSCRPC found that one of the difficulties in assessing the work of those suggesting that the sound of wind turbines results in health problems, is that they often do not appear to be conversant in the existing literature concerning sound. This leads to weak theoretical conceptualizations and a misunderstanding of pervious work.

- *The body of accumulated knowledge provides no evidence that the audible or substantial sounds emitted by wind turbines have any direct adverse physiological effects.*

Based upon the available evidence and the scientific community's understanding of the effects of sound on human health, the panel concluded (p. 5-2) that:

- The sound from wind turbines does not pose a risk of hearing loss or any other adverse health effect in humans.

- Subaudible, low-frequency sound and infrasound from wind turbines, often cited by wind facility opponents as cause for additional regulation, do not present a risk to human health.

- Some people (with several studies indicating about 5% of the population: Pedersen, at al., 2009; Pederson and Waye, 2004; Pederson and Waye, 2007) may be annoyed at the presence of sound from wind turbines, but annoyance is not a pathological entity.

- A major cause of concern about wind turbine sound is its fluctuating nature. Some may find this sound annoying, a reaction that depends primarily on personal characteristics as opposed to the intensity of the sound level.

Vibroacoustic Disease and Wind Turbine Syndrome

Since wind farm opponents have focused on infrasound and low-frequency sound generated by wind turbines as causes for concern, it is relevant to consider them in particular. The SSCRPC found that the studies by those contending that wind turbines have a negative physiological effect on humans are generally limited in method (e.g., lack of control groups or involve no epidemiological studies), anecdotal (e.g., based upon a single case study, newspaper reports, or self-reports from households already pre-disposed to an outcome), misunderstand sound fundamentals (e.g., the relationship between sound pressure, frequency and sound exposure), or have not been subjected to peer review or are incomplete (see for example: Frey and Hadden, 2007; Harry, 2007; Pierpont, 2008).

While some more general complaints have been lodged against the sound generated by wind turbines, a charge has been made that the low-frequency and infrasound generated by wind turbines results in specific health problems for those living near wind farms. These have been termed "vibroacoustic disease" (VAD), which is largely drawn from previous studies of health effects associated with aircraft technicians, and "wind turbine syndrome" (WTS), which has a less secure founding in previous studies of sound effect. The Colby report specifically looked at the issues surrounding VAD and WTS and commented:

> Some reports have suggested a link between low frequency sound from wind turbines and certain adverse health effects. A careful review of these reports, however, leads a critical reviewer to question the validity of the claims for a number of reasons, most notably (1) the level of sound exposure associated with the putative health effects, (2) the lack of diagnostic specificity associated with the health effects reported, and (3) the lack of control group in the analysis. (Colby, et al., 2009, p. 4-5)

Vibroacoustic disease has primarily been proposed by two Portuguese researchers as being caused by wind turbines (Alves-Pereira and Castelo Branco, 2007a, 2007b, 2007c, 2007d). In looking specifically at the research offered to support the contention that the low-frequency or infrasound from wind turbines causes VAD, among other criticisms of this work the study found (Colby, et al., pp. 4-5 – 4-8):

- No epidemiological studies that evaluated risk of VAD from exposure to infrasound, which is contended to cause it. In fact studies of workers subject to much higher levels of infrasound than that produced by wind turbines have not shown a risk of VAD. Some of the cases used to support the contention that wind turbines produced VAD were based upon extremely limited samples (e.g., single households who were self-selected complainants), and at levels similar to common urban environments. The SSCRPC believes that if VAD is a result of exposure to the levels of low-frequency or infrasound generated by wind turbines, one should find it present in the general population living in urban environments. However this is not the case, leading one to conclude that the contention is faulty.

- The likelihood is remote in light of the much lower vibration levels in the human body itself. This may be due to various researchers (e.g., Pierpont, 2009) not clearly understanding the difference between sound vibration, assumed to result from inaudible low-frequency sounds, and mechanical vibration (see Colby et al., pp. 3-9 – 3-11).

- The studies that the VAD concept was based upon were reporting on much higher frequency and sound pressure levels than those produced by wind turbines; for example, studies of aircraft technicians. The SSCRPC believes that this most likely explains why VAD is not found in urban environments and would not be found near wind energy facilities; the frequencies and sound pressure levels in these environments are simply not great enough to result in a physiological effect.

Wind turbine syndrome has been hypothesized and primarily promoted by Pierpont (2009) and appears to be based upon two contentions. The first is that low levels of airborne infrasound from wind turbines (in the range of 1 to 2 Hz) directly affects the vestibular system (the sensory system that contributes to balance and spatial orientation), and the second is that low levels of such sound (4 to 8 Hz) also enter the lungs via the mouth and then vibrates the diaphragm, transmitting vibrations to the internal organs of the body. Pierpont contends that the combined effect of these two vibrations, "sends confusing information to the position and motion detectors of the body, which in turn leads to a range of disturbing symptoms" (Colby, et al., p. 4-8).

The Colby report finds that the first contention results from a misunderstanding of a study related to the vestibular system by Todd and others (2008) that was conducted at much higher frequencies than infrasound (100 Hz and above) and was not addressing air conducted sound. Colby and his fellow researchers note:

> There is no credible scientific evidence that low levels of wind turbine sound at 1 to 2 Hz will directly affect the vestibular system. In fact, it is likely that the sound will be lost in the natural infrasonic background sound of the body. (Colby, et al., p. 4-9)

They also find little support for the second of Pierpont's contention, writing that it is:

> ...equally unsupported with appropriate scientific investigations. The body is a noisy system at low frequencies. In addition to the beating heart at a frequency of 1 to 2 Hz, the body emits sounds from blood circulation, bowels, stomach, muscle contraction, and other internal sources. (Colby, et al., p. 4-9)

They also point out that low sound levels from outside the body do not cause a high enough excitation within the body to exceed internal body sounds:

> Pierpont refers to papers from Takahashi and colleagues on vibration excitation of the head by high levels of external sound (over 100 dB). However, these papers state that response of the head at frequencies below 20 Hz was not measurable due to the masking effect of internal body vibration (Takahashi et al., 2005; Takahashi et al., 1999). When measuring chest resonant vibration caused by external sounds, the internal vibration masks resonance for external sounds below 80 dB excitation level (Leventhall, 2006[b]). (Colby, et al., p. 4-9)

This, according to the analysis, means that Pierpont's second contention is false. Additionally the Colby study points to methodological problems associated with the Pierpont research and notes that its "symptoms" have been better explained and addressed previously within the context of "annoyance" rather than being a substantive syndrome that would indicate a fundamental threat to health (Colby, et al., pp. 4-9 – 4-10).

As noted in closing comments related to Pierpont's hypothesis, "[i]n ordinary life, most of us are exposed for hours every day to sounds louder than those experienced at realistic distances from wind turbines, with no adverse effects" (Colby, et al., p. 4-11), and that at this time "wind turbine syndrome" and associated contentions[i] must be considered "unproven hypotheses (essentially unproven ideas) that have not been confirmed by appropriate research studies, most notably cohort and case control studies. However, the weakness of the basic hypotheses makes such studies unlikely to proceed" (Colby et al., p. 4-12).

Annoyance

If the sound generated by wind turbines (particularly low-frequency and infrasound) does not have a detrimental effect on *human health*, and our review of the literature seems to indicate that it does not, that does not mean that it has no effect on *humans*.

As noted previously, wind turbines *do* make sounds and those sounds can be perceived as noise and be a nuisance to some. In brief, some people find the sound of wind turbines *annoying*. While annoyance is not an adverse health effect or disease of any kind, it is a possible result of wind turbine operations and is worthy of consideration. As Colby and colleagues note (p. 3-13), annoyance is a subjective response to many types of sounds that varies among people and cannot be predicted with a sound meter as the same type of sound may elicit different reactions from different people.

A 2009 study of 725 people living in the vicinity of wind turbines in the Netherlands (Pederson, et al., 2009) found the sounds from wind turbines to be more annoying than several other environmental sources at comparable sound levels, and also noted a strong correlation between noise annoyance and negative opinion of the impact of wind turbines on the landscape. The dominant feature leading to annoyance was the sound of the blades "swishing", which had also been found in previous studies (Cloby, et al., p. 3-15).

The SSCRPC emphasizes the relevance of this result. Correlation is not causation. That is, simply because the study found sound annoyance correlated with negative opinions of wind turbines on the landscape does not mean that sound annoyance led to the negative opinion. It is just as possible that those with a negative opinion of wind turbines were more sensitive to the noise they create, leading to a greater reporting of annoyance (see, for example, Pederson, et al., 2009, for further support of this notion). This may be why the results reported by Pederson and others suggest that while the wind turbine sound is easily perceived and is annoying to a small percentage of people (5% at 35 to 40 dB on an A-weighted scale, and 18% at 40 to 45dBA). Other studies have found similar results, one indicating 10% annoyance at sound levels of 40dB or more and another indicating about 8% (Pederson, 2008).

Annoyance may have indirect physiological effects. Protracted annoyance may generate stress, which can result in such outcomes as sleep disturbance, what has been termed the "nocebo" effect (the opposite of the "placebo" effect, this is a worsening of mental or physical health based upon a fear or belief in adverse effects), anxiety, and other stress-related psychological responses (Colby et al., pp. 4-1 – 4-5). However, it is important to understand that, "no differences were reported among people who were 'annoyed' in contrast to those who were not annoyed with respect to hearing impairment, diabetes, or cardiovascular disease" (Colby et al., 2009) leading one to again conclude that the sound from wind turbines does not increase the risk of detrimental physiological health effects.

In Conclusion

While the SSCRPC staff does not have particular expertise in sound science and the physiological effects that sound might have on the human body, we found that the literature on the effect of wind turbine sound on human health to be relatively straight forward and approachable. Since methods for assessing the internal and external validity of research are known to us, it was also possible to come to at least some general understanding of the scholarly rigor demonstrated in the various papers reviewed.

Based upon this review, which was as noted necessarily limited, it is our current opinion that there is no reliable empirical evidence that the sounds – including low-frequency and infrasound – generated by wind energy facilities is a threat to public health and safety. We find this particularly relevant in considering the necessity for changing land use regulations or increasing the wind energy conversion system setback requirements found in the County's current zoning ordinance.

While there may be other public policy considerations that would lead to changes in the ordinance, we do not believe that the evidence exists to suggest that it should be changed due to fear that the sounds generated by wind turbines present a danger to human health. We believe that this finding is consistent with other studies on this subject found in the published literature.

This Report Prepared by E. Norman Sims, SSCRPC, Executive Director

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The Springfield-Sangamon County Regional Planning Commission (SCRPC) serves as the joint planning body for Sangamon County and the City of Springfield, as well as the Metropolitan Planning Organization for transportation planning in the region.

The Commission has 17 members including representatives from the Sangamon County Board, Springfield City Council, special units of government, and six appointed citizens from the city and county. The Executive Director is appointed by the Executive Board of the Commission and confirmed by the Sangamon County Board.

The Commission works with other public and semi-public agencies throughout the area to promote orderly growth and redevelopment, and assists other Sangamon County communities with their planning needs. Through its professional staff, the SSCRPC provides overall planning services related to land use, housing, recreation, transportation, economics, environment, and special projects. It also houses the Sangamon County Department of Zoning which oversees the zoning code and liquor licensing for the County.

The Commission prepares area-wide planning documents and assists the County, cities, and villages, as well as special districts, with planning activities. The staff reviews all proposed subdivisions and makes recommendations on all Springfield and Sangamon County zoning and variance requests. The agency serves as the county's Plat Officer, Floodplain Administrator, Census coordinator, and local A-95 review clearinghouse to process and review all federally funded applications for the county. The agency also maintains existing base maps, census tract maps, township and zoning maps and the road name map for the county.

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[i] Beyond "wind energy syndrome", Pierpont has also suggested the existence of what she calls "visceral vibratory vestibular disturbance" or VVVD. To Pierpont VVVD is a distinctive feature of WES, but appears to us to be something of a re-theorization of WES to allow it to address psychological features that might be associated with "annoyance" rather than something more physiological; though she contends it has a physiological basis. VVVD is addressed and critiqued in Colby, et al., pp. 4-10 – 4-11.

WTN 2011

Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

A Note on the Debate about Health Effects from Low Frequency Noise (LFN) from Modern Large Wind Turbines

Author: George F. Hessler Jr., Hessler Associates, Inc.

Address: 3862 Clifton Manor Place, Suite B, Haymarket, Virginia, 20169 USA

e-mail: George@HesslerAssociates.com

Abstract

There is an intense debate between proponents and opponents of wind turbine projects on the subject of health effects from LFN attributable to modern wind turbines. Opponents, using mainly early 1970's reports from obsolete-design downwind-turbine models, declare excess LFN to exist and to be a suspect cause of adverse health effects. Proponents point to the fact that there is no credible evidence showing LFN from wind turbines to have any adverse health effects.

Hessler Associates has been a technical consultant on more than 60 wind projects with the primary duty of drafting Noise Assessment Analysis for project developers. We, and I might add most opponents of wind projects, are certainly not qualified as experts in the subject of health effects from LFN. In our capacity, the LFN debate is addressed by referencing studies performed by qualified scientists in the field. However, while not health experts, we can apply engineering measurements, logic and common sense to form an opinion on the subject as described in this note.

Introduction

One can address the LFN debate by answering the following three questions:

- How much LFN noise is created by modern wind turbines?

What pressure spectra attributable to wind turbines occurs both outside and inside residences near wind projects?

- Are the pressure levels at residences excessive based on scientific evaluations and comparison to other LFN sources?

Wind Turbine Sound Power

Figure 1 below plots the measured apparent A-weighted sound power spectra from 78 wind turbines ranging in capacity from 75 kW to 3.6 MW[1]. Measurements were carried out down to 4 Hz in some cases. Electrical tones associated with the generator show up at 50 and 60 Hz.

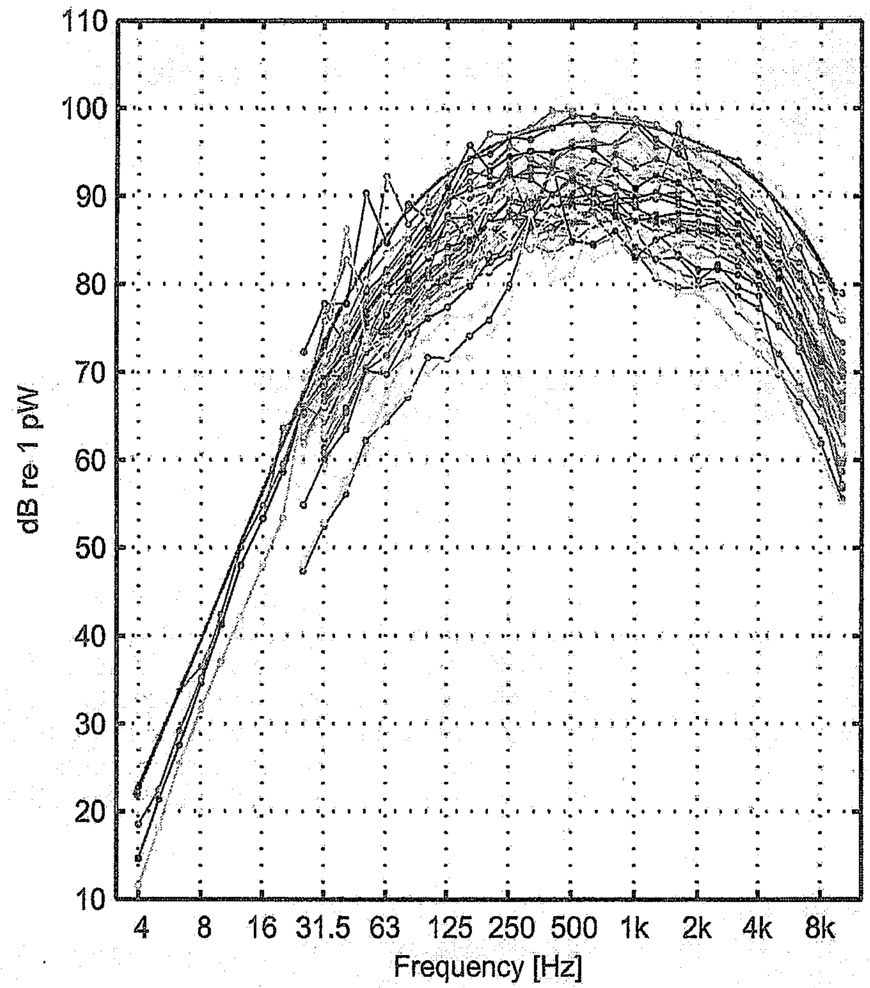


Figure 1

The red overlay was drawn by the author to represent the sound power for the largest wind turbines in use today. **Figure 2** shows the computed A, C and Z weighted overall levels and 1/3 octave spectra for this overlay.

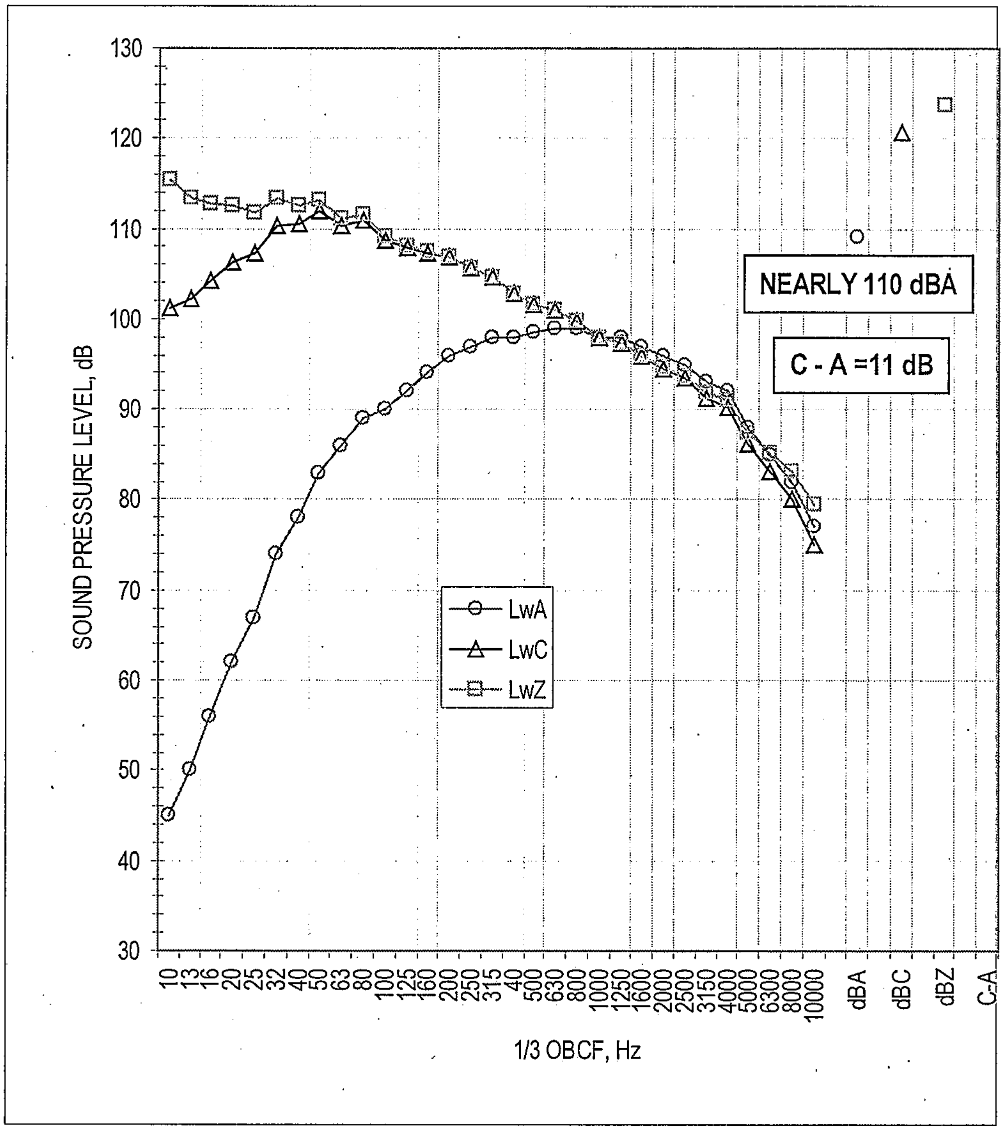
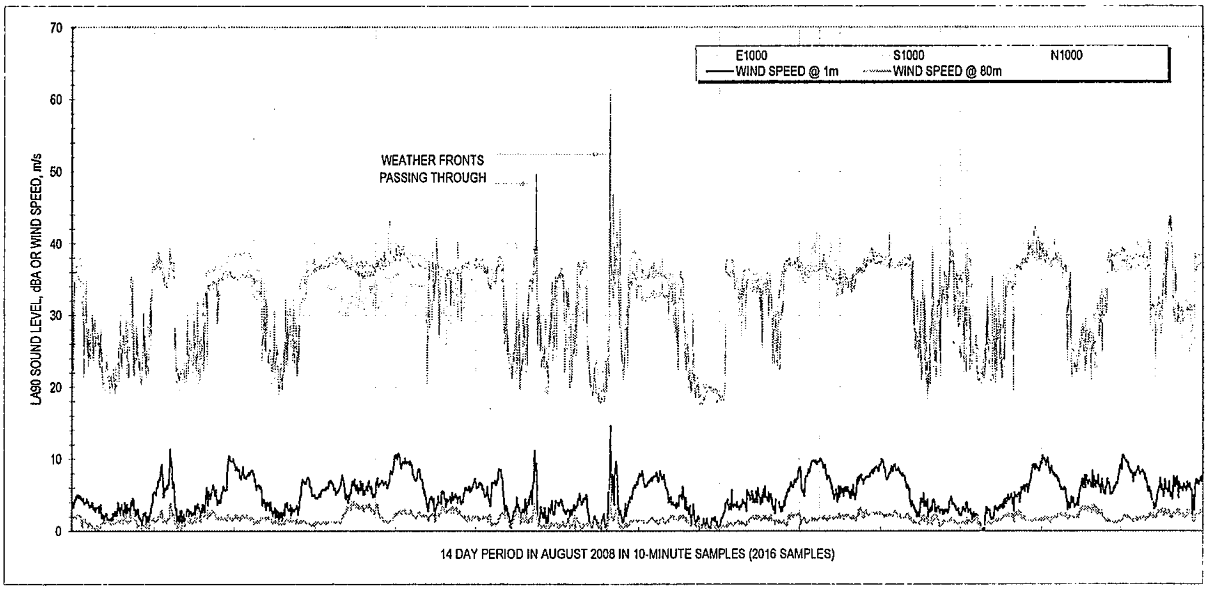


Figure 2

The overall A-weighted level of nearly 110 dBA, re. 1 pW agrees well with specific data from recent large turbine projects. The C-A quantity of 11 dB is the first indicator that large wind turbine spectra are not dominated by the low frequency range. The threshold to determine LFN dominance in a spectrum is typically 15 to 20 dB level difference.

Wind Turbine Pressure Spectra at Residences

Pressure spectra at residences attributable to wind projects is a highly variable with time, whereas measured spectra at the IEC test distance of one hub height plus ½ the rotor diameter is almost perfectly steady with time. This of course is due to atmospheric effects and the very nature of natural wind. To illustrate, **Figure 4** below plots the long term A-weighted LA90 (10 minute) overall level over a 14-day sampling period. The data is for three equal directions of 300 m for a single turbine located at the end of a line of turbines about 300 m apart. Hence, we have upwind, downwind and directional variability as well as the unsteadiness of the wind source. The area is very quiet large farm farmland with typical background sound at about 20 dBA during low wind periods.

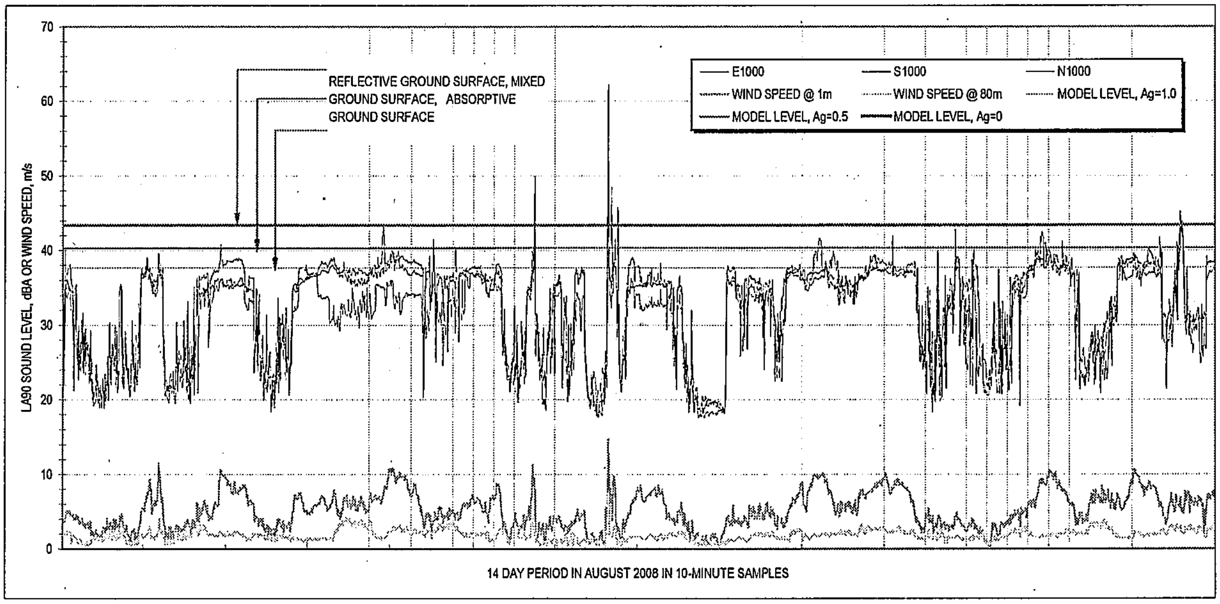


RAW DATA AT 1000' IN THREE DIRECTIONS WITH WIND SPEED AT 1m AND 80m

Figure 4

How do we model such a moving target to get the correct answer? In our repeated experience, using the relatively simple algorithms of ISO 9613, part 2 that does not account for any atmospheric instability gives surprisingly representative results. The wind turbine is modelled as an omni-directional point source at hub height using the measured downwind sound power determined by IEC 61400-11. Ground surface effects are the major variable for typical wind projects without complex topography. **Figure 5** re-plots the above data with ISO 9613 model results for the range of ground absorption between 0 and 1. The ground in this example was a planted soybean field with plants about 400 mm high that would suggest a ground effect input of between 0.5 and 1.0.

Figure 5 shows that an input of 0 is clearly too conservative but an input of 0.5 gives a very representative and slightly conservative prediction of long term wind turbine noise and even an input of 1.0 is correct for substantial time periods.



RAW DATA COMPARED TO ISO 9613 PREDICTION ALGORITHMS

Figure 5

Now that we have a useful model we can calculate the pressure spectra for representative modern day large wind projects using the sound power developed in the first section. The ISO 9613 calculation and plot of the indoor and outdoor spectra results are given below in **Figure 6**.

The distance chosen and additive correction were chosen to result in a wind project sound level of 45 dBA outside of the closest residences. We recommend a design goal of 40 dBA and a regulatory limit of 45 dBA to clients and receptors to minimize audible impact based on our detailed journal article[2]. Therefore, the spectrum is representative of the higher level for a well designed project based on our experience.

CALCULATE Lp AT:	750M	PER ISO 9613, PART 2												
		16	31	63	125	250	500	1k	2k	4k	8k	dB(A)	dB(C)	C-A
MAXIMUM UNIT SIZE SOUND POWER		118	117	117	113	111	107	103	100	95	88	109.2	120.6	11.5
PATH ATTENUATION:														
HEMISPHERICAL SPREADING, R,feet=	2460	-65	-65	-65	-65	-65	-65	-65	-65	-65	-65			
DIRECTIVITY, 0-110 DEG.(HAI), ANGLE=	NONE	0	0	0	0	0	0	0	0	0	0			
AIR ABSORPTION,59F(15C) 50%RH, R=	1	0	0	0	0	-1	-2	-3	-8	-27	-96			
NUMBER OF IDENTICAL SOURCES=	4	6	6	6	6	6	6	6	6	6	6			
ISO GROUND EFFECTS-D,Hs,Hr,ABS=	0.5	0	0	0	-3	-2	-2	-2	-2	-2	-2			
MISCELLANEOUS		0	0	0	0	0	0	0	0	0	0			
MISCELLANEOUS		0	0	0	0	0	0	0	0	0	0			
SUM OF PATH ATTENUATION:		-60	-60	-60	-63	-62	-63	-64	-69	-88	-157			
CALCULATED OUTSIDE Lp PER ISO 9613.2 @	**750M**	**58**	**58**	**57**	**50**	**48**	**44**	**39**	**31**	**7**	**-69**	**45.5**	**60.2**	**14.7**
EST.CONSERVATIVE O TO I NR (CLOSED WINDOWS)		4	9	16	19	22	24	26	27	29	31			
CALCULATED INDOOR Lp PER ISO 9613.2 @	**750M**	**54**	**48**	**42**	**31**	**26**	**20**	**13**	**4**	**-22**	**-100**	**23.2**	**49.5**	**26.3**

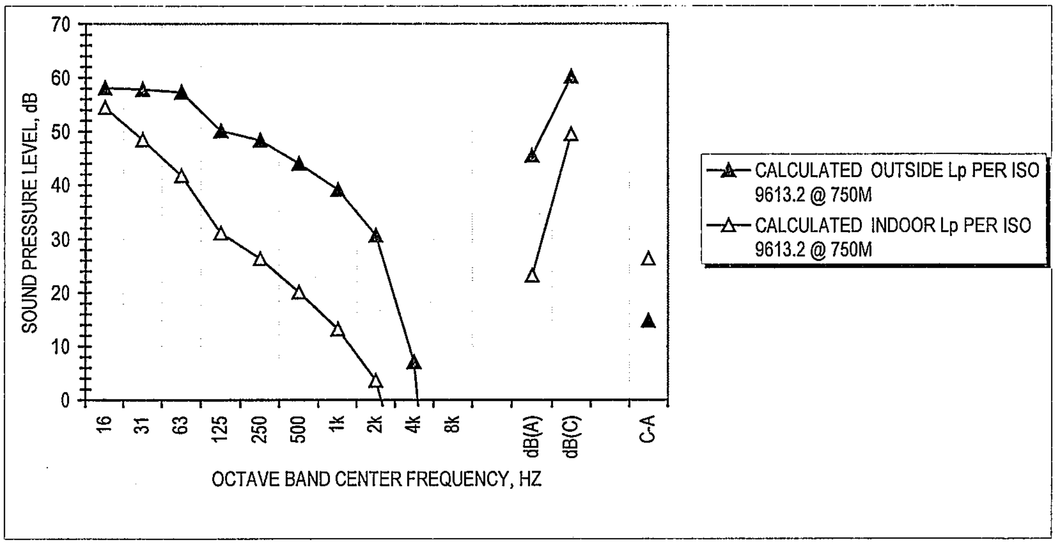


Figure 6

Note the interior spectrum is based on a Noise Reduction (NR) developed as follows.

Figure 7 below plots the NR measured in an early study[3] for aircraft and traffic sources. The black filled and open circles plot the measured NR in the audible frequency range from the 63 to 8000 Hz octave bands. While this study is over 40 years old, its value is the data base of 116 measurement sites. It can be reasoned that energy saving building design today provide higher noise reduction and hence the NR values are almost certainly conservative.

The red dashed line plots the mass law transmission loss (TL) for a relatively lightweight non-masonry building wall and windows. While meaningful above 63 Hz, there is of course no theoretical reason that mass law TL should apply to NR for frequency bands below 63 Hz.

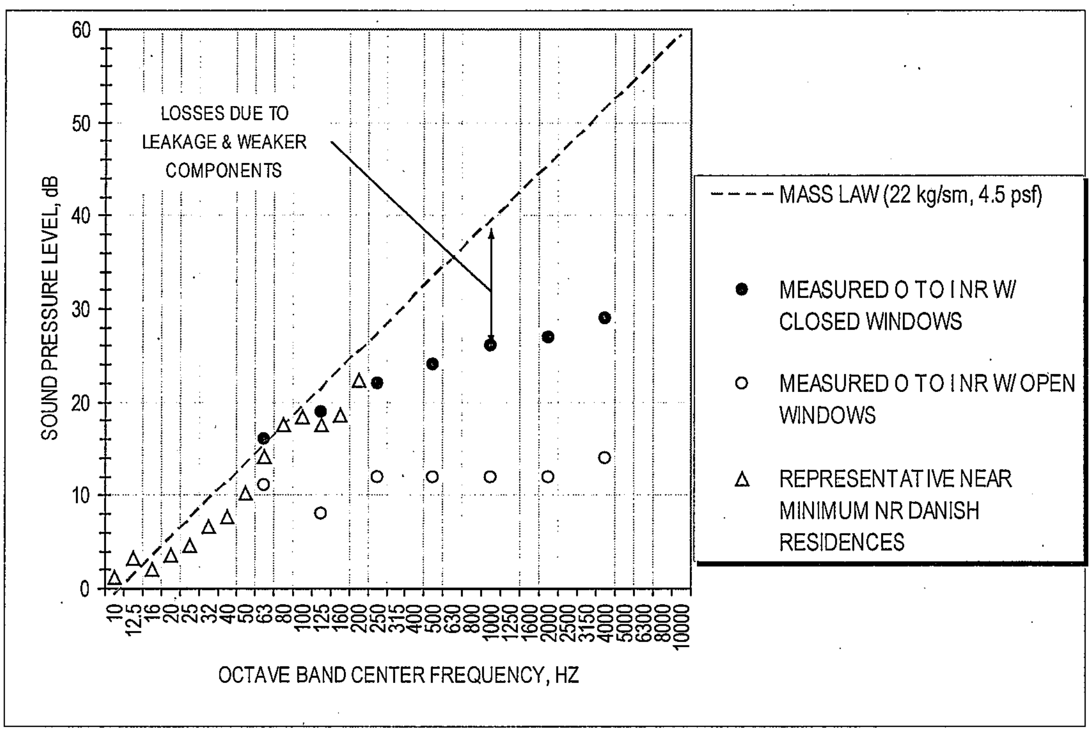


Figure 7

The grey colour triangle markings plot the best *conservative* estimate for low frequency NR of Danish dwellings based on recent a study [4] in 2010. For convenience and conservatism, the NR used in Figure 6 is the calculated mass law TL in the 16 and 31 octave bands and the cited measurements of NR for 63 Hz and above.

Evaluation of Developed Pressure Spectra with Annoyance Thresholds

We have now a representative spectrum for both outdoor and indoor spaces at residences near modern wind projects. The first thing we can look at is the threshold of perception for LFN. This is shown graphically on **Figure 8** below. The range of perception thresholds at low frequencies is discussed and summarized nicely in reference [5] and is shown as the range for current research. We can immediately conclude from this data that infrasound (below 20 Hz) is a non-problem since the wind project noise is 20 to 40 dB below the perception threshold.

We can also see that LFN becomes perceptible at approximately 30 and 60 Hz outdoors and indoors, respectively. When perceptible, are the spectra magnitudes annoying? Research in Japan on LFN annoyance thresholds can provide valuable tools.

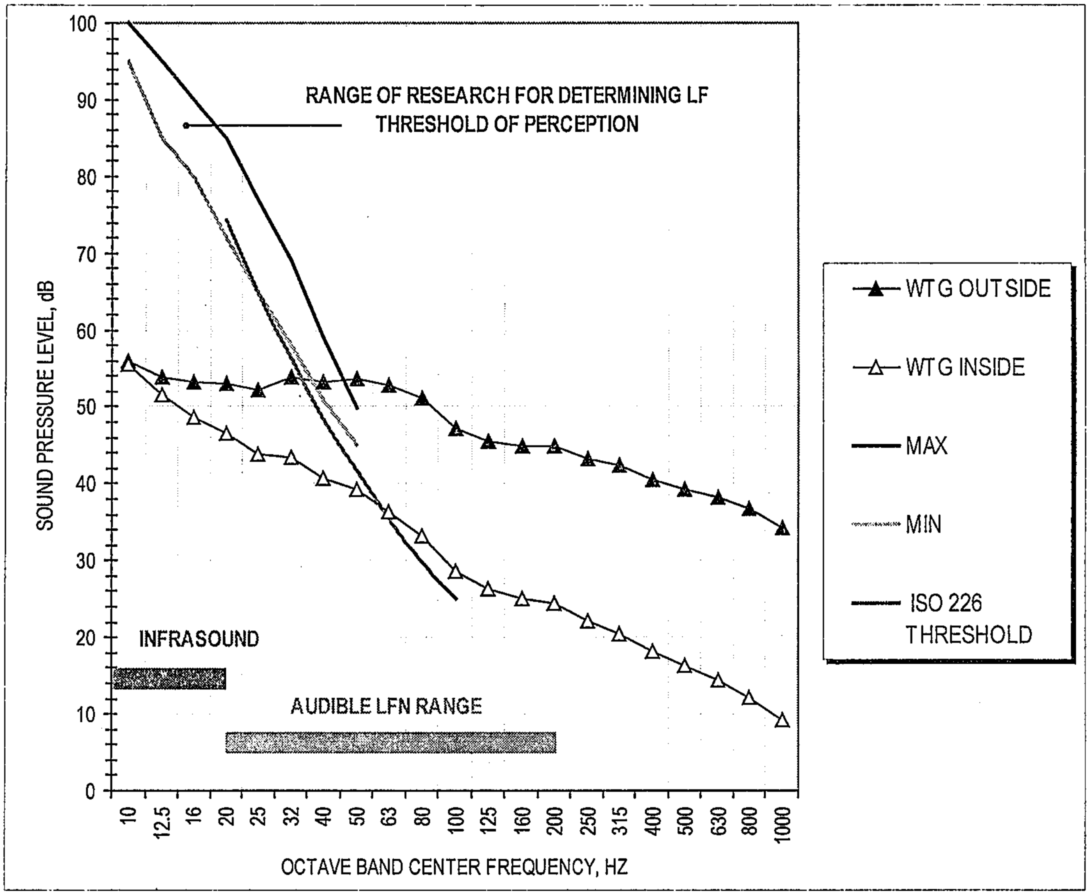


Figure 8

Nakamura and Tokita research[6] using independent test audiences provide the thresholds in **Figure 9** that are plotted with the developed wind project spectra. This work says the outdoor noise spectrum becomes perceptible at 40 Hz, but never exceeds the threshold for potential annoyance. Similarly, Inukai[7] has developed an Unpleasantness Index, again based on test audiences as presented in **Figure 10**. Based on this work, the wind project spectra at the closest residences would be perceived as "Somewhat Unpleasant" and "Not Unpleasant at All" outdoors and indoors. This is based on the normal limit of LFN at 200 Hz.

Some authors and agencies define 'annoyance' as having an adverse effect on health. Even by this definition, one may conclude there are no adverse health effects due to LFN since there is no predictable annoyance.

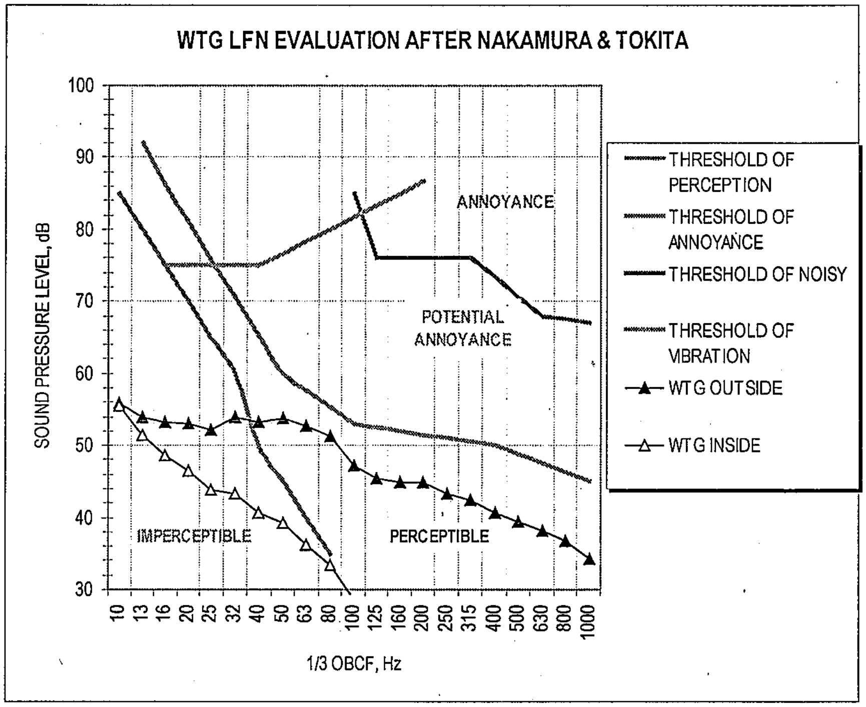


Figure 9

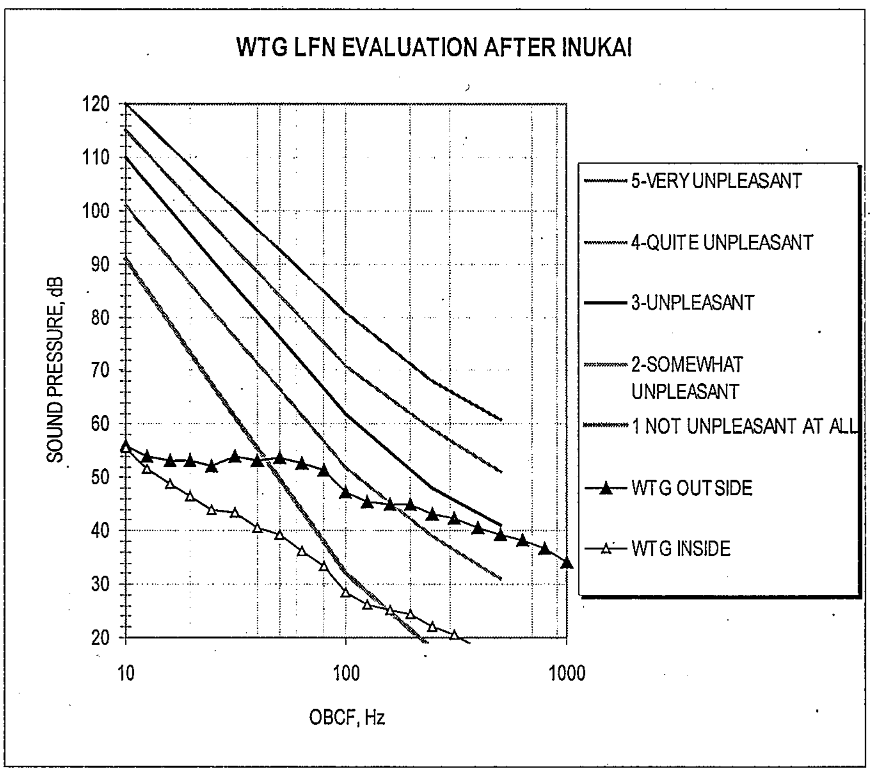


Figure 10

Wind Turbine Project LFN compared to another LFN Source

One way to create infrasound is to simply lower a rear window in an automobile at highway speeds. We often compare LFN encountered in practice against annoyance indexes developed in test audiences. **Figure 11** below plots the measured spectra with a rear window open and closed. Note that painful infrasound in the 16 and 31 Hz 1/3 octave bands is created. Of interest here is that the closed window spectra would be judged at levels 3 to 4 or "Unpleasant to Quite Unpleasant" for this case, a modern automobile at highway speed.

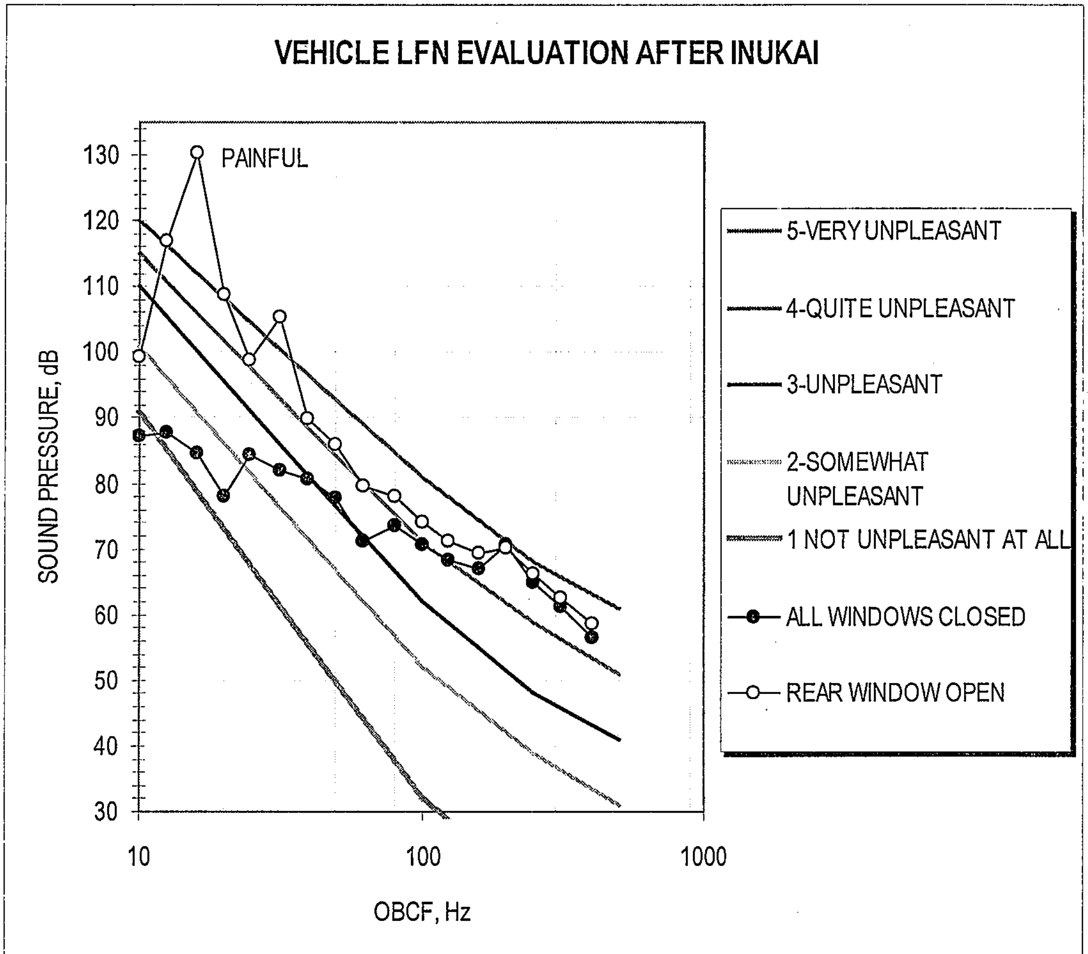


Figure 11

Therefore driving in a modern automobile at highway speed is exposure to LFN. One can safely say there are billions of hours of such exposure to man women and children of all ages throughout the world. To my knowledge, such exposure has never been suspected of causing adverse health effects. It is telling to compare the automobile spectrum with those developed above for wind turbine projects as is done in **Figure 12** below.

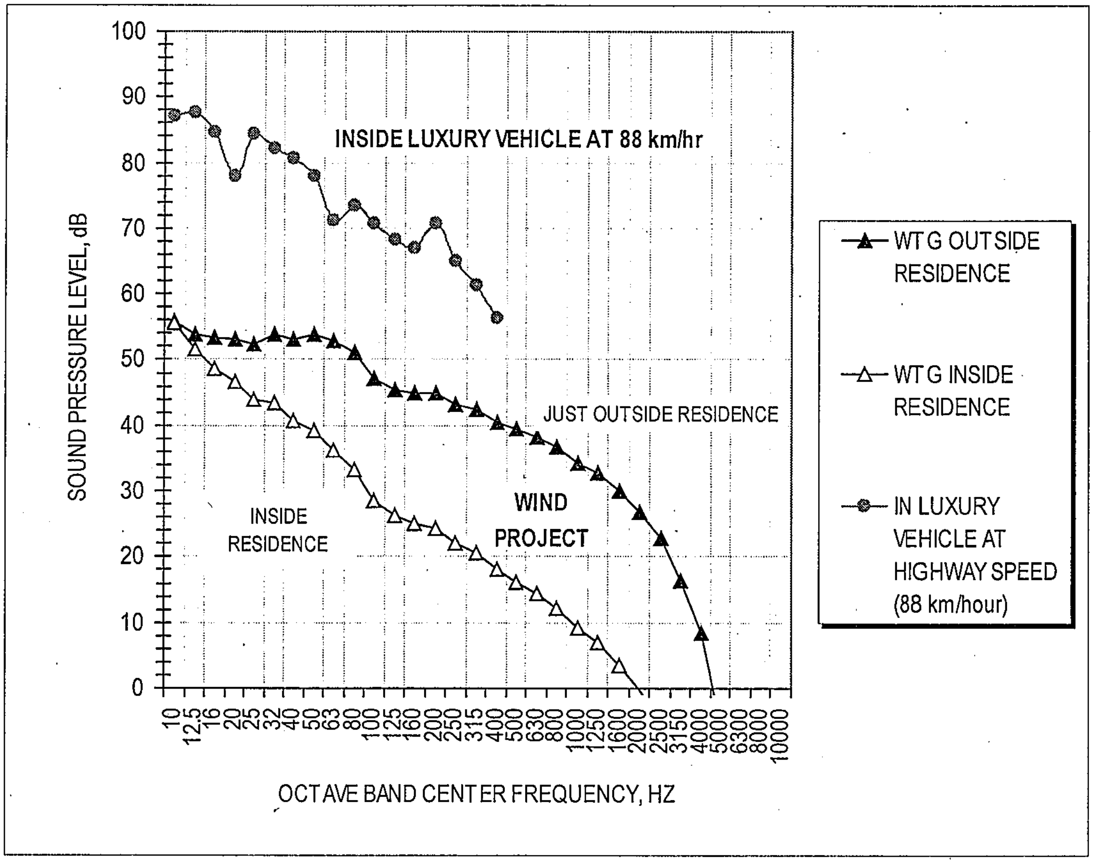


Figure 12

Wind turbine spectra are 20 to 30 dB lower than the level experienced in an automobile at highway speed. It is inconceivable to me that one can reason or even suspect that LFN is an issue at wind projects. Adding to this, we have never received or even heard of noise complaints at any wind farm where complainants reported typical low frequency symptoms.

Conclusions

The indisputable sound power from large wind turbines was developed using independent measurements from 45 wind turbines. Conservative pressure spectra were calculated both outdoors and indoors for the largest possible currently available wind turbine at typical wind project buffer distances. Spectra were compared to scientifically developed LFN annoyance criteria using group response to controlled LFN. In addition, wind turbine spectra were compared to a common source of LFN that has been exposed to men, women and children of all ages for billions of hours with no reported ill effects from noise at any frequency. Common sense brings me to the conclusion that LFN at wind projects is a non-issue and should not be endlessly debated for every proposed wind project.

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Wind Turbine Sound and Health Effects
An Expert Panel Review

Prepared by (in alphabetical order):

W. David Colby, M.D.

Robert Dobie, M.D.

Geoff Leventhall, Ph.D.

David M. Lipscomb, Ph.D.

Robert J. McCunney, M.D.

Michael T. Seilo, Ph.D.

Bo Søndergaard, M.Sc.

Prepared for:

American Wind Energy Association

and

Canadian Wind Energy Association

December 2009

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Acronyms and Abbreviations

µPa	microPascal
ACOEM	American College of Occupational and Environmental Medicine
ANSI	American National Standards Institute
AWEA	American Wind Energy Association
ASHA	American Speech-Language-Hearing Association
CanWEA	Canadian Wind Energy Association
dB	decibel
dBA	decibel (on an A-weighted scale)
DNL	day-night-level
DSM-IV-TR	*Diagnostic and Statistical Manual of Mental Disorders,* Fourth Edition
EPA	U.S. Environmental Protection Agency
FDA	Food and Drug Administration
FFT	Fast Fourier Transform
GI	gastrointestinal
HPA	Health Protection Agency
Hz	Hertz
IARC	International Agency for Research on Cancer
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th Revision
IEC	International Engineering Consortium
ISO	International Organization for Standardization
Km	kilometer
kW	kilowatt
L_{eq}	equivalent level
LPALF	large pressure amplitude and low frequency
m/s	meters per second
m/s^2	meters per second squared
NIESH	National Institute of Environmental Health Sciences
NIHL	noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
N/m^2	Newtons per square meter
NRC	National Research Council
NTP	National Toxicology Program
ONAC	Office of Noise Abatement and Control
OSHA	Occupational Safety and Health Administration
Pa	Pascal
UK	United Kingdom
VAD	vibroacoustic disease
VVVD	vibratory vestibular disturbance
VEMP	vestibular evoked myogenic potential response
WHO	World Health Organization

Executive Summary

People have been harnessing the power of the wind for more than 5,000 years. Initially used widely for farm irrigation and millworks, today's modern wind turbines produce electricity in more than 70 countries. As of the end of 2008, there were approximately 120,800 megawatts of wind energy capacity installed around the world (Global Wind Energy Council, 2009).

Wind energy enjoys considerable public support, but it also has its detractors, who have publicized their concerns that the sounds emitted from wind turbines cause adverse health consequences.

In response to those concerns, the American and Canadian Wind Energy Associations (AWEA and CanWEA) established a scientific advisory panel in early 2009 to conduct a review of current literature available on the issue of perceived health effects of wind turbines. This multidisciplinary panel is comprised of medical doctors, audiologists, and acoustical professionals from the United States, Canada, Denmark, and the United Kingdom. The objective of the panel was to provide an authoritative reference document for legislators, regulators, and anyone who wants to make sense of the conflicting information about wind turbine sound.

The panel undertook extensive review, analysis, and discussion of the large body of peer-reviewed literature on sound and health effects in general, and on sound produced by wind turbines. Each panel member contributed a unique expertise in audiology, acoustics, otolaryngology, occupational/ environmental medicine, or public health. With a diversity of perspectives represented, the panel assessed the plausible biological effects of exposure to wind turbine sound.

Following review, analysis, and discussion of current knowledge, the panel reached consensus on the following conclusions:

- There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.
- The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.
- The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel's experience with sound exposures in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences.

SECTION 1

Introduction

The mission of the American Wind Energy Association (AWEA) is to promote the growth of wind power through advocacy, communication, and education. Similarly, the mission of the Canadian Wind Energy Association (CanWEA) is to promote the responsible and sustainable growth of wind power in Canada. Both organizations wish to take a proactive role in ensuring that wind energy projects are good neighbors to the communities that have embraced wind energy.

Together AWEA and CanWEA proposed to a number of independent groups that they examine the scientific validity of recent reports on the adverse health effects of wind turbine proximity. Such reports have raised public concern about wind turbine exposure. In the absence of declared commitment to such an effort from independent groups, the wind industry decided to be proactive and address the issue itself. In 2009, AWEA and CanWEA commissioned this report. They asked the authors to examine published scientific literature on possible adverse health effects resulting from exposure to wind turbines.

The objective of this report is to address health concerns associated with sounds from industrial-scale wind turbines. Inevitably, a report funded by an industry association will be subject to charges of bias and conflicts of interest. AWEA and CanWEA have minimized bias and conflicts of interest to the greatest possible extent through selection of a distinguished panel of independent experts in acoustics, audiology, medicine, and public health. This report is the result of their efforts.

1.1 Expert Panelists

The experts listed below were asked to investigate and analyze existing literature and publish their findings in this report; their current positions and/or qualifications for inclusion are also provided.

- W. David Colby, M.D.: Chatham-Kent Medical Officer of Health (Acting); Associate Professor, Schulich School of Medicine & Dentistry, University of Western Ontario
- Robert Dobie, M.D.: Clinical Professor, University of Texas, San Antonio; Clinical Professor, University of California, Davis
- Geoff Leventhall, Ph.D.: Consultant in Noise Vibration and Acoustics, UK
- David M. Lipscomb, Ph.D.: President, Correct Service, Inc.
- Robert J. McCunney, M.D.: Research Scientist, Massachusetts Institute of Technology Department of Biological Engineering; Staff Physician, Massachusetts General Hospital Pulmonary Division; Harvard Medical School
- Michael T. Seilo, Ph.D.: Professor of Audiology, Western Washington University

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- Bo Søndergaard, M.Sc. (Physics): Senior Consultant, Danish Electronics Light and Acoustics (DELTA)

Mark Bastasch, an acoustical engineer with the consulting firm of CH2M HILL, acted as technical advisor to the panel.

1.2 Report Terminology

Certain terms are used frequently throughout this report. Table 1-1 defines these terms. An understanding of the distinction between "sound" and "noise" may be particularly useful to the reader.

TABLE 1-1
Definitions of Acoustical Terms

Term	Definitions
Sound	Describes wave-like variations in air pressure that occur at frequencies that can stimulate receptors in the inner ear and, if sufficiently powerful, be appreciated at a conscious level.
Noise	Implies the presence of sound but also implies a response to sound: noise is often defined as unwanted sound.
Ambient noise level	The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.
Decibel (dB)	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the measured pressure to the reference pressure, which is 20 micropascals (µPa).
A-weighted sound pressure level (dBA)	The sound pressure level in decibels as measured on a sound level meter using the A-weighted filter network. The A-weighted filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.
Hertz (Hz)	A unit of measurement of frequency; the number of cycles per second of a periodic waveform.
Infrasound	According to the International Electrotechnical Commission's (IEC's) IEC 1994, infrasound is: Acoustic oscillations whose frequency is below the low-frequency limit of audible sound (about 16 Hz). However this definition is incomplete as infrasound at high enough levels is audible at frequencies below 16 Hz. (IEC (1994): 60050-801:1994 International Electrotechnical Vocabulary - Chapter 801: Acoustics and electroacoustics).
Low-frequency sound	Sound in the frequency range that overlaps the higher infrasound frequencies and the lower audible frequencies, and is typically considered as 10 Hz to 200 Hz, but is not closely defined.

Source: HPA, 2009.

SECTION 2

Methodology

Three steps form the basis for this report: formation of an expert panel, review of literature directly related to wind turbines, and review of potential environmental exposures.

2.1 Formation of Expert Panel

The American and Canadian wind energy associations, AWEA and CanWEA, assembled a distinguished panel of independent experts to address concerns that the sounds emitted from wind turbines cause adverse health consequences.

The objective of the panel was to provide an authoritative reference document for the use of legislators, regulators, and people simply wanting to make sense of the conflicting information about wind turbine sound.

The panel represented expertise in audiology, acoustics, otolaryngology, occupational/ environmental medicine, and public health. A series of conference calls were held among panel members to discuss literature and key health concerns that have been raised about wind turbines. The calls were followed by the development of a draft that was reviewed by other panel members. Throughout the follow-up period, literature was critically addressed.

2.2 Review of Literature Directly Related to Wind Turbines

The panel conducted a search of Pub Med under the heading "Wind Turbines and Health Effects" to research and address peer-reviewed literature. In addition, the panel conducted a search on "vibroacoustic disease." The reference section identifies the peer and non-peer reviewed sources that were consulted by the panel.

2.3 Review of Potential Environmental Exposures

The panel conducted a review of potential environmental exposures associated with wind turbine operations, with a focus on low frequency sound, infrasound, and vibration.

SECTION 3

Overview and Discussion

This section summarizes the results of the review and analysis conducted by the expert panel and responds to a number of key questions:

- How do wind turbine operations affect human auditory response?
- How do we determine the loudness and frequency of sound and its effects on the human ear?
- How do wind turbines produce sound?
- How is sound measured and tested?
- What is vibration?
- What type of exposure to wind turbines is more likely to be perceived by humans (low frequency sound, infrasound or vibration)?
- Can sounds in the low frequency range, most notably the infrasonic range, adversely affect human health? Even when such levels are below the average person's ability to hear them?
- How does the human vestibular system respond to sound?
- What are the potential adverse effects and health implications of sound exposure?
- What does scientific literature say about wind turbines, low frequency sound, and infrasound?

3.1 Wind Turbine Operation and Human Auditory Response to Sound

3.1.1 Overview

The normal operation of a wind turbine produces sound and vibration, arousing concern about potential health implications. This section addresses the fundamental principles associated with sound and vibration, sound measurement, and potential adverse health implications. Sound from a wind turbine arises from its mechanical operation and the turning of the blades.

3.1.2 The Human Ear and Sound

The human ear is capable of perceiving a wide range of sounds, from the high-pitched sounds of a bird song to the low-pitched sound of a bass guitar. Sounds are perceived based on their loudness (i.e., volume or sound pressure level) or pitch (i.e., tonal or frequency content). The standard unit of measure for sound pressure levels is the decibel (dB). The standard unit used to describe the tonal or frequency content is the Hertz (Hz), measured in cycles per second) – Appendix A provides more information on the fundamentals of sound. Customarily, the young, non-pathological ear can perceive sounds ranging from 20 Hz to 20,000 Hz. Appendix B provides more information on the human ear.

Frequencies below 20 Hz are commonly called "infrasound," although the boundary between infrasound and low frequency sound is not rigid. Infrasound, at certain frequencies and at high levels, can be audible to some people. Low frequency sound is customarily referred to as that between 10 Hz and 200 Hz, but any definition is arbitrary to some degree. Low frequency sound is the subject of concern to some with respect to potential health implications.

TABLE 3-1
TYPICAL SOUND PRESSURE LEVELS MEASURED IN THE ENVIRONMENT AND INDUSTRY

Noise Source At a Given Distance	A-Weighted Sound Level in Decibels	Qualitative Description
Carrier deck jet operation	140	
	130	Pain threshold
Jet takeoff (200 feet)	120	
Auto horn (3 feet)	110	Maximum vocal effort
Jet takeoff (1000 feet) Shout (0.5 feet)	100	
N.Y. subway station Heavy truck (50 feet)	90	Very annoying Hearing damage (8-hour, continuous exposure)
Pneumatic drill (50 feet)	80	Annoying
Freight train (50 feet) Freeway traffic (50 feet).	70 to 80	
	70	Intrusive (Telephone use difficult)
Air conditioning unit (20 feet)	60	
Light auto traffic (50 feet)	50	Quiet
Living room Bedroom	40	
Library Soft whisper (5 feet)	30	Very quiet
Broadcasting/Recording studio	20	
	10	Just audible

Adapted from Table E, "Assessing and Mitigating Noise Impacts", NY DEC, February 2001.

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Table 3-1 shows sound pressure levels associated with common activities. Typically, environmental and occupational sound pressure levels are measured in decibels on an A-weighted scale (dBA). The A-weighted scale de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear. For comparison, the sound from a wind turbine at distances between 1,000 and 2,000 feet is generally within 40 to 50 dBA.

Section 3.2 discusses the effects of exposure to wind turbine sound. Section 3.3 describes the potential adverse effects of sound exposure as well as the health implications.

3.1.3 Sound Produced by Wind Turbines

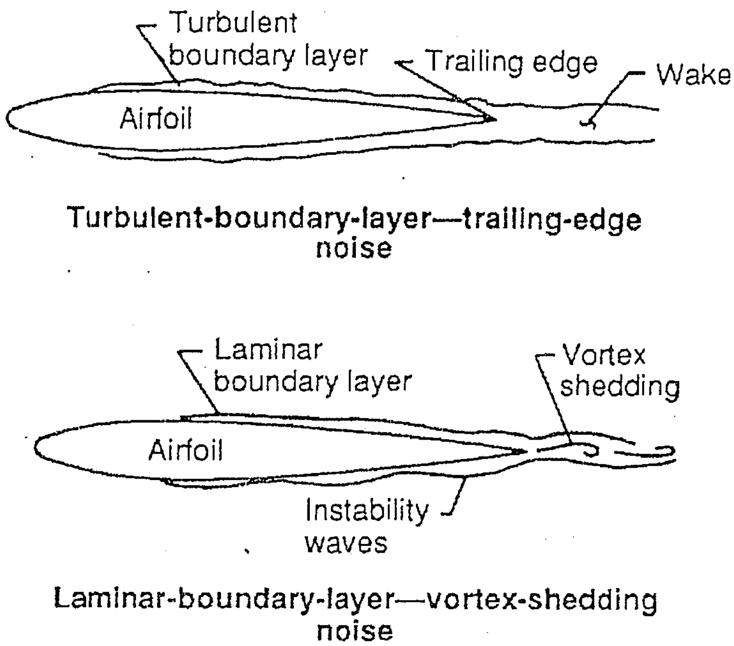
Wind turbine sound originates from either a mechanical or aerodynamic generation mechanism. Mechanical sound originates from the gearbox and control mechanisms. Standard noise control techniques typically are used to reduce mechanical sound. Mechanical noise is not typically the dominant source of noise from modern wind turbines (except for an occasional gear tone).

The aerodynamic noise is present at all frequencies, from the infrasound range over low frequency sound to the normal audible range and is the dominant source. The aerodynamic noise is generated by several mechanisms as is described below. The aerodynamic noise tends to be modulated in the mid frequency range, approximately 500 to 1,000 Hz.

Aerodynamic sound is produced by the rotation of the turbine blades through the air. A turbine blade shape is that of an airfoil. An airfoil is simply a structure with a shape that produces a lift force when air passes over it. Originally developed for aircraft, airfoil shapes have been adapted to provide the turning force for wind turbines by employing a shape which causes the air to travel more rapidly over the top of the airfoil than below it. The designs optimize efficiency by minimizing turbulence, which produces drag and noise. An aerodynamically efficient blade is a quiet one.

The aerodynamic sound from wind turbines is caused by the interaction of the turbine blade with the turbulence produced both adjacent to it (turbulent boundary layer) and in its near wake (see Figure 3-1) (Brooks et al., 1989). Turbulence depends on how fast the blade is moving through the air. A 100-meter-diameter blade, rotating once every three seconds, has a tip velocity of just over 100 meters per second. However, the speed reduces at positions closer to the centre of rotation (the wind turbine hub). The main determinants of the turbulence are the speed of the blade and the shape and dimensions of its cross-section.

FIGURE 3-1
Sound Produced by Wind Turbine Flow



The following conclusions have been derived from the flow conditions shown in Figure 3-1 (Brooks et al., 1989):

- At high velocities for a given blade, turbulent boundary layers develop over much of the airfoil. Sound is produced when the turbulent boundary layer passes over the trailing edge.
- At lower velocities, mainly laminar boundary layers develop, leading to vortex shedding at the trailing edge.

Other factors in the production of aerodynamic sound include the following:

- When the angle of attack is not zero – in other words, the blade is tilted into the wind – flow separation can occur on the suction side near to the trailing edge, producing sound.
- At high angles of attack, large-scale separation may occur in a stall condition, leading to radiation of low frequency sound.
- A blunt trailing edge leads to vortex shedding and additional sound.
- The tip vortex contains highly turbulent flow.

Each of the above factors may contribute to wind turbine sound production. Measurements of the location of the sound source in wind turbines indicate that the dominant sound is produced along the blade – nearer to the tip end than to the hub. Reduction of turbulence sound can be facilitated through airfoil shape and by good maintenance. For example, surface irregularities resulting from damage or to accretion of additional material, may increase the sound.

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Aerodynamic sound has been shown to be generated at higher levels during the downward motion of the blade (i.e., the three o'clock position). This results in a rise in level of approximately once per second for a typical three-bladed turbine. This periodic rise in level is also referred to as amplitude modulation, and as described above for a typical wind turbine, the modulation frequency is 1 Hz (once per second). In other words, the sound level rises and falls about once per second. The origin of this amplitude modulation is not fully understood. It was previously assumed that the modulation was caused when the blade went past the tower (given the tower disturbed the airflow), but it is now thought to be related to the difference in wind speed between the top and bottom of the rotation of a blade and directivity of the aerodynamic noise (Oerlemans and Schepers, 2009).

In other words, the result of aerodynamic modulation is a perceivable fluctuation in the sound level of approximately once per second. The frequency content of this fluctuating sound is typically between 500 Hz and 1,000 Hz, but can occur at higher and lower frequencies. That is, the sound pressure levels between approximately 500 and 1,000 Hz will rise and fall approximately once per second. It should be noted, however, that the magnitude of the amplitude modulation that is observed when standing beneath a tower does not always occur at greater separation distances. A study in the United Kingdom (UK) also showed that only four out of about 130 wind farms had a problem with aerodynamic modulation and three of these have been solved (Moorhouse et al., 2007).

In addition to the sound levels generated by the turbines, environmental factors affect the levels received at more distant locations. For example, warm air near the ground causes the turbine sound to curve upwards, away from the ground, which results in reduced sound levels, while warm air in a temperature inversion may cause the sound to curve down to the earth resulting in increased sound levels. Wind may also cause the sound level to be greater downwind of the turbine—that is, if the wind is blowing from the source towards a receiver—or lower, if the wind is blowing from the receiver to the source. Most modeling techniques, when properly implemented, account for moderate inversions and downwind conditions. Attenuation (reduction) of sound can also be influenced by barriers, ground surface conditions, shrubbery and trees, among other things.

Predictions of the sound level at varying distances from the turbine are based on turbine sound power levels. These turbine sound power levels are determined through standardized measurement methods.

3.1.4 Sound Measurement and Audiometric Testing

A sound level meter is a standard tool used in the measurement of sound pressure levels. As described in Section 3.1.2, the standard unit of sound pressure level (i.e., volume) is dB and the standard unit used to describe the pitch or frequency is Hz (cycles per second). A sound level meter may use the A-weighting filter to adjust certain frequency ranges (those that humans detect poorly), resulting in a reading in dBA (decibels, A-weighted). Appendix C provides more information on the measurement of sound. The pitch or frequencies (sometimes referred to as sound level spectrum) can be quantified using a sound level meter that includes a frequency analyzer. Octave band, one-third octave band, and narrow band (such as Fast Fourier Transform, or FFT) are three common types of frequency analyzers.

Consider, for example, a routine audiometric test (hearing test) in which a person sits in a booth and wears headphones, through which sounds are transmitted to evaluate hearing. Outside the booth, a technician turns a dial which yields certain frequencies (for example, 125 Hz, a low-pitched sound, or 4,000 Hz, a high-pitched sound) and then the technician raises the volume of each frequency until the person recognizes the sound of each tone. This is a standard approach used to measure thresholds for many reasons, including noise-induced hearing loss (NIHL). As the technician raises the volume of the designated frequency, the sound level (in dB) is noted. People who need more than 25 dB at more than one frequency to hear the sound (ie loudness of the tone) are considered to have an abnormal test.

The effects of prolonged, high-level sound exposure on hearing have been determined through audiometric tests of workers in certain occupations. The studies have been published in major medical journals and subjected to the peer review process (see, for example, McCunney and Meyer, 2007). Studies of workers have also served as the scientific basis for regulations on noise in industry that are overseen by the Occupational Safety and Health Administration (OSHA). Workers in noise-intensive industries have been evaluated for NIHL and certain industries are known to be associated with high noise levels, such as aviation, construction, and areas of manufacturing such as canning. Multiyear worker studies suggest that prolonged exposure to high noise levels can adversely affect hearing. The levels considered sufficiently high to cause hearing loss are considerably higher than one could experience in the vicinity of wind turbines. For example, prolonged, unprotected high exposure to noise at levels greater than 90 dBA is a risk for hearing loss in occupational settings such that OSHA established this level for hearing protection. Sound levels from wind turbines do not approach these levels (50 dBA at a distance of 1,500 feet would be a conservative estimate for today's turbines). Although the issue of NIHL has rarely been raised in opposition to wind farms, it is important to note that the risk of NIHL is directly dependent on the intensity (sound level) and duration of noise exposure and therefore it is reasonable to conclude that there is no risk of NIHL from wind turbine sound. Such a conclusion is based on studies of workers exposed to noise and among whom risk of NIHL is not apparent at levels less than 75 dBA.

3.2 Sound Exposure from Wind Turbine Operation

This section addresses the questions of (1) whether sounds in the low frequency range, most notably the infrasonic range, adversely affect human health, and whether they do so even when such levels are below the average person's ability to hear them; (2) what we are referring to when we talk about vibration; and (3) how the human vestibular system responds to sound and disturbance.

3.2.1 Infrasound and Low-Frequency Sound

Infrasound and low frequency sound are addressed in some detail to offer perspective on publicized hypotheses that sound from a wind turbine may damage health even if the noise levels are below those associated with noise-induced hearing loss in industry. For example, it has been proposed that sounds that contain low frequency noise, most notably within the infrasonic level, can adversely affect health even when the levels are below the average person's ability to detect or hear them (Alves-Pereira and Branco, 2007b).

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Comprehensive reviews of infrasound and its sources and measurement have been published (Berglund and Lindvall, 1995; Leventhall et al., 2003). Table 3-2 shows the sound pressure level, in decibels, of the corresponding frequency of infrasound and low frequency sound necessary for the sound to be heard by the average person (Leventhall et al., 2003).

TABLE 3-2
Hearing Thresholds in the Infrasonic and Low Frequency Range

Frequency (Hz)	4	8	10	16	20	25	40	50	80	100	125	160	200
Sound pressure level (dB)	107	100	97	88	79	69	51	44	32	27	22	18	14

NOTE:
Average hearing thresholds (for young healthy people) in the infrasound (4 to 20 Hz) and low frequency region (10 to 200 Hz).
Source: Leventhall et al., 2003

As Table 3-2 indicates, at low frequencies, a much higher level sound is necessary for a sound to be heard in comparison to higher frequencies. For example, at 10 Hz, the sound must be at 97 dB to be audible. If this level occurred at the mid to high frequencies, which the ear detects effectively, it would be roughly equivalent to standing without hearing protection directly next to a power saw. Decibel for decibel, the low frequencies are much more difficult to detect than the high frequencies, as shown in the hearing threshold levels of Table 3-2.

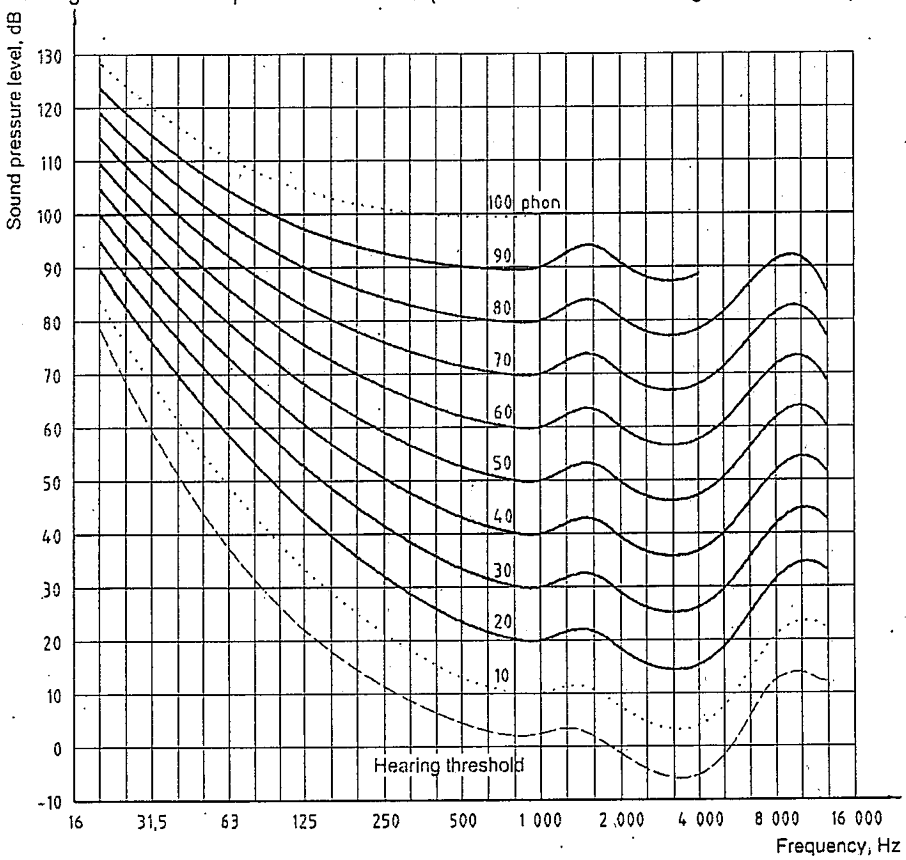
Table 3-2 also shows that even sounds as low as 4 Hz can be heard if the levels are high enough (107 dB). However, levels from wind turbines at 4 Hz are more likely to be around 70 dB or lower, and therefore inaudible. Studies conducted to assess wind turbine noise have shown that wind turbine sound at typical distances does not exceed the hearing threshold and will not be audible below about 50 Hz (Hayes 2006b; Kamperman and James, 2008). The hearing threshold level at 50 Hz is 44 dB, as shown in Table 3-2. Recent work on evaluating a large number of noise sources between 10 Hz and 160 Hz suggests that wind turbine noise heard indoors at typical separation distances is modest on the scale of low frequency sound sources (Pedersen, 2008). The low levels of infrasound and low frequency sound from wind turbine operations have been confirmed by others (Jakobsen, 2004; van den Berg, 2004).

The low frequency sound associated with wind turbines has attracted attention recently since the A-weighting scale that is used for occupational and environmental regulatory compliance does not work well with sounds that have prominently low frequency components. Most environmental low frequency sound problems are caused by discrete tones (pitch or tones that are significantly higher in level (volume) than the neighboring frequencies); from, for example, an engine or compressor, not by continuous broadband sound. The high frequency sounds are assessed by the A-weighted measurement and, given their shorter wavelengths, are controlled more readily. Low frequency sounds may be irritating to some people and, in fact, some low frequency sound complaints prove impossible to resolve (Leventhall et al., 2003). This observation leads to a perception that there is something special, sinister, and harmful about low frequency sound. To the contrary, most external sound when heard indoors is biased towards low frequencies due to the efficient building attenuation of higher frequencies. One may recognize this when noise from a neighbor's stereo is heard within their home – the bass notes are more pronounced than the higher frequency sounds. Any unwanted sound, whether high frequency or low frequency, can be irritating and stressful to some people.

Differences in how a low frequency sound and high frequency sound are perceived are well documented. Figure 3-2 shows that lower-frequency sounds typically need to be at a high sound pressure level (dB) to be heard. Figure 3-2 also demonstrates that as the frequency lowers, the audible range is compressed leading to a more rapid rise in loudness as the level changes in the lower frequencies. At 1,000 Hz, the whole range covers about 100 dB change in sound pressure level, while at 20 Hz the same range of loudness covers about 50 dB (note the contours displayed in Figure 3-2 are in terms of phons, a measure of equal loudness; for additional explanation on phons, the reader is referred to http://www.sfu.ca/sonic-studio/handbook/Phon.html [Truax, 1999]). As the annoyance of a given sound increases as loudness increases, there is also a more rapid growth of annoyance at low frequencies. However, there is no evidence for direct physiological effects from either infrasound or low frequency sound at the levels generated from wind turbines, indoors or outside. Effects may result from the sounds being audible, but these are similar to the effects from other audible sounds.

Low frequency sound and infrasound are further addressed in Section 3.3, Potential Adverse Effects of Exposure to Sound.

FIGURE 3-2
Hearing Contours for Equal Loudness Level (International Standards Organization, 2003)



3.2.2 Vibration

Vibration, assumed to result from inaudible low frequency sounds, has been postulated to have a potential adverse effect on health. This section defines vibration, describes how it is measured, and cites studies that have addressed the risk of vibration on health.

Vibration refers to the way in which energy travels through solid material, whether steel, concrete in a bridge, the earth, the wall of a house or the human body. Vibration is distinguished from sound, which is energy flowing through gases (like air) or liquids (like water).

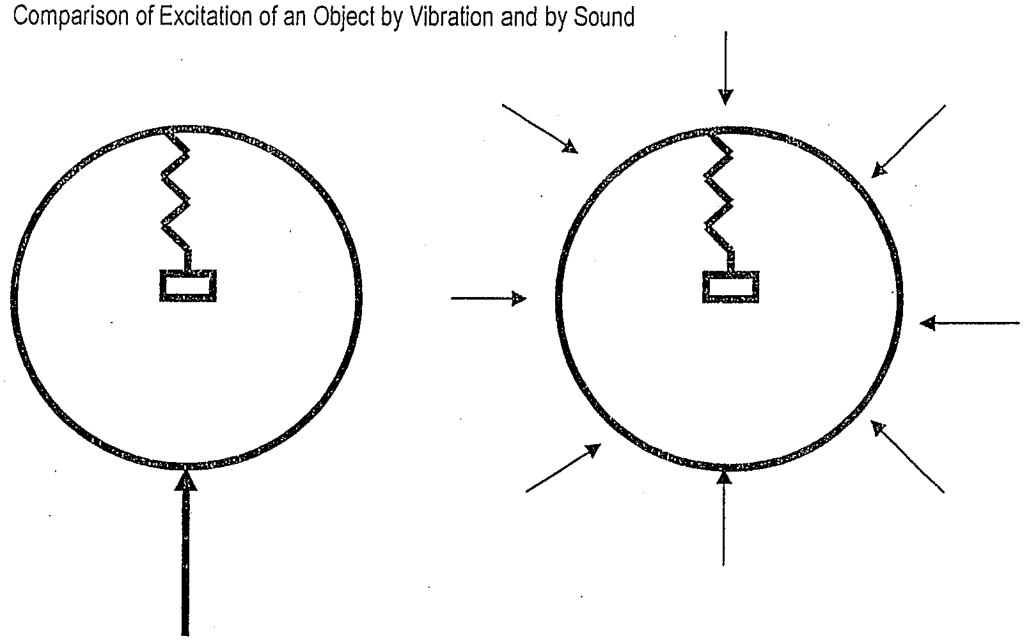
As higher frequency vibrations attenuate rapidly, it is low frequencies which are of potential concern to human health. When vibration is detected through the feet or through the seat, the focus of interest is the vibration of the surface with which one is in contact—for example, when travelling in a vehicle.

Vibration is often measured by the acceleration of the surface in meters per second, squared (m/s^2), although other related units are used. Vibration can also be expressed in decibels, where the reference excitation level used in buildings is often $10^{-5} m/s^2$ and the vibration level is $20\log(A/10^{-5})$ dB, where A is the acceleration level in m/s^2.

The threshold of perception of vibration by humans is approximately 0.01 m/s^2. If a frequency of excitation (vibration) corresponds with a resonant frequency of a system, then excitation at the resonant frequency is greater than at other frequencies. However, excitation by sound is not the same as excitation by mechanical excitation applied at, say, the feet.

Figure 3-3 shows an object excited by point mechanical vibration and by sound. The object contains a resiliently suspended system. For example, if the object was the body, the suspended system might be the viscera (internal organs of the body). The left hand of the figure can be interpreted as the body vibrated by input to the feet. The vibration of the viscera will be maximum at the resonant frequency[1] of the suspended system, which, for viscera, is about 4 Hz. When excitation is by long wavelength low frequency sound waves, as shown at the right of the figure, not only is the force acting on the body much smaller than for vibration input, but, as the wavelength is much greater than the dimensions of the body, it is acting around the body in a compressive manner so that there is no resultant force on the suspended system and it does not vibrate or resonate.

FIGURE 3-3
Comparison of Excitation of an Object by Vibration and by Sound



Unfortunately, this lack of effect has not been addressed by those who have suggested the mechanical vibration response of the body instead of the acoustic response as a potential health consequence. This oversight has led to inaccurate conclusions. For example, Dr. Nina Pierpont bases one of her key hypotheses for the cause of "wind turbine syndrome" on such an egregious error (Pierpont, 2009, pre-publication draft). Although not a recognized medical diagnosis, "wind turbine syndrome" has been raised as a concern for proposed projects—refer to Section 4.3 for more information.

Vibration of the body by sound at one of its resonant frequencies occurs only at very high sound levels and is not a factor in the perception of wind turbine noise. As will be discussed

[1] A common example of resonance is pushing a child on a swing in which energy is given to the swing to maximize its oscillation.

below, the sound levels associated with wind turbines do not affect the vestibular or other balance systems.

3.2.3 Vestibular System

The vestibular system of the body plays a major role in maintaining a person's sense of balance and the stabilization of visual images. The vestibular system responds to pressure changes (sound pressure, i.e., decibels) at various frequencies. At high levels of exposure to low frequency sound, nausea and changes in respiration and blood pressure may occur. Studies have shown, however, that for these effects to occur, considerably high noise levels (greater than 140 dB, similar in sound level of a jet aircraft heard 80 feet away) are necessary (Berglund et al., 1996).

Head vibration resulting from low frequency sound has been suggested as a possible cause of a variety of symptoms that some hypothesize as being associated with wind turbines. In order to properly assess this hypothesis, this section addresses the human vestibular system. The "vestibular system" comprises the sense organs in the vestibular labyrinth, in which there are five tiny sensory organs: three semicircular canals that detect head rotation and two chalk-crystal-studded organs called otoliths (literally "ear-stones") that detect tilt and linear motion of the head. All five organs contain hair cells, like those in the cochlea, that convert motion into nerve impulses traveling to the brain in the vestibular nerve.

These organs evolved millions of years before the middle ear. Fish, for example, have no middle ear or cochlea but have a vestibular labyrinth nearly identical to ours (Baloh and Honrubia, 1979). The vestibular organs are specialized for stimulation by head position and movement, not by airborne sound. Each vestibular organ is firmly attached to the skull, to enable them to respond to the slightest head movement. In contrast, the hair cells in the cochlea are not directly attached to the skull; they do not normally respond to head movement, but to movements of the inner ear fluids.

The otolith organs help fish hear low frequency sounds; even in primates, these organs will respond to head vibration (i.e., bone-conducted sound) at frequencies up to 500 Hz (Fernandez and Goldberg, 1976). These vibratory responses of the vestibular system can be elicited by *airborne* sounds, however, only when they are at a much higher level than normal hearing thresholds[2] (and much higher than levels associated with wind turbine exposure). Thus, they do not help us hear but appear to be vestiges of our evolutionary past.

The vestibular nerve sends information about head position and movement to centers in the brain that also receive input from the eyes and from stretch receptors in the neck, trunk, and

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[2] Young et al. (1977) found that neurons coming from the vestibular labyrinth of monkeys responded to head vibration at frequencies of 200-400 Hz, and at levels as low as 70 to 80 dB below gravitational force. However, these neurons could not respond to airborne sound at the same frequencies until levels exceeded 76 dB sound pressure level (SPL), which is at least 40 dB higher than the normal threshold of human hearing in this frequency range. Human eye movements respond to 100 Hz head vibration at levels 15 dB below audible levels (Todd et al., 2008a). This does not mean that the vestibular labyrinth is more sensitive than the cochlea to airborne sound, because the impedance-matching function of the middle ear allows the cochlea to respond to sounds that are 50-60 dB less intense than those necessary to cause detectable head vibration. Indeed, the same authors (Todd et al., 2008b) found that for airborne sound, responses from the cochlea could always be elicited by sounds that were below the threshold for vestibular responses. Similarly, Welgampola et al. (2003) found that thresholds for vestibular evoked myogenic potential response (VEMP) were higher than hearing thresholds and stated: "the difference between hearing thresholds and VEMP thresholds is much greater for air conducted sounds than for bone vibration." In other words, the vestigial vestibular response to sound is relatively sensitive to bone conduction, which involves vibration of the whole head, and much less sensitive to air conduction.

legs (these stretch receptors tell which muscles are contracted and which joints are flexed, and provide the "proprioceptive" sense of the body's position and orientation in space). The brain integrates vestibular, visual, and proprioceptive inputs into a comprehensive analysis of the position and movement of the head and body, essential for the sense of balance, avoidance of falls, and keeping the eyes focused on relevant targets, even during movement.

Perception of the body's position in space may also rely in part on input from receptors in abdominal organs (which can shift back and forth as the body tilts) and from pressure receptors in large blood vessels (blood pools in the legs when standing, then shifts back to the trunk when lying down). These "somatic graviceptors" (Mittelstaedt, 1996) could be activated by whole-body movement and possibly by structure-borne vibration, or by the blast of a powerful near explosion, but, as described in Section 4.3.2, it is unlikely that intra-abdominal and intra-thoracic organs and blood vessels could detect airborne sound like that created by wind turbines.

Trauma, toxins, age-related degeneration, and various ear diseases can cause disorders of the vestibular labyrinth. A labyrinth not functioning properly can cause a person to feel unsteady or even to fall. Since the semicircular canals of the ear normally detect head rotation (such as shaking the head to indicate "no"), one of the consequences of a dysfunctional canal is that a person may feel a "spinning" sensation. This reaction is described as vertigo, from the Latin word to turn. In normal conversation, words like vertigo and dizziness can be used in ambiguous ways and thus make careful interpretation of potential health claims problematic. "Dizzy," for example, may mean true vertigo or unsteadiness, both of which may be symptoms of inner ear disease. A person who describes being "dizzy" may actually be experiencing light-headedness, a fainting sensation, blurred vision, disorientation, or almost any other difficult-to-describe sensation in the head. The word "dizziness" can represent different sensations to each person, with a variety of causes. This can make the proper interpretation of research studies in which dizziness is evaluated a challenge to interpret.

Proper diagnostic testing to evaluate dizziness can reduce errors in misclassifying disease. The vestibular labyrinth, for example, can be tested for postural stability. Information from the semicircular canals is fed to the eye muscles to allow us to keep our eyes focused on a target; when the head moves; this "vestibulo-ocular reflex" is easily tested and can be impaired in vestibular disorders (Baloh and Honrubia, 1979).

3.3 Potential Adverse Effects of Exposure to Sound

Adverse effects of sound are directly dependent on the sound level; higher frequency sounds present a greater risk of an adverse effect than lower levels (see Table 3-2). Speech interference, hearing loss, and task interference occur at high sound levels. Softer sounds may be annoying or cause sleep disturbance in some people. At normal separation distances, wind turbines do not produce sound at levels that cause speech interference, but some people may find these sounds to be annoying.

3.3.1 Speech Interference

It is common knowledge that conversation can be difficult in a noisy restaurant; the louder the background noise, the louder we talk and the harder it is to communicate. Average

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levels of casual conversation at 1 meter (arm's length) are typically 50 to 60 dBA. People raise their voices—slightly and unconsciously at first—when ambient levels exceed 50 to 55 dBA, in order to keep speech levels slightly above background noise levels. Communication at arm's length requires conscious extra effort when levels exceed about 75 dBA. Above ambient levels of 80 to 85 dBA, people need to shout or get closer to converse (Pearsons et al., 1977; Webster, 1978). Levels below 45 dBA can be considered irrelevant with respect to speech interference.

3.3.2 Noise-Induced Hearing Loss

Very brief and intense sounds (above 130 dBA, such as in explosions) can cause instant cochlear damage and permanent hearing loss, but most occupational NIHL results from prolonged exposure to high noise levels between 90 and 105 dBA (McCunney and Meyer 2007). Regulatory (OSHA, 1983) and advisory (NIOSH, 1998) authorities in the U.S. concur that risk of NIHL begins at about 85 dBA, for an 8-hour day, over a 40-year career. Levels below 75 dBA do not pose a risk of NIHL. Thus, the sound levels associated with wind turbine operations would not cause NIHL because they are not high enough.

3.3.3 Task Interference

Suter (1991) reviewed the effects of noise on performance and behavior. Simple tasks may be unaffected even at levels well above 100 dBA, while more complex tasks can be disrupted by intermittent noise as low as 75 dBA. Speech sounds are usually more disruptive than nonspeech sounds. Levels below 70 dBA do not result in task interference.

3.3.4 Annoyance

Annoyance as a possible "effect" of wind turbine operations is discussed in detail in later sections of this report (Sections 3.4 and 4.1). In summary, annoyance is a subjective response that varies among people to many types of sounds. It is important to note that although annoyance may be a frustrating experience for people, it is not considered an adverse health effect or disease of any kind. Certain everyday sounds, such as a dripping faucet—barely audible—can be annoying. Annoyance cannot be predicted easily with a sound level meter. Noise from airports, road traffic, and other sources (including wind turbines) may annoy some people, and, as described in Section 4.1, the louder the noise, the more people may become annoyed.

3.3.5 Sleep Disturbance

The U.S. Environmental Protection Agency (EPA) document titled *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety* (1974) recommends that indoor day-night-level (DNL) not exceed 45 dBA. DNL is a 24-hour average that gives 10 dB extra weight to sounds occurring between 10p.m. and 7 a.m., on the assumption that during these sleep hours, levels above 35 dBA indoors may be disruptive.

3.3.6 Other Adverse Health Effects of Sound

At extremely high sound levels, such as those associated with explosions, the resulting sound pressure can injure any air-containing organ: not only the middle ear (eardrum perforations are common) but also the lungs and intestines (Sasser et al., 2006). At the other extreme, any sound that is chronically annoying, including very soft sounds, may, for some people, create chronic stress, which can in turn lead to other health problems. On the other hand, many people become accustomed to regular exposure to noise or other potential stressors, and are no longer annoyed. The hypothesis that chronic noise exposure might lead to chronic health problems such as hypertension and heart disease has been the subject of hundreds of contradictory studies of highly variable quality, which will not be reviewed in this document. Other authors have reviewed this literature, and some of their conclusions are quoted below:

> "It appears not likely that noise in industry can be a direct cause of general health problems..., except that the noise can create conditions of psychological stress...which can in turn cause physiological stress reactions..." (Kryter, 1980)

> "Epidemiological evidence on noise exposure, blood pressure, and ischemic heart disease is still limited." (Babisch, 2004), and "contradictory' (Babisch, 1998), but "there is some evidence...of an increased risk in subjects who live in noisy areas with outdoor noise levels of greater than 65 - 70 dBA." (Babisch, 2000)

> "The present state of the art does not permit any definite conclusion to be drawn about the risk of hypertension." (van Dijk, Ettema, and Zielhuis, 1987)

> "At this point, the relationship between noise induced hearing loss and hypertension must be considered as possible but lacking sufficient evidence to draw causal associations." (McCunney and Meyer, 2007)

3.3.7 Potential Health Effects of Vibration Exposure

People may experience vibration when some part of the body is in direct contact with a vibrating object. One example would be holding a chainsaw or pneumatic hammer in the hands. Another would be sitting in a bus, truck, or on heavy equipment such as a bulldozer. Chronic use of vibrating tools can cause "hand-arm vibration syndrome," a vascular insufficiency condition characterized by numbness and tingling of the fingers, cold intolerance, "white-finger" attacks, and eventually even loss of fingers due to inadequate blood supply. OSHA does not set limits for vibration exposure, but the American National Standards Institute (ANSI) (2006) recommends that 8-hour workday exposures to hand-arm vibration (5 to 1400 Hz, summed over three orthogonal axes of movement) not exceed acceleration values of 2.5 m/s^2.

Excessive whole-body vibration is clearly linked to low back pain (Wilder, Wasserman, and Wasserman, 2002) and may contribute to gastrointestinal and urinary disorders, although these associations are not well established. ANSI (1979) recommends 8-hour limits for whole-body vibration of 0.3 m/s^2, for the body's most sensitive frequency range of 4 to 8 Hz. This is about 30 times more intense than the weakest vibration that people can detect (0.01 m/s^2).

Airborne sound can cause detectable body vibration, but this occurs only at very high levels—usually above sound pressure levels of 100 dB (unweighted) (Smith, 2002; Takahashi et al., 2005; Yamada et al., 1983). There is no scientific evidence to suggest that modern wind turbines cause perceptible vibration in homes or that there is an associated health risk.

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3.4 Peer-Reviewed Literature Focusing on Wind Turbines, Low-Frequency Sound, and Infrasound

This section addresses the scientific review of the literature that has evaluated wind turbines, the annoyance effect, low frequency sound, and infrasound.

3.4.1 Evaluation of Annoyance and Dose-Response Relationship of Wind Turbine Sound

To date, three studies in Europe have specifically evaluated potential health effects of people living in proximity to wind turbines (Pedersen and Persson Waye, 2004; Pedersen and Persson Waye, 2007; Pedersen et al., 2009). These studies have been primarily in Sweden and the Netherlands. Customarily, an eligible group of people are selected for possible participation in the study based on their location with respect to a wind turbine. Control groups have not been included in any of these reports.

In an article published in August 2009, investigators reported the results of their evaluation of 725 people in the Netherlands, who lived in the vicinity of wind turbines (Pedersen et al., 2009). The potential study population consisted of approximately 70,000 people living within 2.5 kilometers of a wind turbine at selected sites in the Netherlands. The objective of the study was to (1) assess the relationship between wind turbine sound levels at dwellings and the probability of noise annoyance, taking into account possible moderating factors, and (2) explore the possibility of generalizing a dose response relationship for wind turbine noise by comparing the results of the study with previous studies in Sweden.

Noise impact was quantified based on the relationship between the sound level (dose) and response with the latter measured as the proportion of people annoyed or highly annoyed by sound. Prior to this study, dose response curves had been modeled for wind turbines. Previous studies have noted different degrees of relationships between wind turbine sound levels and annoyance (Wolsink et al., 1993; Pedersen and Persson Waye, 2004; Pedersen and Persson Waye, 2007).

Subjective responses were obtained through a survey. The calculation of the sound levels (dose) in Sweden and the Netherlands were similar. A dose response relationship was observed between calculated A-weighted sound pressure levels and annoyance. Sounds from wind turbines were found to be more annoying than several other environmental sources at comparable sound levels. A strong correlation was also noted between noise annoyance and negative opinion of the impact of wind turbines on the landscape, a finding in earlier studies as well. The dominant quality of the sound was a swishing, the quality previously found to be the most annoying type.

The authors concluded that this study could be used for calculating a dose response curve for wind turbine sound and annoyance. The study results suggest that wind turbine sound is easily perceived and, compared with sound from other sources, is annoying to a small percentage of people (5 percent at 35 to 40 dBA).

In this study, the proportion of people who reported being annoyed by wind turbine noise was similar to merged data from two previous Swedish studies (Pederson and Persson

Waye, 2004; Pedersen and Persson Waye, 2007). About 5 percent of respondents were annoyed at noise levels between 35 to 40 dBA and 18 percent at 40 to 45 dBA.

Pedersen et al. also reported significant dose responses between wind turbine sound and self-reported annoyance (Pedersen and Persson Waye, 2004). High exposed individuals responded more (78 percent) than low exposed individuals (60 percent), which suggests that bias could have played a role in the final results.

An analysis of two cross-sectional socio-acoustic studies – one that addressed flat landscapes in mainly rural settings (Pedersen and Persson Waye, 2004) and another in different terrains (complex or flat) and different levels of urbanization (rural or suburban) (Pedersen and Persson Waye, 2007) – was performed (Pedersen, 2008). Approximately 10 percent of over 1000 people surveyed via a questionnaire reported being very annoyed at sound levels of 40 dB and greater. Attitude toward the visual impact of the wind turbines had the same effect on annoyance. Response to wind turbine noise was significantly related to exposure expressed as A-weighted sound pressure levels dB. Among those who could hear wind turbine sound, annoyance with wind turbine noise was highly correlated to the sound characteristics: swishing, whistling, resounding and pulsating/throbbing (Pedersen, 2008).

A similar study in Sweden evaluated 754 people living near one of seven sites where wind turbine power was greater than 500 kilowatt (kW) (Pedersen and Persson Waye, 2007). Annoyance was correlated with sound level and also with negative attitude toward the visual impact of the wind turbines. Note that none of these studies included a control group. Earlier field studies performed among people living in the vicinity of wind turbines showed a correlation between sound pressure level and noise annoyance; however, annoyance was also influenced by visual factors and attitudes toward the impact of the wind turbines on the landscape. Noise annoyance was noted at lower sound pressure levels than annoyance from traffic noise. Although some people may be affected by annoyance, there is no scientific evidence that noise at levels created by wind turbines could cause health problems (Pedersen and Högskolan, 2003).

3.4.2 Annoyance

A feeling described as "annoyance" can be associated with acoustic factors such as wind turbine noise. There is considerable variability, however, in how people become "annoyed" by environmental factors such as road construction and aviation noise, among others (Leventhall, 2004). Annoyance is clearly a subjective effect that will vary among people and circumstances. In extreme cases, sleep disturbance may occur. Wind speed at the hub height of a wind turbine at night may be up to twice as high as during the day and may lead to annoyance from the amplitude modulated sound of the wind turbine (van den Berg, 2003). However, in a study of 16 sites in 3 European countries, only a weak correlation was noted between sound pressure level and noise annoyance from wind turbines (Pedersen and Högskolan, 2003).

In a detailed comparison of the role of noise sensitivity in response to environmental noise around international airports in Sydney, London, and Amsterdam, it was shown that noise sensitivity increases one's perception of annoyance independently of the level of noise exposure (van Kamp et al., 2004).

In a Swedish study, 84 out of 1,095 people living in the vicinity of a wind turbine in 12 geographical areas reported being fairly or very annoyed by wind turbines (Pedersen, 2008). It is important to note that no differences were reported among people who were "annoyed" in contrast to those who were not annoyed with respect to hearing impairment, diabetes, or cardiovascular disease. An earlier study in Sweden showed that the proportion of people "annoyed" by wind turbine sound is higher than for other sources of environmental noise at the same decibel level (Pedersen and Persson Waye, 2004).

3.4.3 Low-Frequency Sound and Infrasound

No scientific studies have specifically evaluated health effects from exposure to low frequency sound from wind turbines. Natural sources of low frequency sound include wind, rivers, and waterfalls in both audible and non-audible frequencies. Other sources include road traffic, aircraft, and industrial machinery. The most common source of infrasound is vehicular (National Toxicology Program, 2001).

Infrasound at a frequency of 20 Hz (the upper limit of infrasound) is not detectable at levels lower than than 79 dB (Leventhall et al., 2003). Infrasound at 145 dB at 20 Hz and at 165 dB at 2 Hz can stimulate the auditory system and cause severe pain (Leventhall, 2006).These noise levels are substantially higher than any noise generated by wind turbines. The U.S. Food and Drug Administration (FDA) has approved the use of infrasound for therapeutic massage at 70 dB in the 8 to 14 Hz range (National Toxicology Program, 2001). In light of the FDA approval for this type of therapeutic use of infrasound, it is reasonable to conclude that exposure to infrasound in the 70 dB range is safe. According to a report of the National Research Council (NRC), low frequency sound is a concern for older wind turbines but not the modern type (National Research Council, 2007).

SECTION 4

Results

This section discusses the results of the anaylsis presented in Section 3. Potential effects from infrasound, low frequency sound, and the fluctuating aerodynamic "swish" from turbine blades are examined. Proposed hypotheses between wind turbine sound and physiological effects in the form of vibroacoustic disease, "wind turbine syndrome," and visceral vibratory vestibular disturbance are discussed.

4.1 Infrasound, Low-Frequency Sound, and Annoyance

Sound levels from wind turbines pose no risk of hearing loss or any other nonauditory effect. In fact, a recent review concluded that "Occupational noise-induced hearing damage does not occur below levels of 85 dBA." (Ising and Kruppa, 2004) The levels of sound associated with wind turbine operations are considerably lower than industry levels associated with noise induced hearing loss.

However, some people attribute certain health problems to wind turbine exposure. To make sense of these assertions, one must consider not only the sound but the complex factors that may lead to the perception of "annoyance." Most health complaints regarding wind turbines have centered on sound as the cause. There are two types of sounds from wind turbines: mechanical sound, which originates from the gearbox and control mechanisms, and the more dominant aerodynamical sound, which is present at all frequencies from the infrasound range over low frequency sound to the normal audible range.

Infrasound from natural sources (for example, ocean waves and wind) surrounds us and is below the audible threshold. The infrasound emitted from wind turbines is at a level of 50 to 70 dB, sometimes higher, but well below the audible threshold. There is a consensus among acoustic experts that the infrasound from wind turbines is of no consequence to health. One particular problem with many of these assertions about infrasound is that is that the term is often misused when the concerning sound is actually low frequency sound, not infrasound.

Under many conditions, low frequency sound below about 40 Hz cannot be distinguished from environmental background sound from the wind itself. Perceptible (meaning above both the background sound and the hearing threshold), low frequency sound can be produced by wind turbines under conditions of unusually turbulent wind conditions, but the actual sound level depends on the distance of the listener from the turbine, as the sound attenuates (falls off) with distance. The higher the frequency, the greater the sound attenuates with distance—Appendix D provides more information on the propagation of sound. The low frequency sound emitted by spinning wind turbines could possibly be annoying to some when winds are unusually turbulent, but there is no evidence that this level of sound could be harmful to health. If so, city dwelling would be impossible due to the similar levels of ambient sound levels normally present in urban environments. Nevertheless, a small number of people find city sound levels stressful.

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It is not usually the low frequency nonfluctuating sound component, however, that provokes complaints about wind turbine sound. The fluctuating aerodynamic sound (swish) in the 500 to 1,000 Hz range occurs from the wind turbine blades disturbing the air, modulated as the blades rotate which changes the sound dispersion characteristics in an audible manner. This fluctuating aerodynamic sound is the cause of most sound complaints regarding wind turbines, as it is harder to become accustomed to fluctuating sound than to sound that does not fluctuate. However, this fluctuation does not always occur and a UK study showed that it had been a problem in only four out of 130 UK wind farms, and had been resolved in three of those (Moorhouse et al., 2007).

4.1.1 Infrasound and Low-Frequency Sound

Infrasound occurs at frequencies less than 20 Hz. At low and inaudible levels, infrasound has been suggested as a cause of "wind turbine syndrome" and vibroacoustic disease (VAD) – refer to Section 4.2.1 for more information on VAD. For infrasound to be heard, high sound levels are necessary (see Section 3, Table 3-2). There is little risk of short term acute exposure to high levels of infrasound. In experiments related to the Apollo space program, subjects were exposed to between 120 and 140 dB without known harmful effects. High level infrasound is less harmful than the same high levels of sound in the normal audible frequency range.

High levels of low frequency sound can excite body vibrations (Leventhall, 2003). Early attention to low frequency sound was directed to the U.S. space program, studies from which suggested that 24-hour exposures to 120 to 130 dB are tolerable below 20 Hz, the upper limit of infrasound. Modern wind turbines produce sound that is assessed as infrasound at typical levels of 50 to 70 dB, below the hearing threshold at those frequencies (Jakobsen, 2004). Jakobsen concluded that infrasound from wind turbines does not present a health concern. Fluctuations of wind turbine sound, most notably the swish-swish sounds, are in the frequency range of 500 to 1,000 Hz, which is neither low frequency sound nor infrasound. The predominant sound from wind turbines, however, is often mischaracterized as infrasound and low frequency sound. Levels of infrasound near modern-scale wind farms are in general not perceptible to people. In the human body, the beat of the heart is at 1 to 2 Hz. Higher-frequency heart sounds measured externally to the body are in the low frequency range (27 to 35 dB at 20 to 40 Hz), although the strongest frequency is that of the heartbeat (Sakai, Feigen, and Luisada, 1971). Lung sounds, measured externally to the body are in the range of 5 to 35 dB at 150 to 600 Hz (Fiz et al., 2008). Schust (2004) has given a comprehensive review of the effects of high level low frequency sound, up to 100 Hz.

4.1.2 Annoyance

Annoyance is a broad topic on which volumes have been written. Annoyance can be caused by constant amplitude and amplitude modulated sounds containing rumble (Bradley, 1994).

As the level of sound rises, an increasing number of those who hear it may become distressed, until eventually nearly everybody is affected, although to different degrees. This is a clear and easily understood process. However, what is not so clearly understood is that when the level of the sound reduces, so that very few people are troubled by it, there remain a small number who may be adversely affected. This occurs at all frequencies, although there seems to be more subjective variability at the lower frequencies. The effect of low frequency sound on annoyance has recently been reviewed (Leventhall, 2004). The standard deviation of the hearing threshold is approximately 6 dB at low frequencies (Kurakata and Mizunami, 2008), so that about 2.5 percent of the population will have 12 dB more sensitive hearing than the average person. However, hearing sensitivity alone does not appear to be the deciding factor with respect to annoyance. For example, the same type of sound may elicit different reactions among people: one person might say "Yes, I can hear the sound, but it does not bother me," while another may say, "The sound is impossible, it is ruining my life." There is no evidence of harmful effects from the low levels of sound from wind turbines, as experienced by people in their homes. Studies have shown that peoples' attitudes toward wind turbines may affect the level of annoyance that they report (Pedersen et al., 2009).

Some authors emphasize the psychological effects of sounds (Kalveram, 2000; Kalveram et al., 1999). In an evaluation of 25 people exposed to five different wind turbine sounds at 40 dB, ratings of "annoyance" were different among different types of wind turbine noise (Persson Waye and Öhrström, 2002).

None of the psycho-acoustic parameters could explain the difference in annoyance responses. Another study of more than 2,000 people suggested that personality traits play a role in the perception of annoyance to environmental issues such as sound (Persson et al., 2007). Annoyance originates from acoustical signals that are not compatible with, or that disturb, psychological functions, in particular, disturbance of current activities. Kalveram et al. (1999) suggest that the main function of noise annoyance is as a warning that fitness may be affected but that it causes little or no physiological effect. Protracted annoyance, however, may undermine coping and progress to stress related effects. It appears that this is the main mechanism for effects on the health of a small number of people from prolonged exposure to low levels of noise.

The main health effect of noise stress is disturbed sleep, which may lead to other consequences. Work with low frequencies has shown that an audible low frequency sound does not normally become objectionable until it is 10 to 15 dB above hearing threshold (Inukai et al., 2000; Yamada, 1980). An exception is when a listener has developed hostility to the noise source, so that annoyance commences at a lower level.

There is no evidence that sound at the levels from wind turbines as heard in residences will cause direct physiological effects. A small number of sensitive people, however, may be stressed by the sound and suffer sleep disturbances.

4.1.3 Other Aspects of Annoyance

Some people have concluded that they have health problems caused directly by wind turbines. In order to make sense of these complaints, we must consider not only the sound, but the complex factors culminating in annoyance.

There is a large body of medical literature on stress and psychoacoustics. Three factors that may be pertinent to a short discussion of wind turbine annoyance effects are the nocebo effect, sensory integration dysfunction and somatoform disorders.

4.1.4 Nocebo Effect

The nocebo effect is an adverse outcome, a worsening of mental or physical health, based on fear or belief in adverse effects. This is the opposite of the well known placebo effect, where belief in positive effects of an intervention may produce positive results (Spiegel, 1997). Several factors appear to be associated with the nocebo phenomenon: expectations of adverse effects; conditioning from prior experiences; certain psychological characteristics such as anxiety, depression and the tendency to somatize (express psychological factors as physical symptoms; see below), and situational and contextual factors. A large range of reactions include hypervagotonia, manifested by idioventricular heart rhythm (a slow heart rate of 20 to 50 beats per minute resulting from an intrinsic pacemaker within the ventricles which takes over when normal sinoatrial node regulation is lost), drowsiness, nausea, fatigue, insomnia, headache, weakness, dizziness, gastrointestinal (GI) complaints and difficulty concentrating (Sadock and Sadock, 2005, p.2425). This array of symptoms is similar to the so-called "wind turbine syndrome" coined by Pierpont (2009, pre-publication draft). Yet these are all common symptoms in the general population and no evidence has been presented that such symptoms are more common in persons living near wind turbines. Nevertheless, the large volume of media coverage devoted to alleged adverse health effects of wind turbines understandably creates an anticipatory fear in some that they will experience adverse effects from wind turbines. Every person is suggestible to some degree. The resulting stress, fear, and hypervigilance may exacerbate or even create problems which would not otherwise exist. In this way, anti-wind farm activists may be creating with their publicity some of the problems that they describe.

4.1.5 Somatoform Disorders

There are seven somatoform disorders in the Fourth Edition of *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR) (American Psychiatric Association, 2000). Somatoform disorders are physical symptoms which reflect psychological states rather than arising from physical causes. One common somatoform disorder, Conversion Disorder, is the unconscious expression of stress and anxiety as one or more physical symptoms (Escobar and Canino, 1989). Common conversion symptoms are sensations of tingling or discomfort, fatigue, poorly localized abdominal pain, headaches, back or neck pain, weakness, loss of balance, hearing and visual abnormalities. The symptoms are not feigned and must be present for at least six months according to DSM-IV-TR and two years according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10) (WHO, 1993). ICD-10 specifies the symptoms as belonging to four groups: (1) Gastrointestinal (abdominal pain, nausea, bloating/gas/, bad taste in mouth/excessive tongue coating, vomiting/regurgitation, frequent/loose bowel movements); (2) Cardiovascular (breathlessness without exertion, chest pains); (3) Genitourinary (frequency or dysuria, unpleasant genital sensations, vaginal discharge), and (4) Skin and Pain (blotchiness or discoloration of the skin, pain in the limbs, extremities or joints, paresthesias). ICD-10 specifies that at least six symptoms must be present in two or more groups.

One feature of somatoform disorders is *somatosensory amplification*, a process in which a person learns to feel body sensations more acutely and may misinterpret the significance of those sensations by equating them with illness (Barsky, 1979). *Sensory integration dysfunction* describes abnormal sensitivity to any or all sensory stimuli (sound, touch, light, smell, and taste). There is controversy among researchers and clinicians as to whether sensory integration problems exist as an independent entity or as components of a pervasive developmental disorder (Sadock and Sadock, 2005, p. 3135), but their presence can lead to overestimation of the likelihood of being ill (Sadock and Sadock, 2005, p. 1803). Sensory integration dysfunction as such is not listed in the DSM-IV-TR or in the ICD-10.

Day-to-day stressors and adverse life events provide multiple stimuli to which people respond, and that response is often somatic due to catecholamines and activation of the autonomic nervous system. This stress response can become conditioned as memory. There is some evidence that poor coping mechanisms (anger impulsivity, hostility, isolation, lack of confiding in others) are linked to physiological reactivity, which is associated with somatic sensation and amplification (Sadock and Sadock, 2005, p. 1806).

In summary, the similarities of common human stress responses and conversion symptoms to those described as "wind turbine syndrome" are striking. An annoyance factor to wind turbine sounds undoubtedly exists, to which there is a great deal of individual variability. Stress has multiple causes and is additive. Associated stress from annoyance, exacerbated by the rhetoric, fears, and negative publicity generated by the wind turbine controversy, may contribute to the reported symptoms described by some people living near rural wind turbines.

4.2 Infrasound, Low-frequency Sound and Disease

Some reports have suggested a link between low frequency sound from wind turbines and certain adverse health effects. A careful review of these reports, however, leads a critical reviewer to question the validity of the claims for a number of reasons, most notably (1) the level of sound exposure associated with the putative health effects, (2) the lack of diagnostic specificity associated with the health effects reported, and (3) the lack of a control group in the analysis.

4.2.1 Vibroacoustic Disease

Vibroacoustic disease (VAD) in the context of exposure of aircraft engine technicians to sound was defined by Portuguese researchers as a whole-body, multi-system entity, caused by chronic exposure to large pressure amplitude and low frequency (LPALF) sound (Alves-Pereira and Castelo Branco, 2007a; Alves-Pereira and Castelo Branco, 2007b; Alves-Pereira and Castelo Branco, 2007c; Alves-Pereira and Castelo Branco, 2007d). VAD, the primary feature of which is thickening of cardiovascular structures, such as cardiac muscle and blood vessels, was first noted among airplane technicians, military pilots, and disc jockeys (Maschke, 2004; Castelo Branco, 1999). Workers had been exposed to high levels for more than 10 years. There are no epidemiological studies that have evaluated risk of VAD from exposure to infrasound. The likelihood of such a risk, however, is remote in light of the much lower vibration levels in the body itself. Studies of workers with substantially higher exposure levels have not indicated a risk of VAD. VAD has been described as leading from initial respiratory infections, through pericardial thickening to severe and life-threatening illness such as stroke, myocardial infarction, and risk of malignancy (Alves-Pereira and Castelo Branco, 2007a).

4.2.2 High-Frequency Exposure

All of the exposures of subjects for whom the VAD concept was developed, were dominated by higher frequency sounds, a critical point since the frequency range claimed for VAD-inducing sound is much wider than the frequency range of exposures experienced by the aircraft technicians who were diagnosed with VAD (Castelo Branco, 1999). Originally, proponents of the VAD concept had proposed a "greater than 90 dB" criterion for VAD. However, now some claim that VAD will result from exposure to almost any level of infrasound and low frequency sound at any frequency below 500 Hz. This assertion is an extraordinary extrapolation given that the concept of VAD developed from observations that a technician, working around military aircraft on the ground, with engines operating, displayed disorientation (Castelo Branco, 1999). Sound levels near aircraft were very high. In an evaluation of typical engine spectra of carrier based combat aircraft operating on the ground, the spectra peaked at frequencies above 100 Hz with sound levels from 120 to 135 dB close to the aircraft (Smith, 2002). The levels drop considerably, however, into the low frequency region.

There is an enormous decibel difference between the sound exposure of aircraft technicians and the sound exposure of people who live near wind turbines. Animal experiments indicated that exposure levels necessary to cause VAD were 13 weeks of continuous exposure to approximately 100 dB of low frequency sound (Mendes et al., 2007). The exposure levels were at least 50 to 60 dB higher than wind turbine levels in the same frequency region (Hayes, 2006a).

4.2.3 Residential Exposure: A Case Series

Extrapolation of results from sound levels greater than 90 dB and at predominantly higher frequencies (greater than 100 Hz) to a risk of VAD from inaudible wind turbine sound levels of 40 to 50 dB in the infrasound region, is a new hypothesis. One investigator, for example, has claimed that wind turbines in residential areas produce acoustical environments that can lead to the development of VAD in nearby home-dwellers (Alves-Pereira and Castelo Branco, 2007a).

This claim is based on comparison of only two infrasound exposures. The first is for a family which has experienced a range of health problems and which also complained of disturbances from low frequency sound. The second is for a family which lived near four wind turbines, about which they have become anxious (Alves-Pereira and Castelo Branco, 2007a; Alves-Pereira and Castelo Branco, 2007b).

The first family (Family F), was exposed to low levels of infrasound consisting of about 50 dB at 8 Hz and 10 Hz from a grain terminal about 3 kilometers (km) away and additional sources of low frequency sound, including a nearer railway line and road. The second family (Family R) lives in a rural area and was described as exposed to infrasound levels of about 55 dB to 60 dB at 8 Hz to 16 Hz. These exposures are well below the hearing threshold and not uncommon in urban areas. Neither the frequency nor volume of the sound exposures experienced by Families F or R are unusual. Exposure to infrasound (< 20 Hz) did not exceed 50 dB.

4.2.3.1 Family F—Exposure to Low Levels of Infrasound

Family F has a long history of poor health and a 10-year-old boy was diagnosed with VAD due to exposure to infrasound from the grain terminal (Alves-Pereira and Castelo Branco, 2007a; Castelo Branco et al., 2004). However, the infrasound levels are well below hearing threshold and are typical of urban infrasound, which occurs widely and to which many people are exposed.

According to the authors, the main effect of VAD was demonstrated by the 10-year-old boy in the family, as pericardial thickening.[3] However, the boy has a history of poor health of unknown etiology (Castelo Branco et al., 2004). Castelo Branco (1999) has defined pericardial thickening as an indicator of VAD and assumes that the presence of pericardial thickening in the boy from Family F must be an effect of VAD, caused by exposure to the low-level, low frequency sound from the grain terminal. This assumption excludes other possible causes of pericardial thickening, including viral infection, tuberculosis, irradiation, hemodialysis, neoplasia with pericardial infiltration, bacterial, fungal, or parasitic infections, inflammation after myocardial infarction, asbestosis, and autoimmune diseases. The authors did not exclude these other possible causes of pericardial thickening.

4.2.3.2 Family R—Proximity to Turbines and Anxiety

Family R, living close to the wind turbines, has low frequency sound exposure similar to that of Family F. The family does not have symptoms of VAD, but it was claimed that "Family R. will also develop VAD should they choose to remain in their home." (Alves-Pereira and Castelo Branco, 2007b). In light of the absence of literature of cohort and case control studies, this bold statement seems to be unsubstantiated by available scientific literature.

4.2.4 Critique

It appears that Families F and R were self-selected complainants. Conclusions derived by Alves-Pereira and Castelo Branco (2007b) have been based only on the poor health and the sound exposure of Family F, using this single exposure as a measure of potential harmful effects for others. There has been no attempt at an epidemiological study.

Alves-Pereira and Castelo Branco claim that exposure at home is more significant than exposure at work because of the longer periods of exposure (Alves-Pereira and Castelo Branco, 2007e). Because an approximate 50 dB difference occurs between the exposure from wind turbines and the exposure that induced VAD (Hayes, 2006a), it will take 10^5 years (100,000 years) for the wind turbine dose to equal that of one year of the higher level sound.

Among published scientific literature, this description of the two families is known as a case series, which are of virtually no value in understanding potential *causal associations* between exposure to a potential hazard (i.e., low frequency sound) and a potential health effect (i.e., vibroacoustic disease). Case reports have value but primarily in generating hypotheses to test in other studies such as large groups of people or in case control studies. The latter type of study can systematically evaluate people with pericardial thickening who live near wind turbines in comparison to people with pericardial thickening who do not live

[3] Pericardial thickening is unusual thickening of the protective sac (pericardium) which surrounds the heart. For example, see http://www.emedicine.com/radio/topic191.htm.

near wind turbines. Case reports need to be confirmed in larger studies, most notably cohort studies and case-control studies, before definitive cause and effect assertions can be drawn. The reports of the two families do not provide persuasive scientific evidence of a link between wind turbine sound and pericardial thickening.

Wind turbines produce low levels of infrasound and low frequency sound, yet there is no credible scientific evidence that these levels are harmful. If the human body is affected by low, sub-threshold sound levels, a unique and not yet discovered receptor mechanism of extraordinary sensitivity to sound is necessary—a mechanism which can distinguish between the normal, relatively high-level "sound" inherent in the human body[4] and excitation by external, low-level sound. Essential epidemiological studies of the potential effects of exposure at low sound levels at low frequencies have not been conducted. Until the fuzziness is clarified, and a receptor mechanism revealed, no reliance can be placed on the case reports that the low levels of infrasound and low frequency sound are a cause of vibroacoustic disease.[5]

The attribution of dangerous properties to low levels of infrasound continues unproven, as it has been for the past 40 years. No foundation has been demonstrated for the new hypothesis that exposure to sub-threshold, low levels of infrasound will lead to vibroacoustic disease. Indeed, human evolution has occurred in the presence of natural infrasound.

4.3 Wind Turbine Syndrome

"Wind turbine syndrome" as promoted by Pierpont (2009, pre-publication draft) appears to be based on the following two hypotheses:

1. Low levels of airborne infrasound from wind turbines, at 1 to 2 Hz, directly affect the vestibular system.

2. Low levels of airborne infrasound from wind turbines at 4 to 8 Hz enter the lungs via the mouth and then vibrate the diaphragm, which transmits vibration to the viscera, or internal organs of the body.

The combined effect of these infrasound frequencies sends confusing information to the position and motion detectors of the body, which in turn leads to a range of disturbing symptoms.

4.3.1 Evaluation of Infrasound on the Vestibular System

Consider the first hypothesis. The support for this hypothesis is a report apparently misunderstood to mean that the vestibular system is more sensitive than the cochlea to low levels of both sound and vibration (Todd et al., 2008a). The Todd report is concerned with vibration input to the mastoid area of the skull, and the corresponding detection of these vibrations by the cochlea and vestibular system. The lowest frequency used was 100 Hz,

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4 Body sounds are often used for diagnosis. For example see Gross, V., A. Dittmar, T. Penzel, F., Schüttler, and P. von Wichert.. (2000): "The Relationship between Normal Lung Sounds, Age, and Gender." *American Journal of Respiratory and Critical Care Medicine*. Volume 162, Number 3: 905 - 909.

5 This statement should not be interpreted as a criticism of the work of the VAD Group with aircraft technicians at high noise levels.

considerably higher than the upper limit of the infrasound frequency (20 Hz). The report does not address air-conducted sound or infrasound, which according to Pierpont excites the vestibular system by airborne sound and by skull vibration. This source does not support Pierpont's hypothesis and does not demonstrate the points that she is trying to make.

There is no credible scientific evidence that low levels of wind turbine sound at 1 to 2 Hz will directly affect the vestibular system. In fact, it is likely that the sound will be lost in the natural infrasonic background sound of the body. The second hypothesis is equally unsupported with appropriate scientific investigations. The body is a noisy system at low frequencies. In addition to the beating heart at a frequency of 1 to 2 Hz, the body emits sounds from blood circulation, bowels, stomach, muscle contraction, and other internal sources. Body sounds can be detected externally to the body by the stethoscope.

4.3.2 Evaluation of Infrasound on Internal organs

It is well known that one source of sound may mask the effect of another similar source. If an external sound is detected within the body in the presence of internally generated sounds, the external sound must produce a greater effect in the body than the internal sounds. The skin is very reflective at higher frequencies, although the reflectivity reduces at lower frequencies (Katz, 2000). Investigations at very low frequencies show a reduction of about 30 dB from external to internal sound in the body of a sheep (Peters et al., 1993). These results suggest an attenuation (reduction) of low frequency sound by the body before the low frequency sound reaches the internal organs.

Low-level sounds from outside the body do not cause a high enough excitation within the body to exceed the internal body sounds. Pierpont refers to papers from Takahashi and colleagues on vibration excitation of the head by high levels of external sound (over 100 dB). However, these papers state that response of the head at frequencies below 20 Hz was not measurable due to the masking effect of internal body vibration (Takahashi et al., 2005; Takahashi et al., 1999). When measuring chest resonant vibration caused by external sounds, the internal vibration masks resonance for external sounds below 80 dB excitation level (Leventhall, 2006). Thus, the second hypothesis also fails.

To recruit subjects for her study, Pierpont sent out a general call for anybody believing their health had been adversely affected by wind turbines. She asked respondents to contact her for a telephone interview. The case series results for ten families (37 subjects) are presented in Pierpont (2009, pre-publication draft). Symptoms included sleep disturbance, headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, concentration, memory, panic attacks, internal pulsation, and quivering. This type of study is known as a case series. A case series is of limited, if any, value in evaluating causal connections between an environmental exposure (in this case, sound) and a designated health effect (so called "wind turbine syndrome"). This particular case series is substantially limited by selection bias, in which people who already think that they have been affected by wind turbines "self select" to participate in the case series. This approach introduces a significant bias in the results, especially in the absence of a control group who do not live in proximity of a wind turbine. The results of this case series are at best hypothesis-generating activities that do not provide support for a causal link between wind turbine sound and so-called "wind turbine syndrome."

However, these so called "wind turbine syndrome" symptoms are not new and have been published previously in the context of "annoyance" to environmental sounds (Nagai et al., 1989; Møller and Lydolf, 2002; Mirowska and Mroz, 2000). The following symptoms are based on the experience of noise sufferers extending over a number of years: distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, nose bleeds, palpitations, pressure in the ears or head, skin burns, stress, and tension (Leventhall, 2002).

The symptoms are common in cases of extreme and persistent annoyance, leading to stress responses in the affected individual and may also result from severe tinnitus, when there is no external sound. The symptoms are exhibited by a small proportion of sensitive persons and may be alleviated by a course of psychotherapy, aimed at desensitization from the sound (Leventhall et al., 2008). The similarity between the symptoms of noise annoyance and those of "wind turbine syndrome" indicates that this "diagnosis" is not a pathophysiological effect, but is an example of the well-known stress effects of exposure to noise, as displayed by a small proportion of the population. These effects are familiar to environmental noise control officers and other "on the ground" professionals.

"Wind turbine syndrome," not a recognized medical diagnosis, is essentially reflective of symptoms associated with noise annoyance and is an unnecessary and confusing addition to the vocabulary on noise. This syndrome is not a recognized diagnosis in the medical community. There are no unique symptoms or combinations of symptoms that would lead to a specific pattern of this hypothesized disorder. The collective symptoms in some people exposed to wind turbines are more likely associated with annoyance to low sound levels.

4.4 Visceral Vibratory Vestibular Disturbance

4.4.1 Hypothesis

In addition to case reports of symptoms reported by people who live near wind turbines, Pierpont has proposed a hypothesis that purports to explain how some of these symptoms arise: visceral vibratory vestibular disturbance (VVVD) (Pierpont, 2009, pre-publication draft). VVVD has been described as consisting of vibration associated with low frequencies that enters the body and causes a myriad of symptoms. Pierpont considers VVVD to be the most distinctive feature of a nonspecific set of symptoms that she describes as "wind turbine syndrome." As the name VVVD implies, wind turbine sound in the 4 to 8 Hz spectral region is hypothesized to cause vibrations in abdominal viscera (e.g., intestines, liver, and kidneys) that in turn send neural signals to the part of the brain that normally receives information from the vestibular labyrinth. These signals hypothetically conflict with signals from the vestibular labyrinth and other sensory inputs (visual, proprioceptive), leading to unpleasant symptoms, including panic. Unpleasant symptoms (especially nausea) can certainly be caused by sensory conflict; this is how scientists explain motion sickness. However, this hypothesis of VVVD is implausible based on knowledge of sensory systems and the energy needed to stimulate them. Whether implausible or not, there are time-tested scientific methods available to evaluate the legitimacy of any hypothesis and at this stage, VVVD as proposed by Pierpont is an untested hypothesis. A case series of 10 families recruited to participate in a study based on certain symptoms would not be considered evidence of causality by research or policy institutions such as the International Agency for Research on

Cancer (IARC) or EPA. As noted earlier in this report, a case series of self-selected patients does not constitute evidence of a causal connection.

4.4.2 Critique

Receptors capable of sensing vibration are located predominantly in the skin and joints. A clinical neurological examination normally includes assessment of vibration sensitivity. It is highly unlikely, however, that airborne sound at comfortable levels could stimulate these receptors, because most of airborne sound energy is reflected away from the body. Takahashi et al. (2005) used airborne sound to produce chest or abdominal vibration that exceeded ambient body levels. This vibration may or may not have been detectable by the subjects. Takahashi found that levels of 100 dB sound pressure level were required at 20 to 50 Hz (even higher levels would have been required at lower and higher frequencies). Sounds like this would be considered by most people to be very loud, and are well beyond the levels produced by wind turbines at residential distances. Comparison of the responses to low frequency airborne sound by normal hearing and profoundly deaf persons has shown that deaf subjects can detect sound transmitted through their body only when it is well above the normal hearing threshold (Yamada et al., 1983). For example, at 16 Hz, the deaf persons' average threshold was 128 dB sound pressure level, 40 dB higher than that of the hearing subjects. It has also been shown that, at higher frequencies, the body surface is very reflective of sound (Katz, 2000). Similarly, work on transmission of low frequency sound into the bodies of sheep has shown a loss of about 30 dB (Peters et al., 1993)

The visceral receptors invoked as a mechanism for VVVD have been shown to respond to static gravitational position changes, but not to vibration (that is why they are called graviceptors). If there were vibration-sensitive receptors in the abdominal viscera, they would be constantly barraged by low frequency body sounds such as pulsatile blood flow and bowel sounds, while external sounds would be attenuated by both the impedance mismatch and dissipation of energy in the overlying tissues. Finally, wind turbine sound at realistic distances possesses little, if any, acoustic energy, at 4 to 8 Hz.

It has been hypothesized that the vestibular labyrinth may be "abnormally stimulated" by wind turbine sound (Pierpont, 2009, pre-publication draft). As noted in earlier sections of this report, moderately loud airborne sound, at frequencies up to about 500 Hz, can indeed stimulate not only the cochlea (the hearing organ) but also the otolith organs. This is not abnormal, and there is no evidence in the medical literature that it is in any way unpleasant or harmful. In ordinary life, most of us are exposed for hours every day to sounds louder than those experienced at realistic distances from wind turbines, with no adverse effects. This assertion that the vestibular labyrinth is stimulated at levels below hearing threshold is based on a misunderstanding of research that used bone-conducted vibration rather than airborne sound. Indeed, those who wear bone conduction hearing aids experience constant stimulation of their vestibular systems, in addition to the cochlea, without adverse effects.

4.5 Interpreting Studies and Reports

In light of the unproven hypotheses that have been introduced as reflective of adverse health effects attributed to wind turbines, it can be instructive to review the type of research studies that can be used to determine definitive links between exposure to an environmental hazard (in this case, sound and vibration emissions from wind turbines) and adverse health effects (the so-called "wind turbine syndrome").

How do we know, for example, that cigarettes cause lung cancer and that excessive noise causes hearing loss? Almost always, the first indication that an exposure might be harmful comes from the informal observations of doctors who notice a possible correlation between an exposure and a disease, then communicate their findings to colleagues in case reports, or reports of groups of cases (*case series*). These initial observations are usually uncontrolled; that is, there is no comparison of the people who have both exposure and disease to control groups of people who are either non-exposed or disease-free. There is usually no way to be sure that the apparent association is statistically significant (as opposed to simple coincidence), or that there is a causal relationship between the exposure and the disease in question, without control subjects. For these reasons, case reports and case series cannot prove that an exposure is really harmful, but can only help to develop hypotheses that can then be tested in controlled studies (Levine et al., 1994; Genovese, 2004; McLaughlin, 2003).

Once suspicion of harm has been raised, controlled studies (case-control or cohort) are essential to determine whether or not a causal association is likely, and only after multiple independent-controlled studies show consistent results is the association likely to be broadly accepted (IARC, 2006).

Case-control studies compare people with the disease to people without the disease (ensuring as far as possible that the two groups are well-matched with respect to all other variables that might affect the chance of having the disease, such as age, sex, and other exposures known to cause the disease). If the disease group is found to be much more likely to have had the exposure in question, and if multiple types of error and bias can be excluded (Genovese, 2004), a causal link is likely. Multiple case-control studies were necessary before the link between smoking and lung cancer could be proved.

Cohort studies compare people with the exposure to well-matched control subjects who have not had that exposure. If the exposed group proves to be much more likely to have the disease, assuming error and bias can be excluded, a causal link is likely. After multiple cohort studies, it was clear that excessive noise exposure caused hearing loss (McCunney and Meyer, 2007).

In the case of wind turbine noise and its hypothetical relationships to "wind turbine syndrome" and vibroacoustic disease, the weakest type of evidence—case series—is available, from only a single investigator. These reports can do no more than suggest hypotheses for further research. Nevertheless, if additional and independent investigators begin to report adverse health effects in people exposed to wind turbine noise, in excess of those found in unexposed groups, and if some consistent syndrome or set of symptoms emerges, this advice could change. Thus, at this time, "wind turbine syndrome" and VVVD are unproven hypotheses (essentially unproven ideas) that have not been confirmed by appropriate research studies, most notably cohort and case control studies. However, the weakness of the basic hypotheses makes such studies unlikely to proceed.

4.6 Standards for Siting Wind Turbines

4.6.1 Introduction

While the use of large industrial-scale wind turbines is well established in Europe, the development of comparable wind energy facilities in North America is a more recent occurrence. The growth of wind and other renewable energy sources is expected to continue. Opponents of wind energy development argue that the height and setback regulations established in some jurisdictions are too lenient and that the noise limits which are applied to other sources of noise (either industrial or transportation) are not sufficient for wind turbines for a variety of reasons. Therefore, they are concerned that the health and well-being of some residents who live in the vicinity (or close proximity to) of these facilities is threatened. Critics maintain that wind turbine noise may present more than an annoyance to nearby residents especially at night when ambient levels may be low. Consequently, there are those who advocate for a revision of the existing regulations for noise and setback pertaining to the siting of wind installations (Kamperman and James, 2009). Some have indicated their belief that setbacks of more than 1 mile may be necessary. While the primary purpose of this study was to evaluate the potential for adverse health effects rather than develop public policy, the panel does not find that setbacks of 1 mile are warranted.

4.6.2 Noise Regulations and Ordinances

In 1974, EPA published a report that examined the levels of environmental noise necessary to protect public health and welfare (EPA, 1974). Based on the analysis of available scientific data, EPA specified a range of day-night sound levels necessary to protect the public health and welfare from the effects of environmental noise, with a reasonable margin of safety. Rather than establishing standards or regulations, however, EPA simply identified noise levels below which the general public would not be placed at risk from any of the identified effects of noise. Each federal agency has developed its own noise criteria for sources for which they have jurisdiction (i.e., the Federal Aviation Administration regulates aircraft and airport noise, the Federal Highway Administration regulates highway noise, and the Federal Energy Regulatory Commission regulates interstate pipelines (Bastasch, 2005). State and local governments were provided guidance by EPA on how to develop their own noise regulations, but the establishment of appropriate limits was left to local authorities to determine given each community's differing values and land use priorities (EPA, 1975).

4.6.3 Wind Turbine Siting Guidelines

Establishing appropriate noise limits and setback distances for wind turbines has been a concern of many who are interested in wind energy. There are several approaches to regulating noise, from any source, including wind turbines. They can generally be classified as absolute or relative standards or a combination of absolute and relative standards. Absolute standards establish a fixed limit irrespective of existing noise levels. For wind turbines, a single absolute limit may be established regardless of wind speed (i.e., 50 dBA) or different limits may be established for various wind speeds (i.e., 40 dBA at 5 meters per second [m/s] and 45 dBA at 8 m/s). The Ontario Ministry of Environment (2008) wind turbine noise guidelines is an example of fixed limits for each integer wind speed between 4 and 10 meters per second. Relative standards limit the increase over existing levels and may also establish either an absolute floor or ceiling beyond which the relative increase is not considered. That is, for example, if a relative increase of 10 dBA with a ceiling of 50 dBA is allowed and the existing level is 45 dBA, a level of 55 dBA would not be allowed. Similarly, if a floor of 40 dBA was established and the existing level is 25 dBA, 40 dBA rather than 35 dBA would be allowed. Fixed distance setbacks have also been discussed. Critics of this approach suggest that fixed setbacks do not take into account the number or size of the turbines nor do they consider other potential sources of noise within the project area. It is clear that like many other sources of noise, a uniform regulator approach for wind turbine noise has not been established either domestically or internationally.

A draft report titled *Environmental Noise and Health in the UK*, published for comment in 2009 by the Health Protection Agency (HPA) on behalf of an ad hoc expert group, provides insightful comments on the World Health Organization's noise guidelines (WHO, 1999). The HPA draft report can be viewed at the following address:

http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1246433634856

The HPA report states the following:

It is important to bear in mind that the WHO guideline values, like other WHO guidelines, are offered to policymakers as a contribution to policy development. They are not intended as standards in a formal sense but as a possible basis for the development of standards. By way of overall summary, the 1998 NPL report noted [a British report titled *Health-Based Noise Assessment Methods – A Review and Feasibility Study* (Porter et al., 1998) as quoted in HPA 2009]:

> *The WHO guidelines represent a consensus view of international expert opinion on the lowest noise levels below which the occurrence rates of particular effects can be assumed to be negligible. Exceedances of the WHO guideline values do not necessarily imply significant noise impact and indeed, it may be that significant impacts do not occur until much higher degrees of noise exposure are reached. The guidelines form a starting point for policy development. However, it will clearly be important to consider the costs and benefits of reducing noise levels and, as in other areas, this should inform the setting of objectives.*
> (From: HPA, 2009, p. 77)

The HPA report further states the following:

> *Surveys have shown that about half of the UK population lives in areas where daytime sound levels exceed those recommended in the WHO Community Noise Guidelines. About two-thirds of the population live in areas where the night-time guidelines recommended by WHO are exceeded. (p. 81)*
>
> *That sleep can be affected by noise is common knowledge. Defining a dose-response curve that describes the relationship between exposure to noise and sleep disturbance has, however, proved surprisingly difficult. Laboratory studies and field studies have generated different results. In part this is due to habituation to noise which, in the field, is common in many people. (p. 82)*
>
> *Our examination of the evidence relating to the effects of environmental noise on health has demonstrated that this is a rapidly developing area. Any single report will, therefore, need to be revised within a few years. We conclude and recommend that an*

independent expert committee to address these issues on a long-term basis be established. (p. 82)

The statements cited above from the HPA and WHO documents address general environmental noise concerns rather than concerns focused solely on wind turbine noise.

SECTION 5

Conclusions

Many countries have turned to wind energy as a key strategy to generate power in an environmentally clean manner. Wind energy enjoys considerable public support, but it has its detractors, who have publicized their concerns that the sounds emitted from wind turbines cause adverse health consequences.

The objective of the panel was to develop an authoritative reference document for the use of legislators, regulators, and citizens simply wanting to make sense of the conflicting information about wind turbine sound. To this end, the panel undertook extensive review, analysis, and discussion of the peer-reviewed literature on wind turbine sound and possible health effects. The varied professional backgrounds of panel members (audiology, acoustics, otolaryngology, occupational and environmental medicine, and public health) were highly advantageous in creating a diversity of informed perspectives. Participants were able to examine issues surrounding health effects and discuss plausible biological effects with considerable combined expertise.

Following review, analysis, and discussion, the panel reached agreement on three key points:

- There is nothing unique about the sounds and vibrations emitted by wind turbines.
- The body of accumulated knowledge about sound and health is substantial.
- The body of accumulated knowledge provides no evidence that the audible or subaudible sounds emitted by wind turbines have any direct adverse physiological effects.

The panel appreciated the complexities involved in the varied human reactions to sound, particularly sounds that modulate in intensity or frequency. Most complaints about wind turbine sound relate to the aerodynamic sound component (the swish sound) produced by the turbine blades. The sound levels are similar to the ambient noise levels in urban environments. A small minority of those exposed report annoyance and stress associated with noise perception.

This report summarizes a number of physical and psychological variables that may influence adverse reactions. In particular, the panel considered "wind turbine syndrome" and vibroacoustic disease, which have been claimed as causes of adverse health effects. The evidence indicates that "wind turbine syndrome" is based on misinterpretation of physiologic data and that the features of the so-called syndrome are merely a subset of annoyance reactions. The evidence for vibroacoustic disease (tissue inflammation and fibrosis associated with sound exposure) is extremely dubious at levels of sound associated with wind turbines.

The panel also considered the quality of epidemiologic evidence required to prove harm. In epidemiology, initial case reports and uncontrolled observations of disease associations

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need to be confirmed through controlled studies with case-control or cohort methodology before they can be accepted as reflective of casual connections between wind turbine sound and health effects. In the area of wind turbine health effects, no case-control or cohort studies have been conducted as of this date. Accordingly, allegations of adverse health effects from wind turbines are as yet unproven. Panel members agree that the number and uncontrolled nature of existing case reports of adverse health effects alleged to be associated with wind turbines are insufficient to advocate for funding further studies.

In conclusion:

1. Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effect in humans.
2. Subaudible, low frequency sound and infrasound from wind turbines do not present a risk to human health.
3. Some people may be annoyed at the presence of sound from wind turbines. Annoyance is not a pathological entity.
4. A major cause of concern about wind turbine sound is its fluctuating nature. Some may find this sound annoying, a reaction that depends primarily on personal characteristics as opposed to the intensity of the sound level.

SECTION 6

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APPENDIX A

Fundamentals of Sound

APPENDIX A

Fundamentals of Sound

The following appendix provides additional background information on sound and how it is defined.

One atmospheric pressure is given by 100,000 pascals (Pa), where one pascal is one Newton per square meter (N/m^2), and a sound pressure of 94 dB re 20μPa is given by 1 Pa (See later for decibels). The frequency of the fluctuations may be between 20 times a second (20 Hz), and up to 20,000 times a second (20,000 Hz) for the "audible" noise. Frequencies below 20 Hz are commonly called "infrasound," although there is a very fuzzy boundary between infrasound and low frequency noise. Infrasound at high levels is audible. Low frequency noise might be from about 10 Hz to about 200 Hz.

In addition to frequency, the quantities which define a sound wave include:

- Pressure, P
- Wavelength, λ
- Velocity, c = 340m/s approx, depending on temperature

The velocity and wavelength are related by: velocity = wavelength x frequency,

Relating frequency and wavelength by velocity gives

Freq Hz	16	31.5	63	125	250	500	1000	2000	4000
Wavelength m	21	11	5.4	2.7	1.4	0.68	0.34	0.17	0.085

Low frequencies have long wavelengths. It is useful to develop an appreciation of frequencies and related wavelengths, since this helps an understanding of noise propagation and control.

Sound pressure in a wave is force per unit of area of the wave and has units of N/m^2, which is abbreviated to Pa. The sound pressure fluctuates above and below atmospheric pressure by a very small amount.

The sound power is a characteristic of the source, and is its rate of production of energy, expressed in watts. The sound power is the fundamental property of the source, whilst the sound pressure at a measurement location depends on the transmission path from source to receiver. Most sound sources, including wind turbines, are specified in terms of their sound power. The sound power of a wind turbine is typically in the 100-105 dBA range, which is similar to that of a leaf blower. The sound power is used to predict propagation of the sound, where the source is assumed to be at the hub.

Sound Levels

The decibel is the logarithm of the ratio between two values of a quantity such as power, pressure or intensity, with a multiplying constant to give convenient numerical factors. Logarithms are useful for compressing a wide range of quantities into a smaller range. For example:

$\log_{10}10 = 1$
$\log_{10}100 = 2$
$\log_{10}1000 = 3$

The ratio of 1000:10 is compressed into a ratio of 3:1.

This approach is advantageous for handling sound levels, where the ratio of the highest to the lowest sound which we are likely to encounter is as high as 1,000,000 to 1. A useful development, many years ago, was to take the ratios with respect to the quietest sound which we can hear. This is the threshold of hearing at 1,000 Hz, which is 20 microPascals (μPa) (2×10^{-5}Pa) of pressure for the average young healthy person. Sound powers in decibels are taken with respect to a reference level of 10^{-12} watts.

When the word "level" is added to the word for a physical quantity, decibel levels are implied, denoted by L_X, where $_X$ is the symbol for the quantity.

$$\text{Pressure level} \quad L_p = 20\log_{10}\left[\frac{P}{P_0}\right] \text{ dB}$$

where P is the measured pressure and P_0 is the reference pressure level of 2×10^{-5} Pa

A little calculation allows us to express the sound pressure level at a distance from a source of known sound power level as

Sound pressure level, $L_P = L_W - 20\log[r] - 11$ dB

Where L_p is the sound pressure level
L_w is the sound power level of the source
r is the distance from the source

This is the basic equation for spherical sound propagation. It is used in prediction of wind turbine sound but, in a real calculation, has many additions to it, to take into account the atmospheric, ground and topographic conditions. However, as a simple calculation, the sound level at a distance of 500m from a source of sound power 100 dBA is 35 dBA.

Equivalent level (Leq): This is a steady level over a period of time, which has the same energy as that of the fluctuating level actually occurring during that time. A-weighted equivalent level, designated LAeq, is used for many legislative purposes, including for assessment of wind turbine sound.

Percentiles (LN)L These are a statistical measure of the fluctuations in overall noise level, that is, in the envelope of the noise, which is usually sampled a number of times per second, typically ten times. The most used percentiles are L90 and L10. The L90 is the level exceeded for 90 percent of the time and represents a low level in the noise. It is often used to assess background noise. The L10 is the level exceeded for 10 percent of the time and is a measure of the higher levels in a noise. Modern computing sound level meters give a range of percentiles. Note that the percentile is a statistical measure over a specified time interval.

Frequency Analysis

This gives more detail of the frequency components of a noise. Frequency analysis normally uses one of three approaches: octave band, one-third octave band or narrow band.

Narrow band analysis is most useful for complex tonal noises. It could be used, for example, to determine a fan tone frequency, to find the frequencies of vibration transmission from machinery or to detect system resonances. All analyses require an averaging over time, so that the detail of fluctuations in the noise is normally lost.

Criteria for assessment of noise are based on dBA, octave bands, or 1/3-octave band measurements. These measures clearly give increasingly detailed information about the noise.

APPENDIX B

The Human Ear

APPENDIX B

The Human Ear

Humans have ears with three general regions:

1. An *outer ear*, including an ear (auditory) canal
2. An air-containing *middle ear* that includes an eardrum and small bones called ossicles (three in mammals, one in other animals)
3. An *inner ear* that includes organs of hearing (in mammals, this is the organ of Corti in the cochlea) and balance (vestibular labyrinth)

Airborne sound passes thorough the ear canal, making the eardrum and ossicles vibrate, and this vibration then sets the fluids of the cochlea into motion. Specialized "hair cells" convert this fluid movement into nerve impulses that travel to the brain along the auditory nerve. The hair cells, nerve cells, and other cells in the cochlea can be damaged by excessive noise, trauma, toxins, ear diseases, and as part of the aging process. Damage to the cochlea causes "sensorineural hearing loss," the most common type of hearing loss in the United States.

It is essential to understand the role of the middle ear, as well as the difference between air conduction and bone conduction. The middle ear performs the essential task of converting airborne sound into inner ear fluid movement, a process known as impedance matching (air is a low-impedance medium, meaning that its molecules move easily in response to sound pressure, while water is a high-impedance medium). Without impedance matching, over 99.9 percent of airborne sound energy is reflected away from the body. The middle ear enables animals living in air to hear very soft sounds that would otherwise be inaudible, but it is unnecessary for animals that live in water, because sound traveling in water passes easily into the body (which is mostly water). When a child has an ear infection, or an adult places earplugs in his ears, a "conductive hearing loss" dramatically reduces the transmission of airborne sound into the inner ear. People with conductive hearing loss can still hear sounds presented directly to the skull by "bone conduction." This is how both humans and fishes hear underwater or when a vibrating tuning fork is applied to the head, but it requires much more acoustic energy than air conduction hearing.

APPENDIX C

Measuring Sound

APPENDIX C

Measuring Sound

A sound level meter is the standard way of measuring sound. Environmental sound is normally assessed by the A-weighting. Although hand-held instruments appear to be easy to use, lack of understanding of their operation and limitations, and the meaning of the varied measurements which they can give, may result in misleading readings.

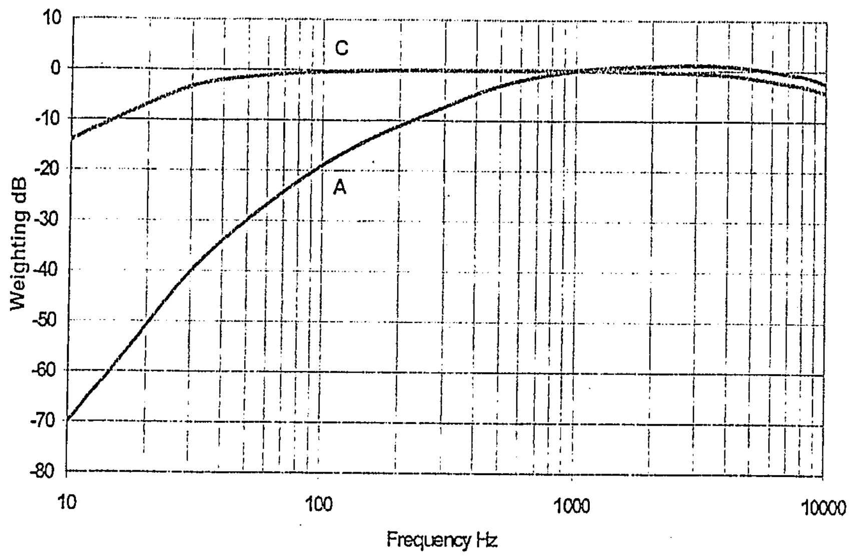
The weighting network and electrical filters are an important part of the sound level meter, as they give an indication of the frequency components of the sound. The filters are as follows:

- A-weighting: on all meters
- C-weighting: on most meters
- Linear (Z-weighting): on many meters
- Octave filters: on some meters
- Third octave filters: on some meters
- Narrow band: on a few meters

Sound level meter weighting networks are shown in Figure C-1. Originally, the A-weighting was intended for low levels of noise. C-weighting was intended for higher levels of noise. The weighting networks were based on human hearing contours at low and high levels and it was hoped that their use would mimic the response of the ear. This concept, which did not work out in practice, has now been abandoned and A- and C-weighting are used at all levels. Linear weighting is used to detect low frequencies. A specialist G-weighting is used for infrasound below 20 Hz.

Figure C-1 shows that the A-weighting depresses the levels of the low frequencies, as the ear is less sensitive to these. There is general consensus that A-weighting is appropriate for estimation of the hazard of NIHL. With respect to other effects, such as annoyance, A-weighting is acceptable if there is largely middle and high frequency noise present, but if the noise is unusually high at low frequencies, or contains prominent low frequency tones, the A-weighting may not give a valid measure. Compared with other noise sources, wind turbine spectra, as heard indoors at typical separation distances, have less low frequency content than most other sources (Pedersen, 2008).

FIGURE C-1
Weighting Networks



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APPENDIX D

Propagation of Sound

APPENDIX D

Propagation of Sound

The propagation of noise from wind turbines is determined by a number of factors, including:

- Geometrical spreading, given by K = 20log[r] –11 dB, at a distance r
- Molecular absorption. This is conversion of acoustic energy to heat and is frequency dependent
- Turbulent scattering from local variations in wind velocity and air temperature and is moderately frequency dependent
- Ground effects – reflection, topography and absorption are frequency dependent; their effects increasing as the frequency increases
- Near surface effects – temperature and wind gradients.

The sound pressure at a point, distant from source, is given by

$$L_P = L_W - K - D - A_A - A_G \qquad \text{(dB)}$$

In which:

L_P is the sound pressure at the receiving point

L_W is the sound power of the turbine in decibels re 10^{-12} watts

K is the geometrical spreading term, which is inherent in all sources

D is a directivity index, which takes non-uniform spreading into account

A_A is an atmospheric absorption and other near surface effects term

A_G is a ground absorption and other surface effects term

Near surface meteorological effects are complex, as wind and temperature gradients affect propagation through the air.

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APPENDIX E

Expert Panel Members

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Expert Panel Members

Members of the expert panel are listed below. Biographies of each member are provided following the list.

Expert Panel Members

W. David Colby, M.D.

Chatham-Kent Medical Officer of Health (Acting)
Associate Professor, Schulich School of Medicine & Dentistry, University of Western Ontario

Robert Dobie, M.D.

Clinical Professor, University of Texas, San Antonio
Clinical Professor, University of California, Davis

Geoff Leventhall, Ph.D.

Consultant in Noise Vibration and Acoustics, UK

David M. Lipscomb, Ph.D.

President, Correct Service, Inc.

Robert J. McCunney, M.D.

Research Scientist, Massachusetts Institute of Technology Department of Biological Engineering,
Staff Physician, Massachusetts General Hospital Pulmonary Division; Harvard Medical School

Michael T. Seilo, Ph.D.

Professor of Audiology, Western Washington University

Bo Søndergaard, M.Sc. (Physics)

Senior Consultant, Danish Electronics Light and Acoustics (DELTA)

Technical Advisor

Mark Bastasch

Acoustical Engineer, CH2M HILL

Panel Member Biographies

W. David Colby, M.D.

W. David Colby M.Sc., M.D., FRCPC, is a fellow of the Royal College of Physicians and Surgeons of Canada in Medical Microbiology. Dr Colby is the Acting Medical Officer of Health in Chatham-Kent, Ontario and Associate Professor of Medicine, Microbiology/Immunology and Physiology/Pharmacology at the Schulich School of Medicine and Dentistry at the University of Western Ontario. He received his M.D. from the University of Toronto and completed his residency at University Hospital, London, Ontario. While still a resident he was given a faculty appointment and later was appointed Chief of Microbiology and Consultant in Infectious Diseases at University Hospital. Dr Colby lectures extensively on antimicrobial chemotherapy, resistance and fungal infections in addition to a busy clinical practice in Travel Medicine and is a Coroner for the province of Ontario. He has received numerous awards for his teaching. Dr. Colby has a number of articles in peer-reviewed journals and is the author of the textbook *Optimizing Antimicrobial Therapy: A Pharmacometric Approach.* He is a Past President of the Canadian Association of Medical Microbiologists. On the basis of his expertise in Public Health, Dr Colby was asked by his municipality to assess the health impacts of wind turbines. The report, titled *The Health Impact of Wind Turbines: A Review of the Current White,Grey, and Published Literature* is widely cited internationally.

Robert Dobie, M.D.

Robert Dobie, M.D., is clinical professor of otolaryngology at both the University of Texas Health Science Center at San Antonio and the University of California-Davis. He is also a partner in Dobie Associates, a consulting practice specializing in hearing and balance, hearing conservation, and ear disorders. The author of over 175 publications, his research interests include age-related and noise-induced hearing loss, as well as tinnitus and other inner ear disorders. He is past president of the Association for Research in Otolaryngology, past chair of the Hearing and Equilibrium Committee of the American Academy of Otolaryngology-Head and Neck Surgery, and has served on the boards and councils of many other professional organizations and scholarly journals.

Geoff Leventhall, Ph.D.

Geoff is a UK-based noise and vibration consultant who works internationally. His academic and professional qualifications include Ph.D. in Acoustics, Fellow of the UK Institute of Physics, Honorary Fellow of the UK institute of Acoustics (of which he is a former President), Distinguished International Member of the USA Institute of Noise Control Engineering, Member of the Acoustical Society of America.

He was formerly an academic, during which time he supervised 30 research students to completion of their doctoral studies in acoustics. Much of his academic and consultancy work has been on problems of infrasound and low frequency noise and control of low frequency noise by active attenuation

He has been a member of a number of National and International committees on noise and acoustics and was recently a member of two committees producing reports on effects of noise on health: the UK Health Protection Agency Committee on the Health Effects of

Ultrasound and Infrasound and the UK Department of Health Committee on the Effects of Environmental Noise on Health.

David M. Lipscomb, Ph.D.

Dr. David M. Lipscomb received a Ph. D. in Hearing Science from the University of Washington (Seattle) in 1966. Dr. Lipscomb taught at the University of Tennessee for more than two decades in the Department of Audiology and Speech Pathology. While he was on the faculty, Dr. Lipscomb developed and directed the department's Noise Research Laboratory. During his tenure at Tennessee and after he moved to the Pacific Northwest in 1988, Dr. Lipscomb has served as a consultant to many entities including communities, governmental agencies, industries, and legal organizations.

Dr. Lipscomb has qualified in courts of law as an expert in Audiology since 1966. Currently, he investigates incidents to determine whether an acoustical warning signal provided warning to individuals in harms way, and, if so, at how many seconds before an incident. With his background in clinical and research audiology, he undertakes the evaluation of hearing impairment claims for industrial settings and product liability.

Dr. Lipscomb was a bioacoustical consultant to the U. S. Environmental Protection Agency Office of Noise Abatement and Control (ONAC) at the time the agency was responding to Congressional mandates contained in the Noise Control Act of 1972. He was one of the original authors of the Criteria Document produced by ONAC, and he served as a reviewer for the ONAC document titled *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*. Dr. Lipscomb's experience in writing and reviewing bioacoustical documentation has been particularly useful in his review of materials for AWEA regarding wind farm noise concerns.

Robert J. McCunney, M.D.

Robert J. McCunney, M.D., M.P.H., M.S., is board certified by the American Board of Preventive Medicine as a specialist in occupational and environmental medicine. Dr. McCunney is a staff physician at Massachusetts General Hospital's pulmonary division, where he evaluates and treats occupational and environmental illnesses, including lung disorders ranging from asbestosis to asthma to mold related health concerns, among others. He is also a clinical faculty member of Harvard Medical School and a research scientist at the Massachusetts Institute of Technology Department of Biological Engineering, where he participates in epidemiological research pertaining to occupational and environmental health hazards.

Dr. McCunney received his B.S. in chemical engineering from Drexel University, his M.S. in environmental health from the University of Minnesota, his M.D. from the Thomas Jefferson University Medical School and his M.P.H. from the Harvard School of Public Health. He completed training in internal medicine at Northwestern University Medical Center in Chicago. Dr. McCunney is past president of the American College of Occupational and Environmental Medicine (ACOEM) and an accomplished author. He has edited numerous occupational and environmental medicine textbooks and over 80 published articles and book chapters. He is the Editor of all three editions of the text book, *A Practical Approach to Occupational and Environmental Medicine*, the most recent edition of which was published in 2003. Dr. McCunney received the Health Achievement Award from ACOEM in 2004.

Dr. McCunney has extensive experience in evaluating the effects of noise on hearing via reviewing audiometric tests. He has written book chapters on the topic and regularly lectures at the Harvard School of Public Health on "Noise and Health."

Michael T. Seilo, Ph.D.

Dr. Michael T. Seilo received his Ph.D. in Audiology from Ohio University in 1970. He is currently a professor of audiology in the Department of Communication Sciences and Disorders at Western Washington University in Bellingham, Washington where he served as department chair for a total of more than twenty years. Dr. Seilo is clinically certified by the American Speech-Language-Hearing Association (ASHA) in both audiology and speech-language pathology and is a long-time member of ASHA, the American Academy of Audiology, and the Washington Speech and Hearing Association.

For many years Dr. Seilo has taught courses in hearing conservation at both the graduate and undergraduate level. His special interest areas include speech perception and the impact of noise on human hearing sensitivity including tinnitus.

Dr. Seilo has consulted with industries on the prevention of NIHL and he has collaborated with other professionals in the assessment of hearing-loss related claims pertaining to noise.

Bo Søndergaard, M.Sc. (Physics)

Bo Søndergaard has more than 20 years of experience in consultancy in environmental noise measurements, predictions and assessment. The last 15 years with an emphasis on wind turbine noise. Mr. Søndergaard is the convenor of the MT11 work group under IEC TC88 working with revision of the measurement standard for wind turbines IEC 61400-11. He has also worked as project manager for the following research projects: Low Frequency Noise from Large Wind Turbines for the Danish Energy Authority, Noise and Energy optimization of Wind Farms, and Noise from Wind Turbines in Wake for Energinet.dk.

Technical Advisor Biography

Mark Bastasch

Mr. Bastasch is a registered acoustical engineer with CH2M HILL. Mr. Bastasch assisted AWEA and CanWEA in the establishment of the panel and provided technical assistance to the panel throughout the review process. Mr. Bastasch's acoustical experience includes preliminary siting studies, regulatory development and assessments, ambient noise measurements, industrial measurements for model development and compliance purposes, mitigation analysis, and modeling of industrial and transportation noise. His wind turbine experience includes some of the first major wind developments including the Stateline project, which when built in 2001 was the largest in the world. He also serves on the organizing committee of the biannual International Wind Turbine Noise Conference, first held in Berlin, Germany, in 2005.

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We acknowledge the following person for suggestions and comments on the manuscript. The final responsibility for the content remains with the authors.

Richard K. Jennings, M.D. —Psychiatrist, Retired

03002388

epilepsy action

Wind turbines

April 2008

Background

Epilepsy Action carried out a survey in late 2007 to find out whether wind turbines had triggered seizures in people with epilepsy.

A number of people with epilepsy had reported to Professor Graham Harding, a leading expert in the field of photosensitive epilepsy, that they had been affected when looking at wind turbines. These reports ranged from feeling uncomfortable and unwell to concerns over the installation of wind turbines on people known to have photosensitive epilepsy.

Epilepsy Action, in conjunction with Professor Harding, decided to seek further information about whether there may be an issue for people with epilepsy.

Survey

Epilepsy Action, in partnership with Professor Harding, designed an online survey which asked people various questions about whether they had been affected by wind turbines.

The survey was available on Epilepsy Action's website home page for one month when over 115,000 people visited the website. It was also advertised through Epilepsy Action's newsletters and online community.

Results

Twenty six people responded to the survey and only one of them reported that they had had a seizure whilst looking at a wind turbine. However as this person also told us that they did not have photosensitive epilepsy it is difficult to conclude whether or not the seizure was actually caused by the wind turbine.

A typical Epilepsy Action survey on our home page for this period would probably receive several hundred responses.

In addition Epilepsy Action's helpline receives around 20,000 calls a year from people with epilepsy. We have never received a call from anyone who believes they have had a seizure as a result of a wind turbine.

Theory

A paper has recently been published in Epilepsia, a leading epilepsy peer reviewed journal, looking at the theoretical risks of wind turbines [1 [1]].

Position

Epilepsy Action does not challenge the theory that wind turbines may create circumstances where photosensitive seizures can be triggered. However from our experience and that of our members and website users it does appear that this risk is minimal.

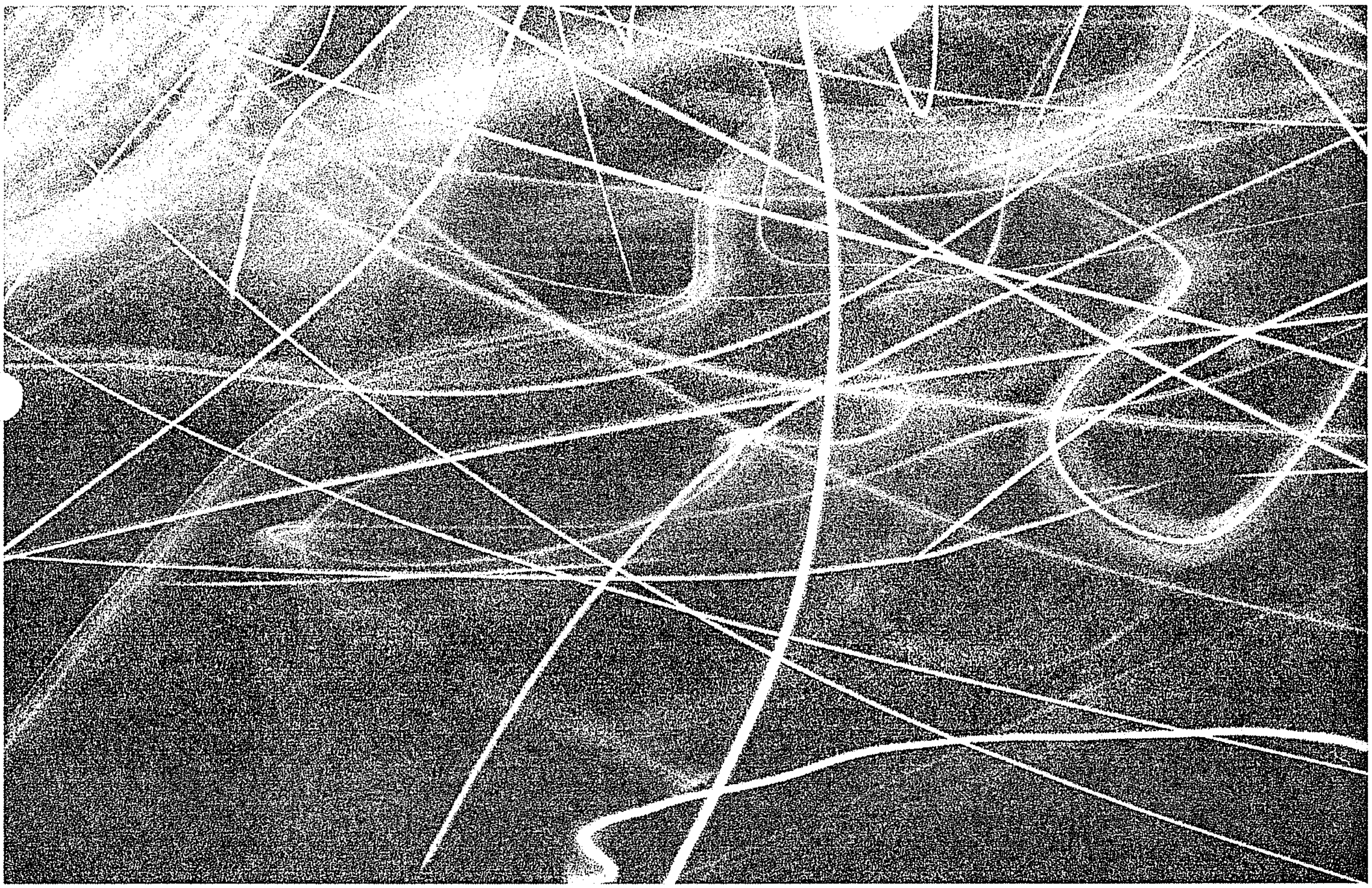
[1] Graham Harding, Pamela Harding, Arnold Wilkins (2008)
Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them
doi:10.1111/j.1528-1167.2008.01563.x [2]

Links:
[1] http://www.epilepsy.org.uk/book/export/html/1391#1
[2] http://www.blackwell-synergy.com/doi/abs/10.1111/j.1528-1167.2008.01563.x

epilepsy action

www.epilepsy.org.uk
Epilepsy Helpline: 0808 800 5050

Photosensitive epilepsy



epilepsy

Epilepsy Action aims to improve the quality of life and promote the interests of people living with epilepsy.

Our work...

- We provide information to anyone with an interest in epilepsy.
- We improve the understanding of epilepsy in schools and raise educational standards.
- We work to give people with epilepsy a fair chance of finding and keeping a job.
- We raise standards of care through contact with doctors, nurses, social workers, government and other organisations.
- We promote equality of access to quality care.

Epilepsy Action has local branches in most parts of the UK. Each branch offers support to local people and raises money to help ensure our work can continue.

Join us...

You can help us in our vital work by becoming a member. All members receive our magazine *Epilepsy Today*, free cover under our unique personal accident insurance scheme and access to our services and conferences.

Introduction

Photosensitive epilepsy is the name given to epilepsy in which all, or almost all, seizures are provoked by flashing or flickering light, or some shapes or patterns. Both natural and artificial light may trigger seizures. Various types of seizure may be triggered by flickering light.

Many people think that everybody with epilepsy is photosensitive, but in fact only five in every hundred people with epilepsy are. Photosensitive epilepsy usually begins before the age of 20 years, although it is most common between the ages of seven and 19. Photosensitivity tends to affect girls more than boys. There is also evidence that photosensitive epilepsy can be passed on through the genes.

Diagnosing photosensitive epilepsy

One investigation that is carried out to diagnose epilepsy is an electroencephalogram, or EEG. The EEG records brainwave patterns from the continuous tiny electrical signals coming from the brain. During one part of the EEG, you are asked to look at flashing lights, to see if this triggers epileptic activity in the brain. If it does, then this may indicate that you have photosensitive epilepsy.

Hertz

The word hertz (Hz) refers to how often something happens in a given time. In photosensitive epilepsy, hertz (Hz) refers to the number of flashes or flickers a second. When talking about televisions or computer screens, hertz refers to the rate the scanning lines 'refresh' themselves.

Most people with photosensitive epilepsy are sensitive to 16-25 Hz, although some people may be sensitive to rates as low as 3 Hz and as high as 60 Hz.

Television

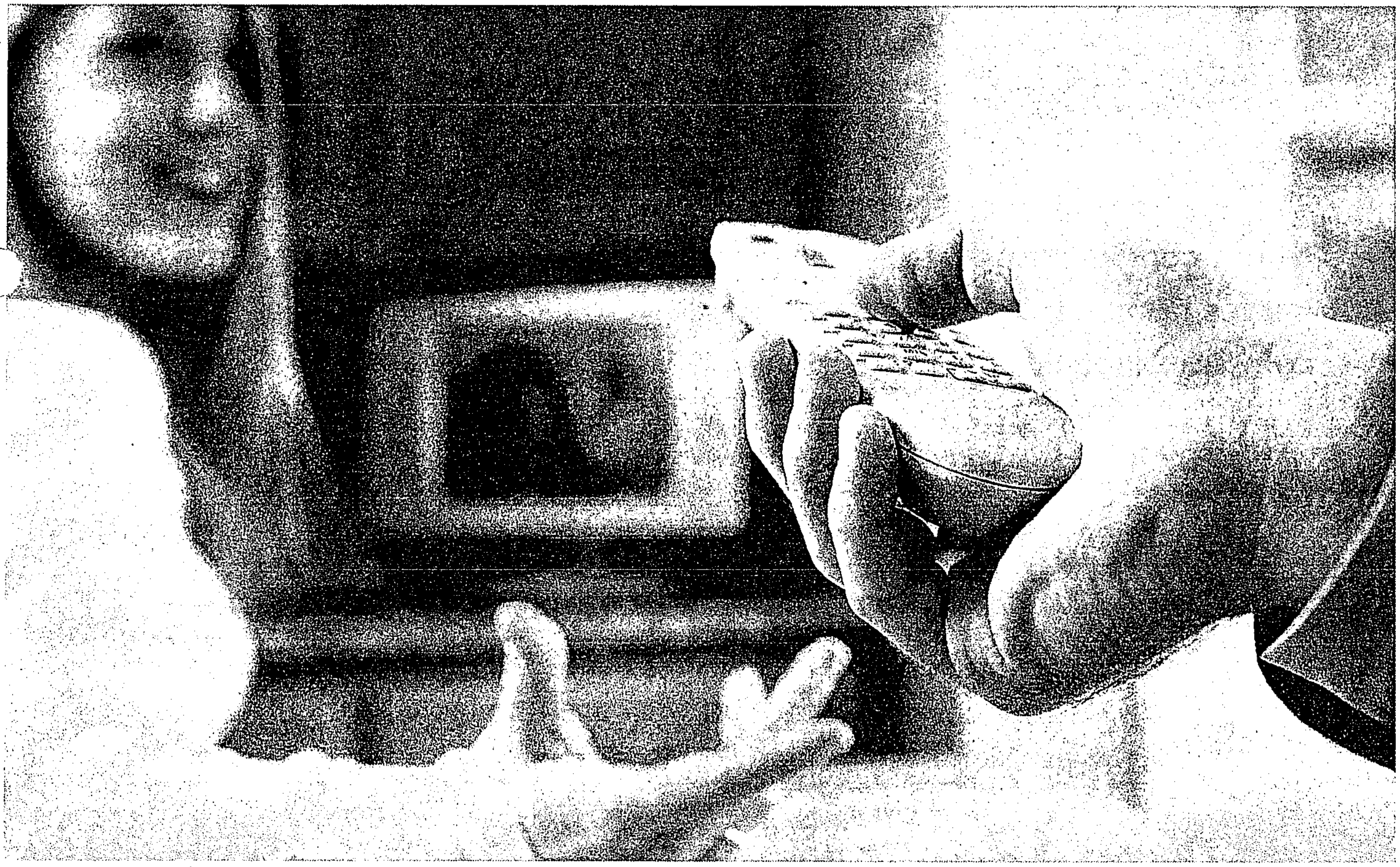
Watching television is a common trigger for photosensitive seizures. The nearer you are to the screen the more likely it is to trigger a seizure. This is because a larger area of your eye's retina is stimulated by the flicker of the picture, increasing the risk of a seizure. If you sit close to the screen you can see the 25 Hz flicker of the lines as well as the 50 Hz mains flicker on the screen as a whole. It is common for people with photosensitive epilepsy to be sensitive to 25 Hz, so it makes sense to sit well back from the television to reduce the risk of seizures.

The pictures shown on the screen can also make seizures more likely to occur. For example, if there is a particular combination of colour and flicker, or where there are many press photographers using flash photography all at the same time.

New types of television

100 Hz televisions

100 Hz televisions are unlikely to trigger seizures in people with photosensitive epilepsy.



Plasma or liquid crystal display (LCD) televisions

Plasma and LCD screens do not use the scanning lines of other televisions and are therefore less likely to trigger seizures. However, plasma screens tend to be brighter, with high contrast. This could make seizures more likely for some people with photosensitive epilepsy. If you are choosing between these types of screens, and you have photosensitive epilepsy, the current advice is to buy an LCD.

Precautions when watching television

- Watch the television in a well-lit room.
- Have a small, lit lamp on top of, or close to the television.
- Don't sit too close to the television. Watch from a distance of at least 2.5 metres (8 feet).
- Use the remote control wherever possible – from a safe distance - to adjust the television or to change channels.
- If you have to go near the television, cover one of your eyes with the palm of your hand. This will cut down the number of brain cells that are stimulated by any flicker on the screen.

Computer monitors

Many people think that people with photosensitive epilepsy are not able to use computers, because they will trigger a seizure. Although some images being displayed on the screen could be a problem, using a computer in itself is extremely unlikely to trigger a seizure.

Types of monitors

Cathode ray tube (CRT)

These are the traditional, large monitors. CRTs have scan frequencies of 70 Hz and above. As most people with photosensitive epilepsy are sensitive to 16-25 Hz, CRTs, provided they are not faulty, are unlikely to trigger seizures.

Liquid crystal display (LCD) – also known as thin film transistor (TFT)

These thin, flat, screens are flicker free. This means they are unlikely to trigger seizures.

Risk from material displayed on computer monitors

If the material contains flashing, flickering or repetitive patterns, it will carry the same risk, whether it is viewed on a CRT monitor or an LCD monitor. Images displayed on LCDs are sharper and brighter than on CRTs. Some people are sensitive to patterns with a high contrast. Where these appear on an LCD screen, the brightness and sharpness of the screen may increase the risk to people with photosensitive epilepsy.

Anti-glare screens

Anti-glare screens can be of help in reducing glare. However, they do not reduce the flicker rate and are therefore of no specific benefit to people with photosensitive epilepsy.

Interactive whiteboards

Interactive whiteboards do not flicker, so are not likely to trigger seizures. However, there could be a risk to people with photosensitive epilepsy if the images shown on the whiteboard contain high contrast patterns or flashing or flickering at the frequencies known to trigger seizures.

Video games

Although some video games may be quite safe to play, others could present some risk if you have photosensitive epilepsy. There are things you can do to minimise the risk of video games triggering seizures.

- If you are using a television rather than a computer monitor, follow the precautions for watching television (see page 5), as well as those below.
- Before playing, check to see if there are any warnings that come with the game. Most games manufacturers, but not all, follow the Office of Communications (Ofcom) television guidelines. Some put a warning on the packaging while others put it on the instructions inside.
- Avoid playing when tired as tiredness/lack of sleep may increase the risk of a seizure.
- Take frequent breaks for rest and food between playing games.
- Play video games in well-lit areas.
- Sit as far back from the monitor as possible.
- If possible, use an LCD/TFT monitor, but remember to reduce the brightness of the screen to reduce the contrast.
- For most people, covering one eye while playing will reduce the effect of any flickering on the screen. You should cover your eye, not simply close it.
- If your child has photosensitive epilepsy, you may wish to keep a close eye on them when they are playing video games. If they show any signs of distress or discomfort such as dizziness, blurred vision, loss of awareness or muscle twitching, you should immediately stop them playing the video game.

Patterns

Some non-moving patterns with high contrast may trigger seizures in some people with photosensitive epilepsy. Examples of high contrast patterns are black and white stripes, some patterned materials and wallpapers, and sunlight through slatted blinds.

Strobe lighting

Although the flash rate of strobe lights is restricted to four flashes a second by the Health and Safety Executive, some people with photosensitive epilepsy may still find strobe lights could trigger a seizure. You may therefore wish to avoid night clubs or discos with strobe lights and other places where you could come across strobe lights (for example some theme park attractions). If strobe lighting, or other flashing or flickering lights come on without warning, you should immediately cover one eye with the palm of your hand and turn away from the light.

Fluorescent lighting

Although some people find fluorescent lighting uncomfortable, the flicker rate (100 Hz) means it should not be a problem for most people. The flicker of a faulty fluorescent light, however, could trigger a seizure in people with photosensitive epilepsy.

Sunlight

Sunlight in itself is unlikely to trigger seizures. However, sunlight reflected off wet surfaces, seen through leaves of trees, or when walking quickly past railings where the sun is shining through, could trigger seizures in people with photosensitive epilepsy.

Polarised sunglasses

Polarised lenses work by removing reflected horizontal light. Wearing polarised sunglasses out of doors on sunny days, therefore, can help to minimise the risk of seizures occurring, although it will not remove it entirely. Your optician or retailer should be able to tell you which of the sunglasses they stock have polarised lenses.

Ceiling fans

Light seen through a fast-rotating ceiling fan could trigger seizures in some people with photosensitive epilepsy. Therefore, one with a slow rotating motion is advisable.

Flashing bicycle lights

There have been cases where red flashing lights (red light emitting diodes) on the back of bicycles have triggered seizures in people with photosensitive epilepsy, when they have been close to the lights as they were setting them up. If you have photosensitive epilepsy you may wish to avoid being close to these types of lights.

Flashing Christmas tree lights

These lights should comply with health and safety regulations before going on sale. The lights should not, therefore, flicker at a rate which could trigger seizures in the vast majority of people with photosensitive epilepsy.

Sun beds

These should not trigger seizures, unless it is possible to see a flicker, similar to one you might see with faulty fluorescent tubes.

Wind farms

There is no evidence that wind turbines can trigger seizures. The flicker frequency of wind turbines should be limited to 3 Hz. Newer wind turbines are usually built to operate at a frequency of 1 Hz or less.

If you have concerns about a planned or existing wind farm, you may wish to contact the British Wind Energy Association (BWEA), who can provide contact details of specific wind farm operators. (See 'Useful information and contacts' section at end.)

Useful information and contacts

- British Wind Energy Association, Renewable Energy House, 1 Aztec Row, Berners Road, London, N1 0PW. Telephone: 020 7689 1960 www.bwea.com; enquiries via email – info@bwea.com

- Health & Safety Executive guide on disco lights and flicker sensitive epilepsy can be found at: www.hse.gov.uk/lau/lacs/51-1.htm Helpline: 0845 345 0055

- Ofcom guidelines are available from Office of Communications (Ofcom), Riverside House, 2a Southwark Bridge Road, London, SE1 9HA. Telephone: 020 7981 3000 www.ofcom.org.uk

Acknowledgments

This booklet is based on the previous publication, Photosensitive Epilepsy, by Professor G F A Harding, formerly of Aston University, England. Epilepsy Action is most grateful for his help and support. Epilepsy Action is also grateful to Professor Stefano Seri, of Aston University and the Birmingham Children's Hospital NHS Foundation Trust, for providing information included in this booklet.

Epilepsy Services, Epilepsy Action, August 2007

Further information

If you have any questions about epilepsy, please contact the Epilepsy Helpline, freephone 0808 800 5050 or email helpline@epilepsy.org.uk. Or visit our website www.epilepsy.org.uk.

Epilepsy Action has a wide range of publications about many different aspects of epilepsy. Please contact the Epilepsy Helpline to request your free information catalogue.

Information is available in the following formats: booklets, factsheets, posters, books, videos, DVDs and CDs.

Information is also available in Braille and large text.

Epilepsy Action's support services

Local meetings: around 100 local branches offer support across England, Northern Ireland and Wales.

Volunteers: these are local people (usually with epilepsy or with a family member who has epilepsy) who have been specially trained by Epilepsy Action to give advice on a one-to-one basis. They can also give presentations about epilepsy to groups of people.

Forum4e: our online community provides an opportunity to contact other people with epilepsy from all over the world, in a safe and secure website: www.forum4e.com. (For ages 16 years and over.)

Live online advice: we run regular advice forums, where trained advisers answer your epilepsy questions live on our website. For more details, visit www.epilepsy.org.uk/liveadvice.

If you would like more information about any of these services, please contact the Epilepsy Helpline or visit our website.

Photosensitive epilepsy

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"We want to live in a society where everyone understands epilepsy and where attitudes towards people with epilepsy are based on fact and not fiction"

How to contact us

Telephone the Epilepsy Helpline freephone **0808 800 5050**

Monday to Thursday 9.00 am to 4.30 pm Friday 9.00 am to 4.00 pm

Our Helpline staff are Typetalk trained

Fax your enquiry to us free of charge on **0808 800 5555**

Write to us free of charge at **FREEPOST LS0995, Leeds, LS19 7YY**

email us at **helpline@epilepsy.org.uk** or visit our website: **www.epilepsy.org.uk**

About the Epilepsy Helpline

In partnership with the organisation Language Line, the Helpline is able to offer advice and information in 150 languages.

We provide confidential advice and information to anyone living with epilepsy but we will not tell them what to do. We can give general medical information but cannot offer a medical diagnosis or suggest treatment. We can give general information on legal and welfare benefit issues specifically related to epilepsy. We cannot, however, take up people's cases on their behalf.

Our staff are trained Advice and Information Officers with an extensive knowledge of epilepsy related issues. Where we cannot help directly, we will do our best to provide contact details of another service or organisation better able to help with the query. In doing this, Epilepsy Action is not making a recommendation.

We welcome comments, both positive and negative about our services.

To ensure the quality of our services we may monitor calls to the helpline.

08/07 - B007

epilepsy action

Epilepsy Helpline freephone: 0808 800 5050
helpline@epilepsy.org.uk
www.epilepsy.org.uk

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Epilepsy Action
New Anstey House, Gate Way Drive, Yeadon, Leeds LS19 7XY
tel: 0113 210 8800 **fax:** 0113 391 0300 **epilepsy helpline freephone:** 0808 800 5050
email: epilepsy@epilepsy.org.uk **www.epilepsy.org.uk**

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Environmental statement
All Epilepsy Action booklets are printed on environmentally friendly, low-chlorine bleached paper. All paper used to make this booklet is from sustainable forests.

Section 5

SCIENTIFIC REPORTS: Setbacks

Document List

- New York State Energy Research Development Authority. 2005. *Public Health and Safety.* Report by Global Energy Concepts.
- GE Energy. 2006. *Ice Shedding and Ice Throw – Risk and Mitigation.* Greenville, SC.
- Garrad Hassan Canada Inc. 2007. *Recommendations for Risk Assessments of Ice Throw and Blade Failure in Ontario.* 38079/OR/01.
- Springfield-Sangamon County Regional Planning Commission. *Sangamon County Wind Energy Conversion System Setback Requirements.* January 2010.

Investing in a Cleaner NY

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Available at:
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NYS Energy Research & Development Authority
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NYSERDA New York State Energy Research and Development Authority

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This document is one of a series of reports and guides that are all part of the NYSERDA Wind Energy Tool Kit. Interested parties can find all the components of the kit at: www.powernaturally.org. All sections are free and downloadable, and we encourage their production in hard copy for distribution to interested parties, for use in public meetings on wind, etc.

Any questions about the tool kit, its use and availability should be directed to: Vicki Colello; vac@nyserda.org; 518-862-1090, ext. 3273.

In addition, other reports and information about Wind Energy can be found at www.powernaturally.org in the on-line library under "Large Wind."

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Public Health and Safety

Public health and safety issues associated with wind energy projects are different from other forms of energy generation since a combustible fuel source, fuel storage, and generation of toxic or hazardous materials are not present. However, wind energy projects do share similar electrical infrastructure requirements with conventional power generation facilities such as medium-voltage power lines and substation equipment. Unique concerns for wind turbines relate to the configuration of the equipment: blade throws, ice shedding, fire, and tower collapses. While most of these are extremely unusual events, public agencies generally address these potential occurrences by establishing reasonable setbacks from residences and public corridors based on the size of the turbine and blades.

Blade Throw

A turbine blade can break due to improper design, improper manufacturing, improper installation, wind gusts that exceed the maximum design load of the turbine structure, impact with cranes or towers, or lightning. The distance a blade piece can be thrown from a turbine depends on its mass, shape, speed at the time it breaks from the machine, the orientation of the blade at the time of the throw, and the prevailing wind speed.

Although a few instances of blade throws were reported during the early years of the wind industry, these occurrences are now rare, due in large part to better testing, design, and engineering of commercial wind turbines. Testing and design of blades is discussed in more detail later in this paper.

Fire

Wind turbines have caught fire; however, this is an extremely rare event. Typically, a turbine fire is allowed to burn itself out while staff personnel and fire personnel maintain a safety area around the turbine and protect against the potential for spot ground fires that might start due to sparks or falling material. Power to the section of the project with the turbine fire is also disconnected. An effective method for extinguishing a turbine fire from the ground does not yet exist, and the events do not last long enough to warrant aerial attempts to extinguish the fire. However, since the public typically does not have access to the private land on which the turbines are positioned, the public's well-being should not be at risk.

Tower Collapse

Although turbine tower collapses are rare, there are reported instances of tower collapse due to various circumstances. The reasons for collapses vary depending on conditions and tower type, but have included blade strikes, rotor overspeed, cyclonic winds, and poor or improper maintenance (torque bolts). In cases where information is available, the majority of the major components (rotor, tower, and nacelle) have fallen to within 1 to 2 hub-height distances from the base. As with turbine fires, members of the public do not typically have access to the private lands on which wind farms are located. As of May 2005, no member of the public has been killed or injured by a failure of a wind turbine.

Ice Shedding

Ice can accumulate on the blades, nacelle, and tower during certain extreme cold-weather conditions. Many times turbines will shut down in icing conditions because the wind vane and/or anemometer sensors become frozen, rendering the turbine inoperable. Ice formation can also reduce power production, which is sensed by the control system that subsequently halts turbine operation. As the ice melts it will fall to the ground in the vicinity of the turbine.

During operable wind speeds and when the turbine has not yet been shut down automatically or manually, ice can break off the blades and be thrown from the turbine (instead of dropping straight down). The distance traveled by a piece of ice depends on the position of the blade when the ice breaks off, the location of the ice on the blade when it breaks off, the rotational rate of the blade when the ice breaks from the blade, the mass of the ice, the shape of the ice (e.g., spherical, flat, smooth), and the prevailing wind speed.

No injuries have been reported as a result of ice throws, however, manufacturers and blade designers continue to research materials and methods that could be employed to reduce the possibility of ice accumulation and subsequent throws. Design features such as the use of black blades and the applications of special coatings have been used at some cold-weather sites. The best practices to reduce the possibility of ice throws include establishment of setback safety zones around the turbines and modifications to the turbine operation during periods of icing, as listed below:

- Turbine Controls – In addition to accumulating on the blades, icing also affects the wind speed and direction sensors on the nacelle that provide information to the control system of the turbine. If the sensors become iced up, the control computer detects no wind speed and/or no change in the wind direction and then stops turbine operation automatically. When ice melts from the sensor, the control computer automatically returns the turbine to operation. Icing on the blades also results in reduced performance, unusual loads, or vibrations that are detected by the control system and trigger an automatic stop. In these cases, the turbine remains off-line until an operator inspects and manually restarts the turbine. If the turbine is not operating, ice from the blades, nacelle, and tower falls to the ground in the immediate vicinity of the machine.

- Operator Intervention – Project operators can halt operation of certain turbines (or the entire project) during icing events to prevent ice throws and equipment damage. Provided some wind is available, site operators can manually 'bump' the rotor for a few slow rotations to make the blades flex and relieve some of the ice build-up. Under these conditions, the slow rotor speed will again result in ice falling to the ground in the immediate vicinity of the machine.
- Safety Zones – Establishing adequate setback areas from inhabited buildings, roads, and power lines significantly reduces the risk of injury or damage in the event of ice throws. Research into quantifying ice throws is limited, probably due to the fact that there have been no reported injuries associated with these events. The most complete study to date has been performed in the UK by C. Morgan, et al. The study quantified the risk of possible strikes from ice throws, in terms of distance from the turbine. The study does not propose specific setback distances but provides information to help establish setbacks that are comparable to other levels of risk. For moderate icing conditions (5 icing days per year) setback distances of 750 ft to 1150 ft correspond to potential strike risks of 1 in 10,000 to 1 in 1,000,000 per year, respectively. (The probability of being struck by lightning is 1 in 1,000,000 per year). This study assumes a wind turbine with a 50-m (164-ft) rotor.

Another factor to consider when assessing the risk of ice throws from wind turbines is that the power grid is also impacted by ice formation and power to the project may be interrupted by the utility due to repair work or actual outages. Turbine operations stop immediately when grid power is lost, thereby reducing ice throw risks.

The people most at risk from falling ice are the site personnel, as most ice falls from the blades, nacelle, and rotor near the base of the tower. Most project developers have strict rules established for personnel and operations during icing events to prevent worker injury and to protect the public.

Vandalism

Though not unique to wind turbine installations, the potential for vandalism or trespassing can also cause safety concerns. Wind turbines may attract more attention than other structures. Project developers report incidences of unauthorized access on their sites ranging from curiosity seekers to bullet holes in blades. Permits usually require fencing and postings at project entrances to prevent unauthorized access. Other requirements intended to reduce personal injury and public hazards include locked access to towers and electrical equipment, warning signs with postings of 24-hour emergency numbers, and fenced storage yards for equipment and spare parts. Fencing requirements will depend on existing land uses such as grazing. Some communities have established information kiosks along roadsides to channel curious sightseers out of road traffic and into an area that is a safe distance from the turbines.

Working with Local Emergency Response Teams

Project developers commonly work with local emergency response teams to provide information or training on tower rescues and other wind-specific concerns. Falls, injuries from heavy or rotating equipment, and injuries from electricity represent the types of events that can occur at a wind energy facility. The height of the nacelles provides an additional challenge for medical responders. The national Occupational Safety and Health Administration (OSHA) regulations, in addition to state worker safety regulations, cover all of the worker safety issues associated with electricity, structural climbing, and other hazards present in a wind farm.

Mitigation Through Setbacks

Many concerns associated with safety, noise, and aesthetics can be addressed by placing distance between the wind turbines and people, property lines, roads, and scenic areas. Although no consensus on appropriate distances or types of setbacks exists, there are several common themes that appear in a number of wind energy regulations in place as of May 2005.

Most local government requirements include setback specifications for the distance between the wind turbine and structures (residences and other buildings), property lines, and roads. A few agencies have also defined setbacks from railroads and above-ground transmission lines. The most common way to define a setback distance is in terms of a multiple of the turbine height (for example 1.5 times the wind turbine height). Other options are to specify a fixed distance or a combination of a fixed distance and a multiple of the turbine height. When specifying the structure height, it is important to define whether the height is the top of the nacelle or the highest point reached by the rotor blade (maximum tip height, or MTH).

Examples

Wind turbine setbacks from residences

- Fenner/Stockbridge, NY – 1.5 x MTH
- Martinsburg, NY – 1500 ft
- Contra Costa County, CA – 2 x MTH
- Palm Springs, CA – 1200 ft

With regard to setbacks from structures and residences, some permitting agencies differentiate between houses and buildings on the property leased for the project, and houses and buildings on *adjacent* parcels. The implication is that a greater distance is appropriate from structures on adjacent parcels since those properties have less control over the development than the landowner. A waiver of such requirements is typically granted if written permission is provided from the neighboring landowner.

Setbacks from property lines may vary for side and rear lot lines but are generally specified in the same way as setbacks from residences. Setbacks from property lines can pose a challenge for small wind turbines since these installations tend to occur on smaller landparcels. To address this issue, some agencies define setbacks for *commercial* wind turbines only. Small turbines are either exempt or evaluated on a case-by-case basis. Turbines should be exempt from property line setbacks if the adjacent property contains a wind turbine from the same plant, or the adjacent property is a participant in the project through a land lease and/or wind access agreement. This is an important consideration particularly in New York, since turbine layouts and plant infrastructure can result in many parcels of land being utilized for one project.

Examples

Wind turbine setbacks from property lines

- Fenner/Stockbridge, NY – 1.5 x MTH
- Martinsburg, NY – 300 ft (rear and side lot lines)
- Contra Costa County, CA – 3 x MTH or 500 ft, whichever is greater (from all boundaries)
- Cook County, MN – tower height
- Wasco County, OR – at least 5 rotor diameters

Setbacks from roads are typically greater for major highways than for local roads. In some cases, scenic setbacks have been required from particular state highways in close proximity to designated wind development areas.

When establishing setbacks, the intended effect must be balanced with economic considerations for the project and overall permitting objectives. For example, a setback decision made by a Town Board in Addison, Wisconsin, had the effect of reducing the number of proposed turbines by more than two-thirds for a wind project in their jurisdiction. The project developer proposed a setback of 650 ft around each turbine (approximately 2.5 x MTH) to address concerns raised about noise, safety and visual impacts. The Town Board decided to expand the setback to a minimum of 1000 ft from any residences, road right-of-ways, or property boundaries. The developer had a limited ability to re-position the turbines on the remaining leased property while still maintaining an acceptable energy output from the project. As a result, the number of proposed turbine sites was reduced from 28 to approximately 8 and the developer dropped the project because it was uneconomical.

Safety in Design, Construction, and Operation

Wind turbines and wind power projects are inspected by the utilities (for grid and system safety) prior to being energized and during operation. In the design phase, state and local laws require that licensed professional engineers review and stamp the structural elements (tower, foundation, roads, building, etc.) and the electrical collection system.

Depending on the local requirements and permits, building inspectors can inspect the project. Finally OSHA has the authority to inspect working conditions.

Wind turbines and wind energy project installations are designed to meet numerous applicable standards. Many of these standards are common to a wide range of industrial equipment and electrical and structural installations. All engineered structures and power generating equipment in the United States must meet a number of codes and standards as dictated typically by the local municipalities and the interconnecting utilities. At the top level of these are the National Building Code and the National Electrical Code. All, or part, of these codes are typically included in municipal permitting regulations. These codes include standards for earthquakes, structural integrity, electrical specifications, and power quality. Local municipalities may have noise, environmental, and safety codes as well. The interconnecting utility may also have its own set of design requirements that pertain to power factor, voltage, frequency and the like. These are often based on applicable Institute of Electrical and Electronic Engineers (IEEE) standards.

Others pertain to wind-turbine-specific design standards, including the International Electrotechnical Commission (IEC) standards for design and safety. The IEC standards are contained in Sections 61400 and can be found at http://www.awea.org/standards/iec_stds.html. Some of the areas addressed in the wind-turbine-specific design standards include, but are not limited to, wind regime definitions, load cases, and safety factors. The overall certification requirements are codified in an individual standard, as are the detailed methodologies for testing power performance, acoustic noise emissions, power quality, and blade structure.

For example, the IEC 61400 group of wind turbine standards includes a section on blade testing. Testing to these standards is conducted by both independent agents and by the blade and turbine vendors themselves. The test standards include procedures for both fatigue and maximum-strength tests. The fatigue testing typically includes long-duration testing (one to three months) by continuously cycling the load on the blade. The maximum strength test is designed to mimic an extreme load event. In each case the blade is either proof tested to a predetermined load or tested to failure, depending on the goals of the test. Blade tests are carried out at the NREL/NWTC facility in Boulder, Colorado, in the U.S., at the Risø National Laboratory in Denmark, the Technical University at Delft in the Netherlands, and CRES in Greece. In addition, LM in Denmark, a blade manufacturer, maintains its own blade test facilities as does turbine manufacturer Vestas (NEG Micon has its own facility, which is now also Vestas).

Three certifying bodies have established procedures for reviewing manufacturer's designs and confirming compliance with these standards: Underwriters Laboratory, Germanischer Lloyd, and Det Norske Veritas. All wind turbines must meet the design and safety requirements in order to be certified by one of these bodies. Certification to these standards is a nearly universal requirement for a wind power project to be built or financed.

Additional Resources

NWCC Siting Subcommittee (1998) Permitting of Wind Energy Facilities: A Handbook. Washington, National Wind Coordinating Committee

Morgan, C., E. Bossanyi, et. al. (1998) Assessment of Safety Risks Arising From Wind Turbine Icing. BOREAS IV Conference Paper, Finland.

The Germanischer Lloyd, Det Norske Veritas, and Underwriter's Laboratory standards are available from these entities. For information about these certifying bodies, see the following web sites: http://www.gl-group.com/start.htm and http://www.dnv.com/ and http://www.ul.com/.

GE
Energy

Ice Shedding and Ice Throw – Risk and Mitigation

David Wahl
Philippe Giguere
Wind Application Engineering

GE Energy
Greenville, SC

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.

References

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.

[1] *Wind Turbine Icing and Public Safety – a Quantifiable Risk?:* Colin Morgan and Ervin Bossanyi of Garrad Hassan, 1996.

[2] *Assessment of Safety Risks Arising From Wind Turbine Icing:* Colin Morgan and Ervin Bossanyi of Garrad Hassan, and Henry Seifert of DEWI, 1998.

[3] *Risk Analysis of Ice Throw From Wind Turbines:* Henry Seifert, Annette Westerhellweg, and Jürgen Kröning of DEWI, 2003.

[4] *State-of-the-Art of Wind Energy in Cold Climates:* produced by the International Energy Agency, IEA, 2003.

[5] *On-Site Cold Climate Problems:* Michael Durstewitz, Institut fur Solare Energieversorgungstechnik e.V. (ISET), 2003.

[6] *Wind Energy Production in Cold Climate:* Tammelin, Cavaliere, Holttinen, Hannele, Morgan, Seifert, and Säntti, 1997.

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GARRAD HASSAN

RECOMMENDATIONS FOR RISK ASSESSMENTS OF ICE THROW AND BLADE FAILURE IN ONTARIO

Client	**Canadian Wind Energy Association**
Contact	David Timm
Document No	38079/OR/01
Classification	Client's Discretion
Date	31 May 2007

Authors:

M P LeBlanc

Checked by:

C A Morgan/ E A Bossanyi

Approved by:

A D Garrad

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CONTENTS

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 1,00,000 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 x 0.01 = 0.000016 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 vehicles x 600 m / 60 km/hr / (5 days x 24 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 x 0.008 x 0.8 x 10 m^2 = 0.000010 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 x (1 m^2 / 275,000 m^2) x 275,000 m^2 = 0.002 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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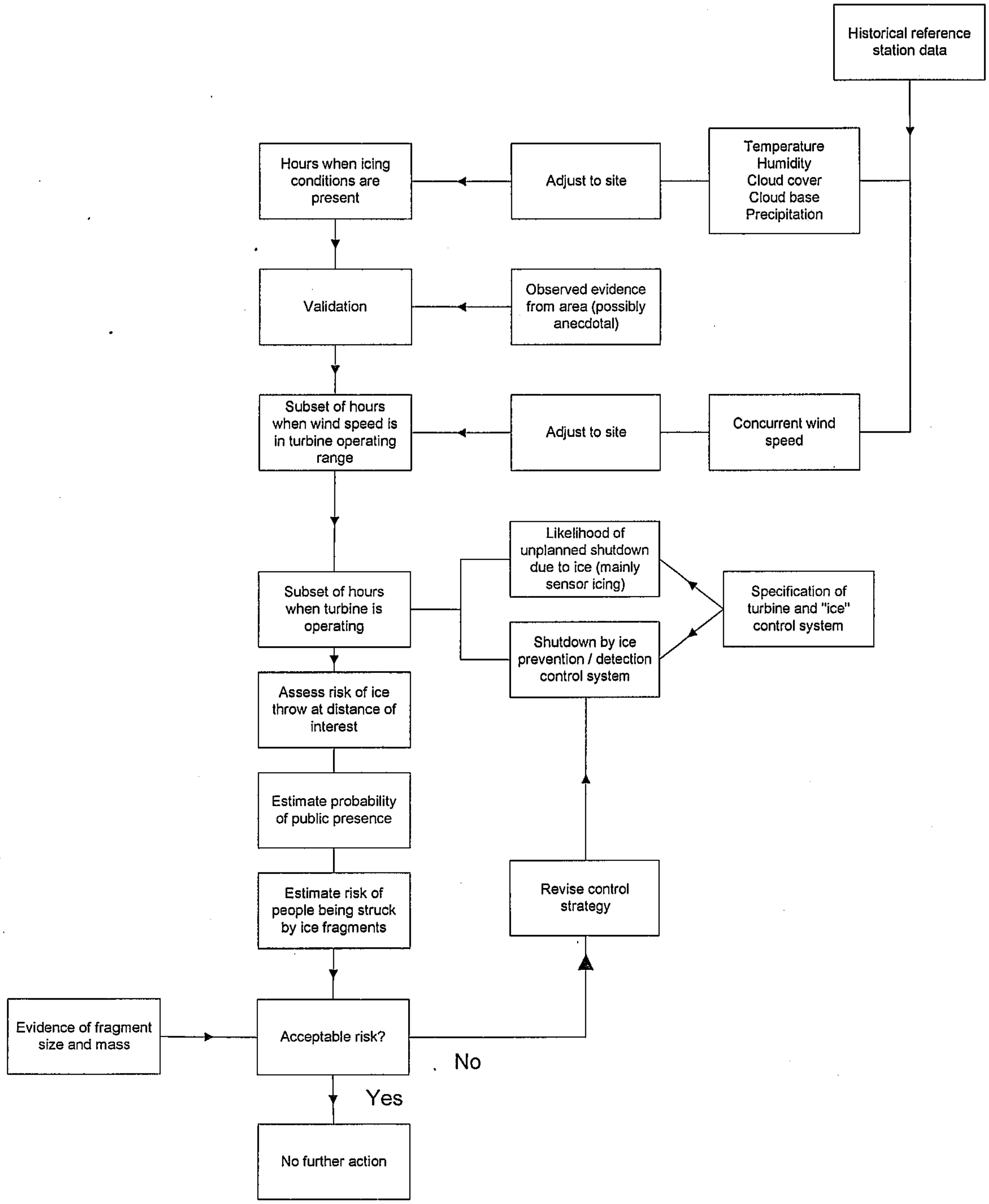

Figure 3.1 Ice throw risk assessment procedure

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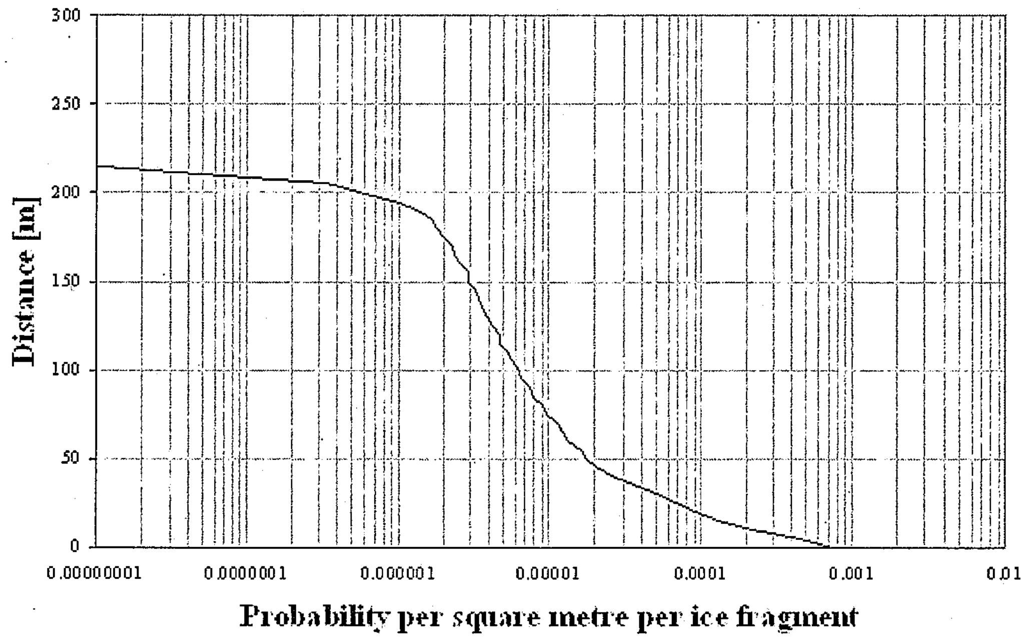

Figure 3.2 Calculated probability of ice fragment throw distances

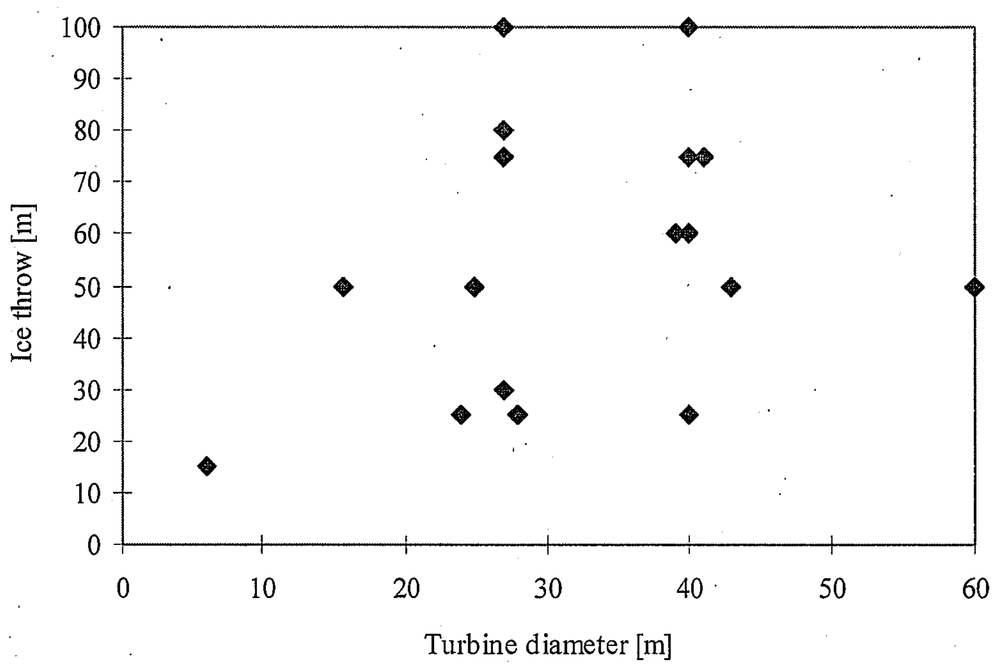

Figure 3.3 Recorded ice throw data (from [3.4])

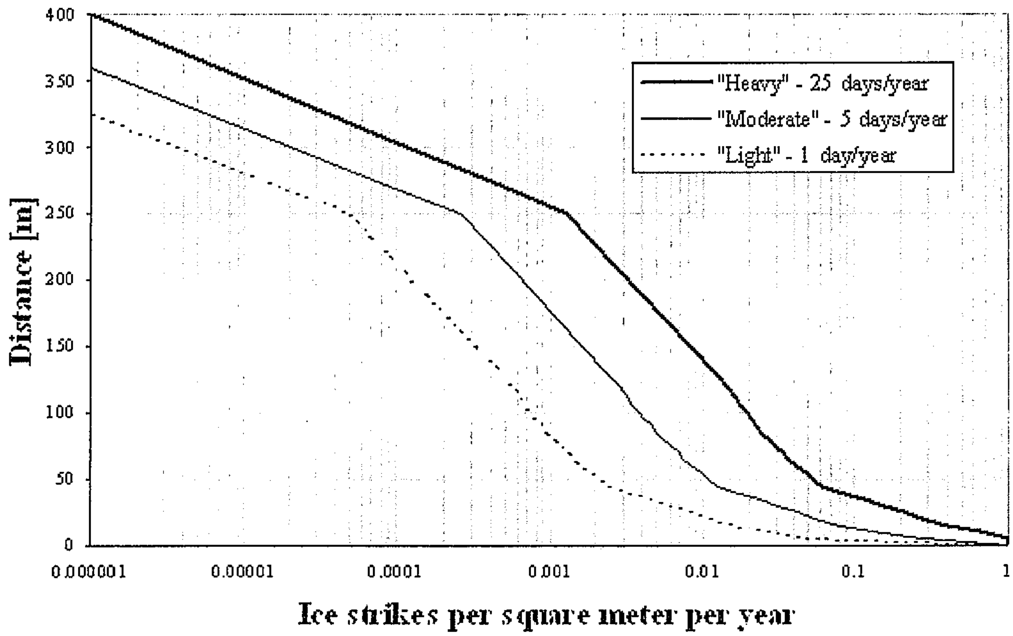

Figure 3.4 Recommended probability for ice fragment strikes in Ontario

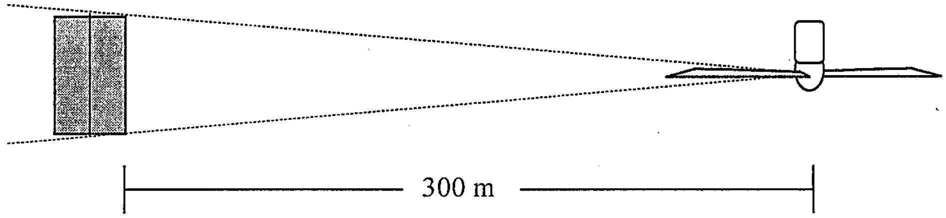

Figure 3.5 Scenario A – Fixed dwelling

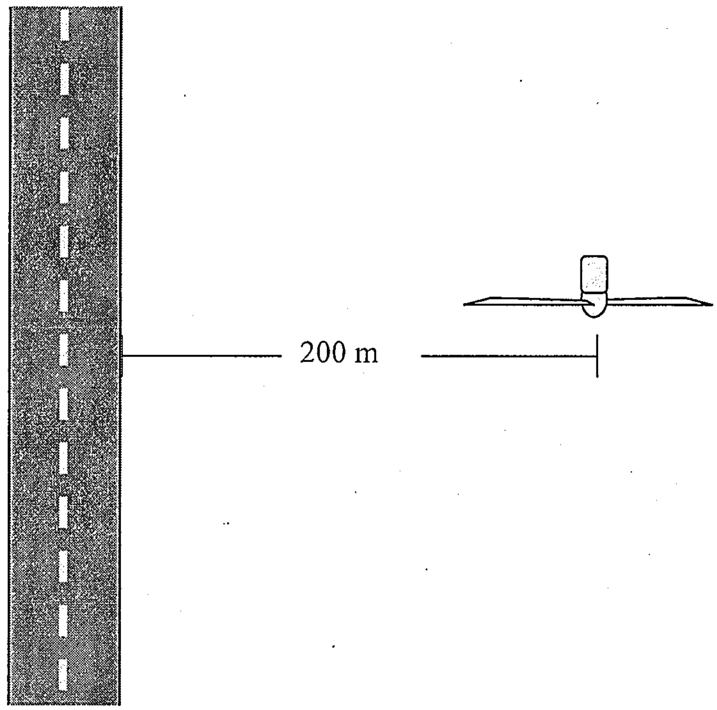

Figure 3.6 Scenario B – Road

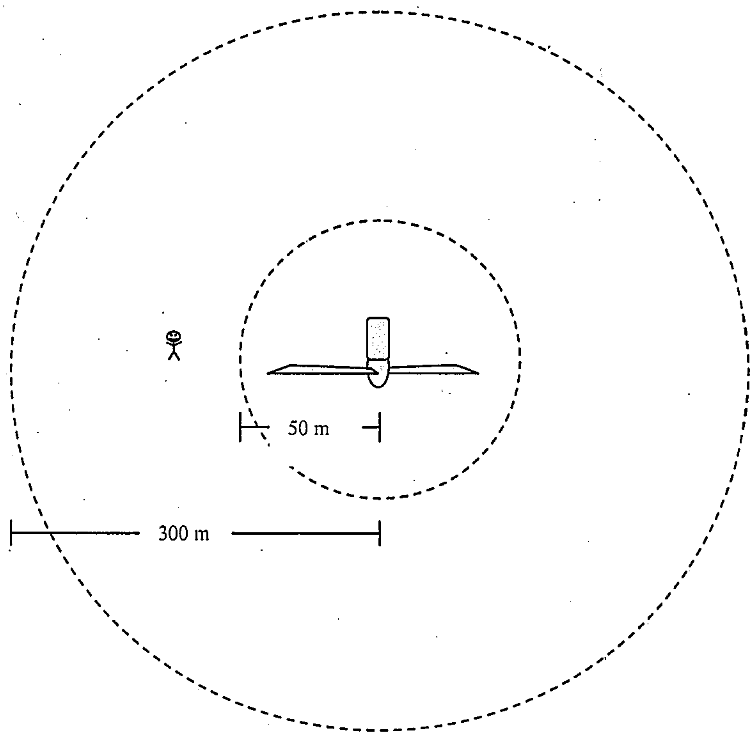

Figure 3.7 Scenario C – Individual

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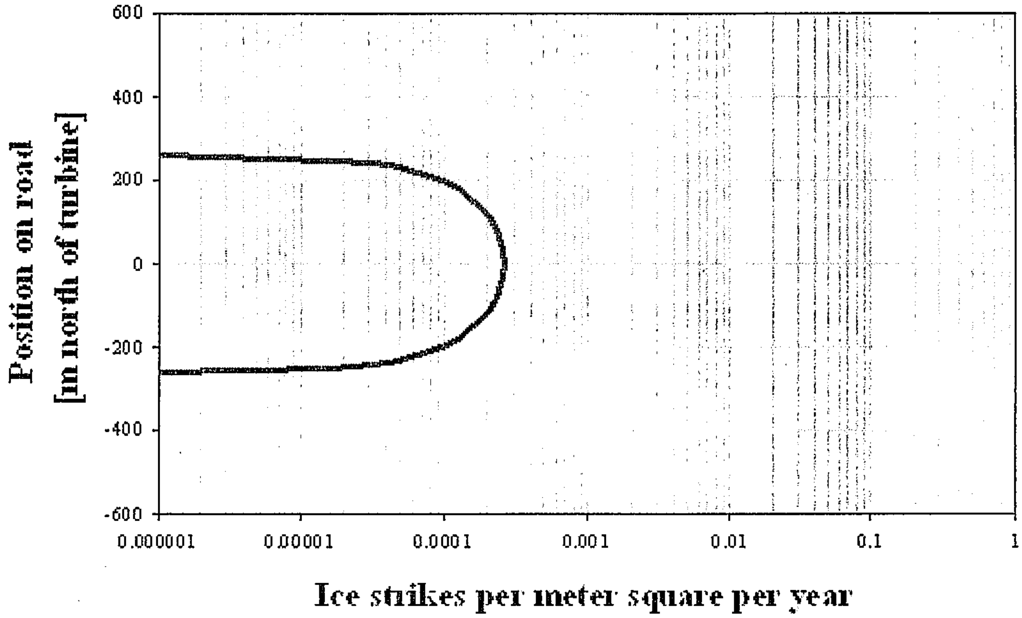

Figure 3.8 Risk profile for Scenario B

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.

Information Brief

SSC RPC Springfield-Sangamon County Regional Planning Commission

January 8, 2010

Key Findings:

After reviewing a number of wind energy conversion system ordinances from other county jurisdictions as well as suggested model state codes, the SSCRPC finds that the Sangamon County WECS ordinance is not less restrictive than any of the ordinances studied, and in its totality may be considered more restrictive.

This is particularly the case when considering Sangamon County's setback requirements relative to incorporated areas, and its inclusion of contiguous urban development areas as subject to the same setback as the nearby incorporated areas.

The Springfield-Sangamon County Regional Planning Commission

Room 212
200 South 9th Street
Springfield, Illinois 62701

Phone: 217.535.3110
Fax: 217.535.3110
Email: sscrpc@co.sangamon.il.us

www.sscrpc.com

Sangamon County Wind Energy Conversion System Setback Requirements

A Comparison with Some Other Jurisdictions

Similar to other areas of zoning and land regulation, the Sangamon County Wind Energy Conversion System (WECS) ordinance (Chapter 17.49.010 et seq.) requires certain *setbacks* associated with the location of wind turbines. Setbacks generally refer to the space requirements established around structures or uses that prescribes the distance a structure or use must be from another. Most often these setbacks are designed to address public purposes; such as the side-yard setback requirements in residential zoning areas which are intended to address access to air and light as well as aid in fire safety.

Questions have been raised concerning the setback requirements – i.e., the distance from a feature to a wind turbine tower – in the Sangamon County WECS ordinance and whether they are sufficient. In order to help address this question, the Springfield-Sangamon County Regional Planning Commission (SSCRPC) compared setback requirements in the County's code to other, similar codes in some other jurisdictions (27 counties in Illinois and 5 in other states) as well as in 5 model state codes, including the Illinois model code. The results of this comparison are presented below.

The SSCRPC found that only in rare instances do these other codes exceed the Sangamon County requirements, and in the vast majority of cases the Sangamon code was much more restrictive. We found this to particularly be the case related to setbacks from incorporated areas

The following pages outline the results of our study.

Comparing Setback Requirements

Comparing and contrasting municipal ordinances is often difficult because there may be many subtleties in specific sections of the codes which have an effect on other sections. It is also difficult because different definitions may be in use affecting the results of the comparison. However, and with this difficulty in mind, the SSCRPC attempted to compare the setbacks of the Sangamon County wind energy ordinance with others, since the question had been raised.

No attempt was made to compare the setbacks in the Sangamon County WECS ordinance with *all* other similar ordinance as that would simply be too great a task. The SSCRPC did, however, look at a number of model ordinances, ordinances from other Illinois counties, and ordinances from counties in other states that had originally guided the development of the Sangamon County WECS ordinance. We would also note that time was insufficient to review the requirements in any great detail; although we believe that the results reported here are still illustrative of the extent to which these requirements are included in other county codes and useful in considering the rigor of the Sangamon ordinance.

Some of the information listed below was collected by Western Illinois University's Illinois Institute of Rural Affairs. The Institute keeps a very useful listing of available Illinois wind farm ordinances and points of contact on its website: www.illinoiswind.org. Other information was collected directly by the SSCRPC. The SSCRPC did not seek to compare the County's code with that of urban areas since we believe that projects in these areas must address somewhat different issues than those in rural ones.

Sangamon County Setback Requirements

The Sangamon County WECS ordinance provides for both setbacks – which establish the distance from a feature to a wind turbine tower – from incorporated areas as well as setbacks from certain property perimeters and structures.

As the table below indicates, the setback from incorporated areas differs in the Sangamon County ordinance based upon the population of the incorporated area. The ordinance also makes a provision for also considering "contiguous urban development" in defining the area perimeter where the incorporated area setback applies. SSCRPC sees these as areas that are adjacent to incorporated areas but not yet incorporated, or areas where significant development has occurred near incorporated areas regardless of adjacency.

Incorporated Area Setback Provision	Required Setback from Incorporated Areas of 10,000 or More in Population	Required Setback from Incorporated Areas of 10,000 or Less in Population	Contiguous Urban Development Included in Setback Provision?
Sangamon County Required Setback	1.5 Mile Setback	0.5 Mile Setback	Yes. May not be located "so they interfere with contiguous urban development."

The County's code also includes certain setbacks from perimeters and structures. These are listed below. The *WECS Perimeter* is defined in Sangamon County code as the "outer boundaries of the WECS site", so the perimeter involves a larger area than the point where an individual wind turbine would be located. A *structure* is defined in the County's code as "anything erected, the use of which requires more or less permanent location on the ground; or attached to something having a permanent location on the ground. A sign, billboard, or other advertising medium detached or projecting shall be construed to be a structure." Please note that this definition does not limit the setback only to residential structures (which some other WECS ordinances do), but to the principal structure on a relevant parcel.

Perimeters and Structures Setback Provisions	Required Perimeter Setback	Required Principal Structures Setback	Required Setback from Third Party Utility Lines	Required Setback from Public Roads
Sangamon County Required Setback	1,200 feet. Allows for setback easements.	1,000 feet or 3 times rotor diameter, whichever is greater.	1.1 times system height.	1.1 times system height.

Comparison with Sample Ordinances Regarding Incorporated Areas Setbacks

For the purpose of comparison, the SSCRPC considered 37 other ordinances. The first comparison involved 27 other Illinois counties and their inclusion of setbacks from incorporated areas. Of these 27, only 4 (15%) specifically included such a setback. Of these 4, none provided for a greater setback than that included in the Sangamon County WECS ordinance, 3 provided less, and one provided a similar setback distance. None specifically included areas of contiguous urban development.

Jurisdiction	Setback from Incorporated Areas	Contiguous Urban Development Included
Illinois Ordinances		
Sangamon County	1.5 Mile Setback for areas greater than 10,000 in population; 0.5 mile from areas less than 10,000.	Yes. May not be located "so they interfere with contiguous urban development."
Carroll County	Not Addressed	Not Addressed
Champaign County	Not Addressed	Not Addressed
Coles County	1500' from any platted community.	
Ford County	1500'	
Henry County	Not Addressed	Not Addressed
Iroquois County	Not Addressed	Not Addressed
Jo Daviees County	Not Addressed	Not Addressed
Kankakee County	Not Addressed	Not Addressed
Kendall County	Not Addressed	Not Addressed
Knox County	Not Addressed	Not Addressed
La Salle County	Not Addressed	Not Addressed
Lake County	Not Addressed	Not Addressed
Lee County	Not Addressed	Not Addressed
Livingston County	1.5 mi. from incorporated area	
Logan County	Not Addressed	Not Addressed
Macon County	Not Addressed	Not Addressed
Marshall County	Not Addressed	Not Addressed
McLean County	None – Possibly by negotiation.	None – Possibly by negotiation.
Mercer County	Not Addressed	Not Addressed
Moultrie County	1500' from incorporated area	
Ogle County	As A-1 special use	
Rock Island County	Not Addressed	Not Addressed
Shelby County	Not Addressed	Not Addressed
Stark County	Not Addressed	Not Addressed
Stephenson County	Not Addressed	Not Addressed
Tazwell County	Not Addressed	Not Addressed
Woodford County	Not Addressed	Not Addressed

The SSCRPC then compared the Sangamon County ordinance to 4 often used state model ordinances as well as the Illinois state model ordinance. The Illinois model was developed for the Illinois Clean Energy Community Foundation by the law firm of Baker & McKenzie. The SSCRPC found that none of these ordinances included setbacks from incorporated areas.

Jurisdiction	Setback from Incorporated Areas	Contiguous Urban Development Included
Sangamon County	1.5 Mile Setback for areas greater than 10,000 in population; 0.5 mile from areas less than 10,000.	Yes. May not be located "so they interfere with contiguous urban development."
Wisconsin Model Ordinance	Not Addressed	Not Addressed
Mass. Model Ordinance	Not Addressed	Not Addressed
Michigan Model Ordinance	Not Addressed	Not Addressed
North Carolina Model Ordinance	Not Addressed	Not Addressed
Illinois Model Ordinance	Not Addressed	Not Addressed

Finally, the SSCRPC compared the County's ordinance to 5 county ordinances from other states to determine if those codes were significantly different. These ordinances were randomly selected based upon an internet search. We found that only 2 of these ordinances included provisions for setbacks from incorporated areas, and neither were as restrictive as the Sangamon County provisions.

Jurisdiction	Setback from Incorporated Areas	Contiguous Urban Development Included
Sangamon County	1.5 Mile Setback for areas greater than 10,000 in population; 0.5 mile from areas less than 10,000.	Yes. May not be located "so they interfere with contiguous urban development."
Calumet Co., WI	1000'	
Fillmore Co., MN	Not Addressed	Not Addressed
Martin Co., MN	Not Addressed	Not Addressed
Washtenaw Co., MI	Not Addressed	Not Addressed
Renville Co., MN	1/4 mile	

Other Perimeter and Structure Setbacks

As with setbacks from incorporated areas, the SSCRPC compared the Sangamon County provisions with the restrictions in the wind farm ordinances from other Illinois counties, the state model ordinances, and the county ordinances from other states selected at random.

Since many ordinances establish setbacks based upon WECS height, we had to make some assumptions in order to compare the ordinances. Assuming a general turbine height of 500 – 600 ft. (pylon plus blades), we found no Illinois county with a perimeter setback requirement as restrictive as the Sangamon County one. Most do not deal with perimeters at all, addressing only property line setbacks, and require a setback of only 1.1 times system height. Three of the 27 (11%) require greater distances from principal/primary structures (though this may be some what complicated by their limiting the requirement to residential structures while the Sangamon ordinance does not), 2 (7.4%) require a greater distance from utility lines and towers, and 2 (7.4%) require a greater distance from roads. In almost every case, the Sangamon County ordinance requirements equal or exceed that of the other Illinois counties reviewed.

Jurisdiction	Perimeter or Property Lines	Principal/Primary Structures	Third Party Utility Lines or Towers	Public Roads
Sangamon County	1,200 feet. Setback easement allowed	1,000 feet or 3 times rotor diameter: whichever is greater	1.1 x system height	1.1 x system height
Carroll County	1.1x system height	1.1x system height		1.1x system height
Champaign County	Same as I-2 industrial	Same as I-2 industrial	Same as I-2 industrial	Same as I-2 industrial
Coles County	1.1x system height or 350'	1400' – 1.0 MW turbines 1000' -- < 1.0 MW	1.1x system height	1.1x system height
Ford County	1.0x system height	1000'	1.1x system height	1.1x system height
Henry County	100' from tip		1.1x system height	1000'
Iroquois County	1.1x system height	1.1x system height	1.1x system height	1.1x system height
Jo Daviees County	1.1x system height	1400'	1.1x system height	1.1x system height
Kankakee County	1.1x system height	600' (zero setback from any prop. Line shared by 2 or more participating parties)	1.1x system height	1.1x system height
Kendall County			1.5x system height	1.5x system height
Knox County	1000'		1.1x system height	1.1x system height
La Salle County	1.1x system height	750'	1.25x system height	1.1x system height
Lake County	As AG, RE, E zoning requirements	As AG, RE, E zoning requirements	As AG, RE, E zoning requirements	As AG, RE, E zoning requirements
Lee County	350'		350'	350'
Livingston	1.1x system height	3x system height or 1200'	1.1x system height	1.1x system height
Logan County	1.1x system height	750' or 1.1x system height		1.1x system height
Peoria County	1.1x system height	1.1x system height; 750' adjoining property dwelling unit	1.1x system height	1.1x system height
Macon County	1.5x system height	1,000' and 1.1x system height		1.1x system height
Marshall County	1.0x system height	1000'	1.0x system height	1.0x system height
McLean County	Not within 2000' of an R-1 or R-2 district	By hearing.	By hearing	By hearing
Moultrie County	1.1x system height	1.0 MW or less, 1000'; More than 1.0 MW, 1400'	1.1x system height	1.1x system height
Ogle County	As AG-1 Special Use	As AG-1 Special Use	As AG-1 Special Use	As AG-1 Special Use
Peoria County	750'	1.1x system height	1.1x system height	1.1x system height
Rock Island County	100' from tip	1.1x system height	1.1x system height	1.1x system height
Shelby County	1.1x system height	1.1x system height	1.1x system height	1.1x system height
Stark County	1.0x system height	1000'	1.1x system height	1.1x system height
Stephenson County	1.1x system height	1.1x system height	1.1x system height	1.1x system height
Tazwell County	1.1x system height	1.1x system height (zero for shared properties). 750' for adjoining property dwelling units.	1.1x system height	1.1x system height
Woodford County	1.1x system height	1.1x system height (zero for shared properties). 750' for adjoining property dwelling units.	1.1x system height	1.1x system height

In regard to the various state model ordinances, we found no ordinance that exceeded the Sangamon County requirement on perimeter setback, though it is possible that the North Carolina ordinance could, depending upon the height of the system being considered. The Wisconsin model could possibly be close to or exceed the Sangamon ordinance in regard to structure setback, and the North Carolina ordinance does exceed the Sangamon County ordinance in regard to the public road setback. However, as with the Illinois counties, the local ordinance appears very comparable.

Jurisdiction	Perimeter or Property Lines	Principal/Primary Structures	Third Party Utility Lines or Towers	Public Roads
Sangamon County	1,200 feet. Setback easement allowed.	1,000 feet or 3 times rotor diameter: whichever is greater.	1.1 times system height.	1.1 times system height.
Illinois Model Ordinance	1.1x system height.	1000' or 1.1x system height.	1.1x system height.	1.1x system height.
Wisconsin Model Ordinance	1.1x system height.	2x system height or 1000'.	1.1x system height.	1.1x system height.
Mass. Model Ordinance	100'	1.5x blade tip height.		100'
Michigan Model Ordinance	1.1x system height.			1.1x system height.
North Carolina Model Ordinance	1.5x system height.	1.1x system height.		1.5x system height.

In looking at the sample of county ordinances from other states, we found that only one (Washtenaw Co., MI) could potentially provide for equal to or greater setbacks from perimeter or property lines, one (Calumet Co., WI) clearly exceeds the local ordinance's provisions concerning setback from structures (though, again, this setback may only relate to residential structures), and none could be determined to exceeded the Sangamon ordinance in the other two areas.

Jurisdiction	Perimeter or Property Lines	Principal/Primary Structures	Third Party Utility Lines or Towers	Public Roads
Sangamon County	1,200 feet. Setback easement allowed.	1,000 feet or 3 times rotor diameter: whichever is greater.	1.1 times system height.	1.1 times system height.
Calumet Co., WI	1.1x system height.	1,800'		1.1x system height.
Fillmore Co., MN	1.1x system height.	750'		1.1x system height.
Martin Co., MN	1.1x system height.	750'		1.1x system height.
Washtenaw Co., MI	1.5x system height.			
Renville Co., MN		750'		1.1x system height.

Overall, it appears to the Commission that the Sangamon County ordinance is not less restrictive than any of the ordinances studied, and in its totality is more restrictive: at least in terms of the considered setback requirements.

This report prepared by E. Norman Sims, SSCRPC, Executive Director

The Springfield-Sangamon County Regional Planning Commission (SCRPC) serves as the joint planning body for Sangamon County and the City of Springfield, as well as the Metropolitan Planning Organization for transportation planning in the region.

The Commission has 17 members including representatives from the Sangamon County Board, Springfield City Council, special units of government, and six appointed citizens from the city and county. The Executive Director is appointed by the Executive Board of the Commission and confirmed by the Sangamon County Board.

The Commission works with other public and semi-public agencies throughout the area to promote orderly growth and redevelopment, and assists other Sangamon County communities with their planning needs. Through its professional staff, the SSCRPC provides overall planning services related to land use, housing, recreation, transportation, economics, environment, and special projects. It also houses the Sangamon County Department of Zoning which oversees the zoning code and liquor licensing for the County.

The Commission prepares area-wide planning documents and assists the County, cities, and villages, as well as special districts, with planning activities. The staff reviews all proposed subdivisions and makes recommendations on all Springfield and Sangamon County zoning and variance requests. The agency serves as the county's Plat Officer, Floodplain Administrator, Census coordinator, and local A-95 review clearinghouse to process and review all federally funded applications for the county. The agency also maintains existing base maps, census tract maps, township and zoning maps and the road name map for the county.

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Section 6

SCIENTIFIC REPORTS: Sound

Document List

- Bastasch, Mark. Prepared for Renewable Northwest Project. *Summary of International Wind Turbine Noise Regulations.* April 2011.

- Sonus. Prepared for: Pacific Hydro Pty Ltd. *Infrasound Measurements from Wind Farms and Other Sources.* November 2010

- Leventhall, Geoff. *Infrasound from Wind Turbines—Fact, Fiction or Deception.* Canadian Acoustics. 29-36. Vol. 34 No. 2. (2006).

- Lawrence Technological University. *Primer for Addressing Wind Turbine Noise.* Revised Oct. 2006.

- Howe Gastmeier Chapnik Engineering. Submitted to CanWEA. *Wind Turbines and Sound: Review and Best Practice Guidelines.* February 2007.

- "Wind Turbine Acoustic Noise," A White Paper by Dr. Anthony Rodgers, James F. Manwell, and Sally Wright, at the University of Massachusetts at Amherst. January 2006.

- Bass, Bowdler, McCaffery, Grimes. *Abstract: Fundamental Research in Amplitude Modulation—a Project by RenwewableUK.* Italy. April 2011.

- Dr. Ramani Ramakrishnan for the Ontario Ministry of the Environment. *Wind Turbine Facilities Noise Issues.* December 2007.

Summary of International Wind Turbine Noise Regulations

PREPARED FOR: Renewable Northwest Project

PREPARED BY: Mark Bastasch, P.E./CH2M HILL

DATE: April 13, 2011

The purpose of this memorandum is to summarize wind turbine noise regulations from various international regulations. It is important to note that several regulations were recently updated including Australia, New Zealand and The Netherlands. The regulatory approach established for wind energy facilities may or may not be consistent with how other sources of environmental noise are evaluated. Overall, there are two distinct approaches: (1) establishment of absolute limits, or (2) relative limits. These approaches may also be combined as described below.

Absolute Limits

Absolute limits establish a fixed numeric threshold that may not be exceeded. The numeric threshold is commonly presented in terms of overall A-weighted level.

Relative Limits

The fact that sound emissions from a wind energy facility depends on wind speed is a defining characteristic. In a rural setting, it is not uncommon for the level of existing noise to increase with increasing wind speed. Relative limits, otherwise known as a background plus approach, attempt to take this into account and establish a threshold that is relative to the existing sound level, thereby regulating the change or increase resulting from a new noise source. When winds at a residence or receptor are calm and a lower level of background noise is documented, a lower overall project level would be required compared to times when a higher level of existing noise under more substantial wind conditions.

Combination of Absolute and Relative Limits

A combination or hybrid of both approaches may also be established. Such approaches may establish an effective floor (lower bound or absolute minimum level) or ceiling (higher bound or absolute maximum level), regardless of the existing level of noise documented.

Examples of Regulatory Approaches

What follows are brief examples of the varying regulatory approaches. As indicated, Oregon's approach is among the most restrictive.

Country	Regulations or Guideline	Reference/Regulation
Australia	Greater of 35/40 dBA or existing plus 5 dBA	Australian Standard AS 4959 (2010)
Canada (Ontario)	40 dBA to 51 dBA; increasing with increasing wind speed. 40 dBA is typically controlling limit	Ontario Ministry of the Environment (MOE). 2008. *Noise Guidelines for Wind Farms – Interpretation for Applying MOE NPC Publications To Wind Power Generation Facilities*. October 2008. http://www.ene.gov.on.ca/environment/en/resources/STD01_078286.html
Denmark	Typically 42 dBA @ 6 m/s and 44 dBA @ 8 m/s	Personal Communication
Germany	35 to 40 dBA at night	Technische Anleitung Lärm (TA Lärm, Technical Instruction Noise)
Netherlands	41 dBA at night or 47 dBA as annual average	Personal Communication
New Zealand	Greater of 40 dBA or 5 dBA above existing	New Zealand Standard 6808, Acoustics – Wind farm noise (2010)
United Kingdom	Greater of 43 dBA or 5 dBA above existing at night	ETSU-R-97, *The Assessment and Rating of Noise from Wind Farms*
Oregon	Typically assessed as 36 dBA at non-participating residents	OAR-340-035

WTN 2011

Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

Measurement of Infrasound from Wind Farms and Other Sources

Turnbull CP, Turner JP
Sonus Pty Ltd
17 Ruthven Avenue, Adelaide, South Australia 5000
ct@sonus.com.au, jturner@sonus.com.au

Abstract

Infrasound is generated by a range of natural sources, including waves on the coastline, waterfalls and wind. It is also generated by a wide range of man-made sources such as industrial processes, vehicles, air conditioning and wind farms.

The measurement of infrasound at low levels requires a specific methodology, as it is readily affected by wind on the microphone. Such a methodology has been developed for this study to measure infrasound from two Australian wind farms.

The specific methodology is based on measurements being conducted below the ground surface in a test chamber that is approximately 500mm square and 500mm deep to reduce the influence that even light surface breezes can have on the infrasound results.

The below ground methodology has been tested and it has been confirmed that levels of infrasound above the ground and within the chamber are the same in the absence of surface winds when measuring a known and constant source of infrasound.

Infrasound was measured using the below ground methodology at two Australian wind farms, Clements Gap in the mid-north of South Australia and Cape Bridgewater in the coastal region of south-western Victoria. Infrasound was also measured in the vicinity of a beach, a coastal cliff, the city of Adelaide and a power station using the below ground methodology. The measured levels of infrasound from the wind farms have been compared with the other natural and man-made noise sources and all measurements have been compared with recognised audibility thresholds.

Introduction

Infrasound is generally considered to be sound at frequencies less than 20 Hz and is often described as inaudible, However, sound below 20 Hz remains audible provided that the sound level is sufficiently high [1]. The thresholds of audibility for infrasound have been determined in a range of studies [2].

The G-weighting has been standardised to determine the human perception and annoyance due to noise that lies within the infrasound frequency range [3]. A common audibility threshold from the range of studies is an infrasound level of 85 dB(G) or greater. The audibility threshold limit of 85 dB(G) is consistent with other European standards and studies, including the UK Department for Environment, Food and Rural Affairs threshold developed in 2003 [2], the UK Department of Trade and Industry study [4], the German Standard DIN 45680 [5] and independent research conducted by Watanabe and Moeller [6].

The generation of infrasound was detected on early turbine designs, which incorporated the blades 'downwind' of the tower structure [7]. The mechanism for the generation was the blade passing through the wake caused by the presence of the tower.

Australian States presently assess the noise from wind farms under a range of Standards and Guidelines [8, 9, 10, 11, 12]. These Standards and Guidelines do not provide prescriptive requirements for infrasound from wind farms due to the absence of evidence that infrasound should be assessed.

Notwithstanding, there have been concerns raised by the community regarding infrasound levels from wind farms.

To further investigate infrasound in the vicinity of Australian wind farms, this study, which was commissioned by Pacific Hydro:

- Develops a methodology to measure infrasound that minimises the influence of wind on the microphone;
- Measures the levels of infrasound at a range of distances from two wind farms;
- Compares the results against recognised audibility thresholds; and
- Compares the results with infrasound measurements made of natural sources, such as beaches, and man-made sources, such as a power station and general activity within the city of Adelaide.

Measurement Technique

Equipment

All measurements were conducted with a SVANTEK 957 Type 1 NATA calibrated sound and vibration analyser. The SVANTEK 957 Type 1 meter has a measured frequency response to 0.5 Hz. A GRAS 40AZ ½" free field microphone with a frequency response of ±1dB to 1 Hz and ±2dB to 0.5 Hz was also used. The meter and microphone arrangement is therefore suitable for measurement of noise levels in the infrasound range to the level of accuracy required for the assessment.

Microphone Mounting Method

A microphone mounting method is provided in IEC 61400-11 [13]. The method was developed to minimise the influence of wind on the microphone for the measurement of noise in frequencies higher than those associated with infrasound. This is achieved by mounting the microphone at ground level on a reflecting surface and by protecting the microphone with two windshields constructed from open cell foam. The method was not developed specifically for the measurement of infrasound, and wind gusts can be clearly detected when measuring in the infrasound frequency range using the above method.

Therefore, this study has developed an alternative method to reduce the influence of wind on the microphone that would otherwise mask the infrasound from the turbine.

A below ground surface method was developed based on a similar methodology [14]. This method has been adapted for this study, and includes a dual windshield arrangement, with an open cell foam layer mounted over a test chamber and a 90mm diameter primary windshield used around the microphone.

The microphone mounting arrangement is depicted in Figure 1.

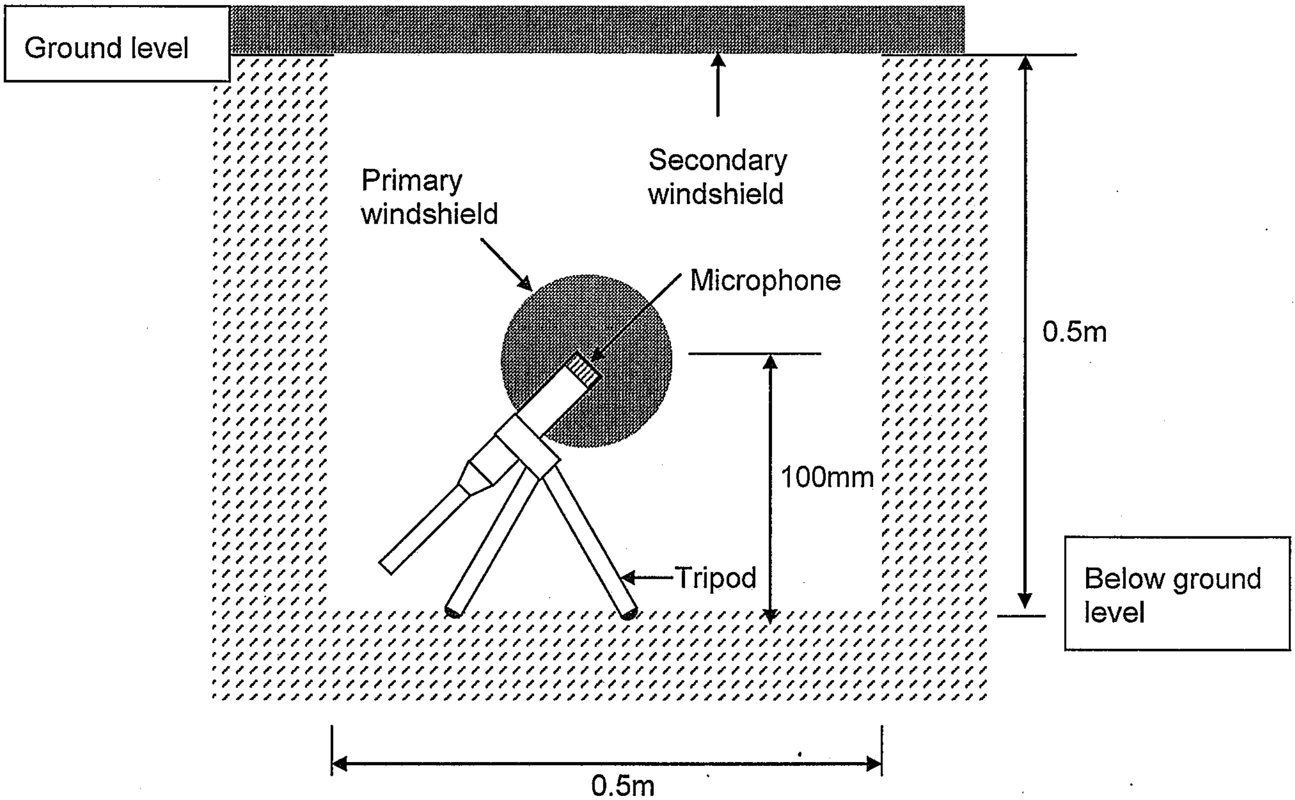

Figure 1 - Schematic of Microphone Position (not to scale)

Verification of Technique

The below ground technique was analysed at a remote site away from wind farms, transport corridors and other appreciable noise sources and in very still conditions.

The aim of the analysis was to determine the level of transfer of infrasound from outside to inside the chamber. The following procedure was used:

- A constant level of infrasound was generated using a tone signal generator and sub-woofer speaker (B&W Type ASW CDM), mounted 1m above the ground at a distance of 10m horizontally from the chamber. The infrasound was generated at a number of discrete frequencies between 8 and 20 Hz;
- The infrasound was measured using the IEC 61400-11 above ground technique;
- The infrasound was measured using the below ground technique;
- The infrasound was measured without the tone signal generator operating to determine the ambient level of infrasound.

The measurement results are summarised in Table 1.

Table 1 - Measurement approximately 10m from controlled source with no wind

Frequency (Hz)		8.00	10.0	12.5	16.0	20.0
Noise Level (dB)	Inside chamber	47	50	54	60	63
	Outside chamber	47	50	54	60	63
	Ambient Level	39	38	39	39	37

The measured levels inside and outside of the chamber were consistent at all of the frequencies produced by the signal generator. The table therefore confirms that the measurement of a constant source of infrasound in still conditions is the same above the ground as in the chamber using the technique described above. Therefore, the below ground technique is considered to be suitable to measure the infrasound from a source, whilst minimising the influence of wind on the microphone.

Results

Infrasound was measured at the Clements Gap Wind Farm in the mid-north of South Australia and Cape Bridgewater Wind Farm in the coastal region of south-western Victoria, using the verified below ground methodology. In addition, the level of infrasound was measured in the vicinity of a beach, a coastal cliff, a city and a power station.

At Clements Gap Wind Farm, the infrasound was measured at distances of 85m, 185m and 360m from the base of the turbine in a downwind direction. The testing was conducted between approximately 7pm and 11pm on Tuesday the 11th of May, 2010, under a clear night sky with a light breeze. Operational data indicates that the turbines were subject to hub height wind speeds of the order of 6 to 8m/s during the period of the testing.

At Cape Bridgewater Wind Farm, the infrasound was measured at distances of 100m and 200m from the base of the turbine in a downwind direction. The testing at the wind farm site was conducted between approximately 4am and 6am on Wednesday the 2nd of June, 2010, under a clear night sky with a light breeze. During the testing, the operational status of the turbines was constantly observed and confirmed. Measurements were conducted with the turbines operational and with the turbine blades stationary.

To determine the level of infrasound from natural sources, measurements were made in the vicinity of the Cape Bridgewater Wind Farm at 25m from the high waterline of a beach, at approximately 250m inland from a coastal cliff face and at 8km inland from the coast.

To determine the level of infrasound from other man-made noise sources, measurements were conducted at a distance of approximately 350m from a gas fired power station as well as within the city of Adelaide at approximately 70m and 200m from two major roads.

The measured levels of infrasound are summarised in Table 2 and are shown graphically in one third octave bands in Figures 2, 3, 4 and 5.

Table 2 – Measured levels of infrasound

Frequency (Hz)	Measured Level (dB(G))
Clements Gap Wind Farm at 85m	72
Clements Gap Wind Farm at 185m	67
Clements Gap Wind Farm at 360m	61
Cape Bridgewater Wind Farm at 100m	66
Cape Bridgewater Wind Farm at 200m	63
Cape Bridgewater Wind Farm ambient	62
Beach at 25m from high water line	75
250m from coastal cliff face	69
8km inland from coast	57
Gas fired power station at 350m	74
Adelaide city at 70 and 200m from roads	76

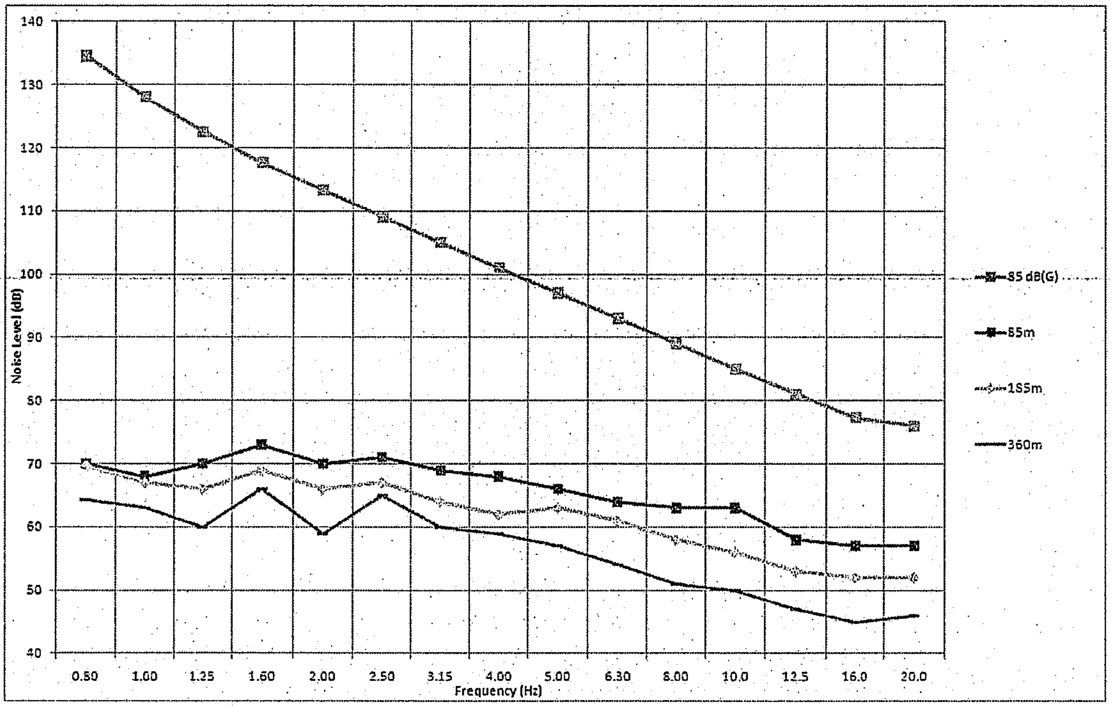

Figure 2 – Measured Levels of Infrasound at Clements Gap Wind Farm

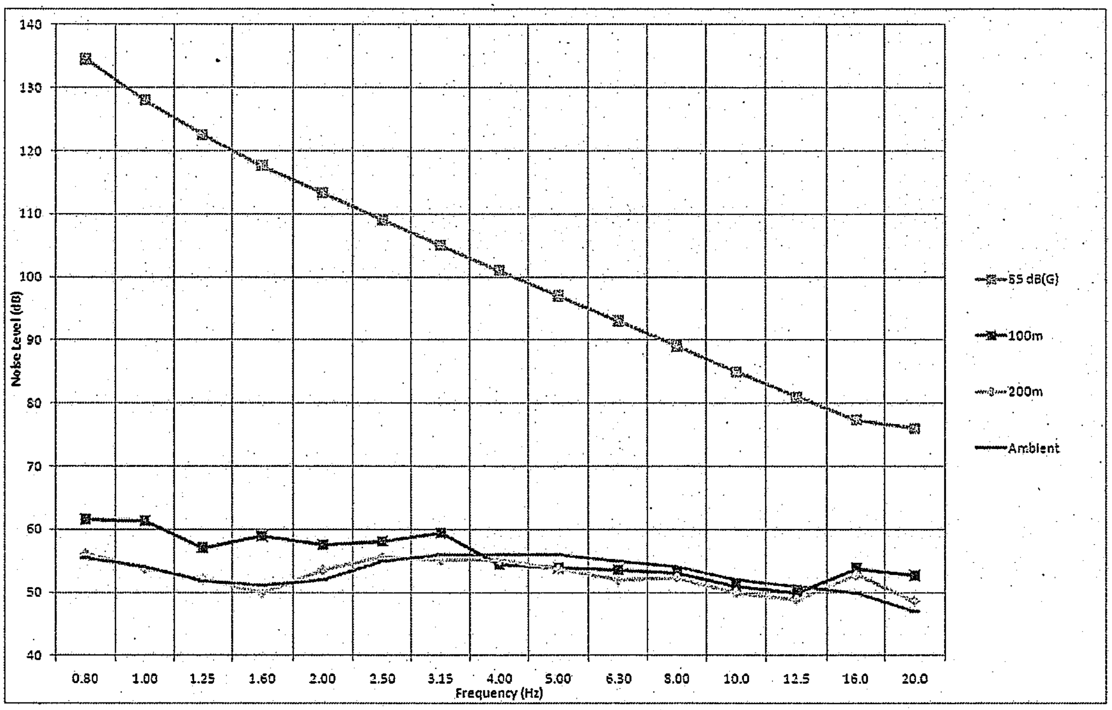

Figure 3 – Measured Levels of Infrasound at Cape Bridgewater Wind Farm

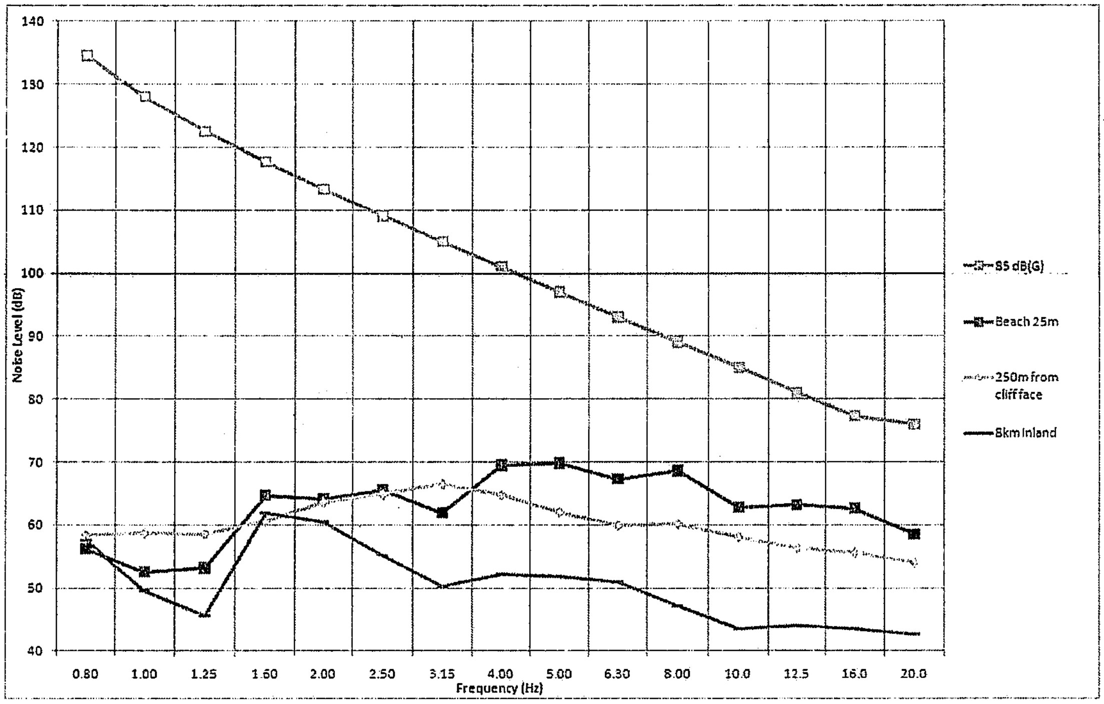

Figure 4 – Measured Levels of Infrasound from Natural Sources

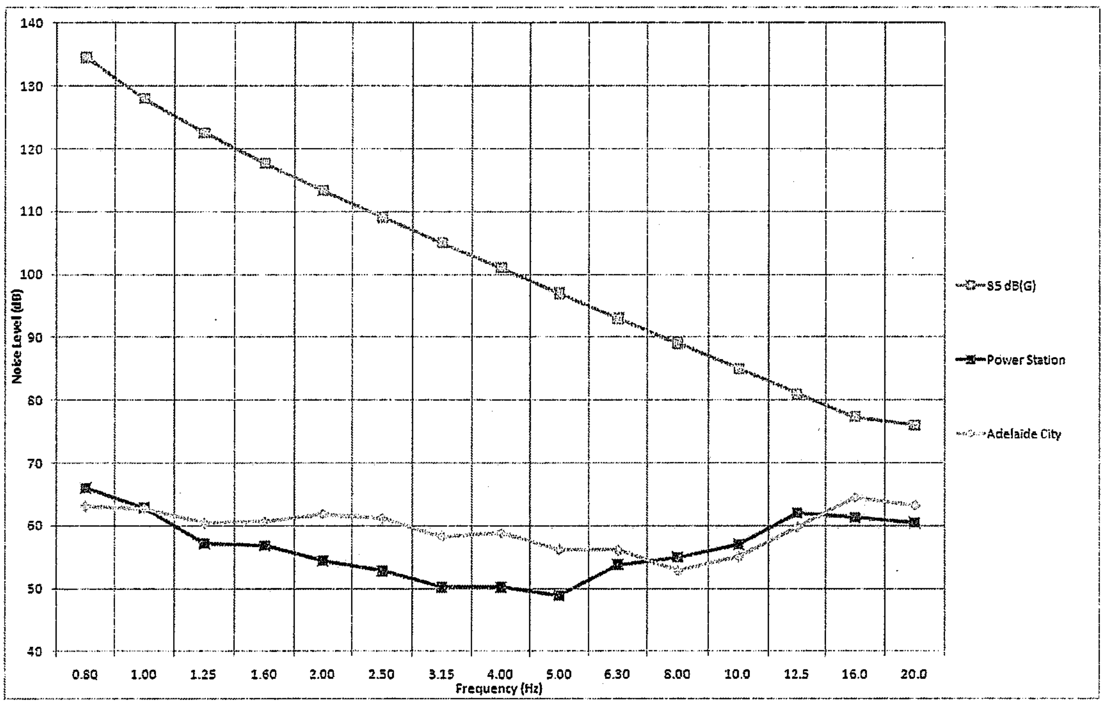

Figure 5 – Measured Levels of Infrasound from Man-made Sources

Discussion

At the Clements Gap Wind Farm, the level of attenuation with increasing distance from the turbine is consistent with the theoretical reduction of 6dB for each doubling of the distance due to "hemispherical spreading" of the sound wave. This observation confirms that the measured levels were predominantly produced by the turbine.

At the Cape Bridgewater Wind Farm, higher ambient noise levels (without the turbines rotating) were encountered than at the Clements Gap Wind Farm and therefore the same attenuation with increasing distance could not be observed. This indicates that the measured levels included a significant contribution of infrasound from the turbine at 100m but at a distance of 200m, the infrasound from other sources was at least as significant.

The levels of infrasound from waves at a beach (in light swell conditions) and in the vicinity of a coastal cliff were in the same order of magnitude as the infrasound measured close to turbines.

At 8km from the coast, the level of infrasound was significantly lower than in close proximity to the beach and the coastal cliff. This observation provides an explanation for the higher ambient levels of infrasound at the Cape Bridgewater Wind Farm.

The levels of infrasound in the city of Adelaide and in the vicinity of a gas fired power station were greater than the levels observed close to a wind turbine.

The measured levels of infrasound from the wind turbines and all other natural and man-made sources were well below the 85dB(G) threshold of audibility.

Conclusions

A method for measuring infrasound from wind turbines has been successfully demonstrated. The method shows that wind turbines generate infrasound and that close to wind turbines, the level of infrasound is well below the audibility threshold of 85 dB(G). An attenuation rate of 6dB per doubling of distance from a single turbine was also demonstrated.

The levels of infrasound produced by a wind turbine are similar to the levels produced by other man-made sources as well as natural sources along the coast.

The level of infrasound measured close to a wind turbine is prevalent in urban and coastal environments.

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Sonus Pty Ltd
17 Ruthven Avenue
ADELAIDE SA 5000
Phone: (08) 8231 2100
Facsimile: (08) 8231 2122
www.sonus.com.au
ABN: 67 882 843 130

INFRASOUND MEASUREMENTS FROM WIND FARMS AND OTHER SOURCES

Prepared for:

Pacific Hydro Pty Ltd
Level 11, 474 Flinders Street
Melbourne VIC 3000

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CONTENTS

EXECUTIVE SUMMARY

Infrasound is generated by a range of natural sources, including waves on a beach and against the coastline, waterfalls and wind. It is also generated by a wide range of man-made sources such as industrial processes, vehicles, air conditioning and ventilation systems and wind farms.

Specific International studies, which have measured the levels of infrasound in the vicinity of operational wind farms, indicate the levels are significantly below recognised perception thresholds and are therefore not detectable to humans.

The measurement of infrasound at low levels requires a specific methodology, as it is readily affected by wind on the microphone. Such a methodology has been developed for this study to measure infrasound from two Australian wind farms for the purposes of comparison against recognised perception thresholds. This study also measures the levels of infrasound from a range of natural and man made sources using the same methodology for the purposes of comparison against the wind farm results.

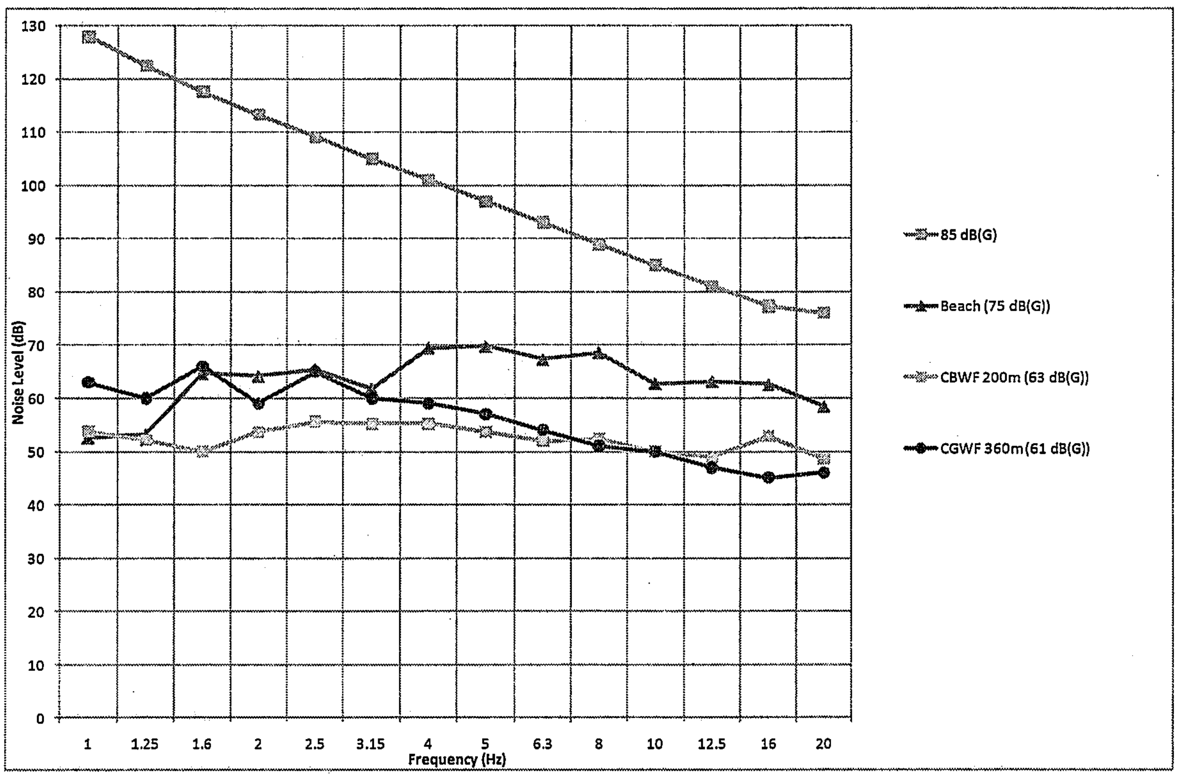
The specific methodology is based on measurements being conducted below the ground surface in a test chamber that is approximately 500mm square and 500mm deep to reduce the influence that even light surface breezes can have on the infrasound results.

The below ground methodology has been tested as part of this study and it has been confirmed that levels of infrasound above the ground and within the chamber are the same in the absence of surface winds when measuring a known and constant source of infrasound.

The methodology has also been tested on site, and it has been confirmed that the expected theoretical reduction in infrasound of 6 dB per doubling of distance can be measured from a wind turbine. This reduction cannot be measured above the ground surface due to wind on the microphone influencing the results. This result confirms that the below ground methodology is able to reduce the influence of wind on the microphone to identify the level of infrasound from a noise source.

Infrasound was measured at two Australian wind farms, Clements Gap in the mid-North of South Australia (CGWF) and Cape Bridgewater in the coastal region of south-western Victoria (CBWF), using the below ground methodology. Infrasound was also measured in the vicinity of a beach, the coastline, a central business area and a power station using the below ground methodology.

A summary graph of the results of the infrasound measurement results at the wind farms and at a beach are shown below against the perception threshold for infrasound established in international research as 85 dB(G).



Summary Graph – Infrasound measurement results from two Australian wind farms (Clements Gap at 61 dB(G) and Cape Bridgewater at 63 dB(G)) compared against measurement results at a beach (measured at 75 dB(G)) and the internationally recognised Audibility Threshold (85 dB(G))

The measurement results indicate that the levels of infrasound in the vicinity of the two Australian wind farms are:

- well below the perception threshold established in International research as 85 dB(G); and
- of the same order as other International infrasound measurement results (a table summarising the results of other measurements is provided in this study); and
- of the same order as that measured from a range of sources including the beach, the Adelaide Central Business District and a power station.

This Australian study therefore reinforces several international studies by government organisations that infrasound emissions from wind farms are well below the hearing threshold and are therefore not detectable to humans.

This study goes beyond the international studies by providing comparative measurements of natural and other human made sources. These sources, including waves on a beach and motor vehicles, have been found to generate infrasound of a similar order to that measured in close proximity to wind farms.

In addition, measurements of the transfer of infrasound from outside to inside a dwelling have been made in this study, to confirm that the levels of infrasound inside a dwelling will be lower than the levels of infrasound outside a dwelling for an external noise source. This information is important because there is limited research available on this transfer.

INTRODUCTION

Noise is often the most important factor in determining the separation distance between wind turbines and sensitive receivers. The assessment of noise therefore plays a significant role in determining the viability of and the size of wind farms.

Australian States presently assess the noise from wind farms under a range of Standards and Guidelines. These Standards and Guidelines do not provide prescriptive requirements for infrasound from wind farms due to the absence of evidence that infrasound should be assessed.

Notwithstanding, there have been concerns raised by the community regarding infrasound levels from wind farms.

Pacific Hydro has therefore engaged Sonus to make an independent assessment of the infrasound produced by wind farms.

To further investigate infrasound in the vicinity of Australian wind farms, this study:

- Develops a methodology to measure infrasound that minimises the influence of wind on the microphone;
- Measures the levels of infrasound at a range of distances from two wind farms;
- Compares the results against recognised audibility thresholds;
- Compares the results with previous wind farm infrasound measurements made in a range of other studies; and
- Compares the results with infrasound measurements made of natural sources, such as beaches, and man-made sources, such as a power station and general activity within the Central Business District of Adelaide.

INTERNATIONAL DESKTOP RESEARCH

Noise is inherently produced by movement. There are two main moving parts that generate the environmental noise from a wind turbine, being the external rotating blades and the internal mechanical components such as the gearbox and generator.

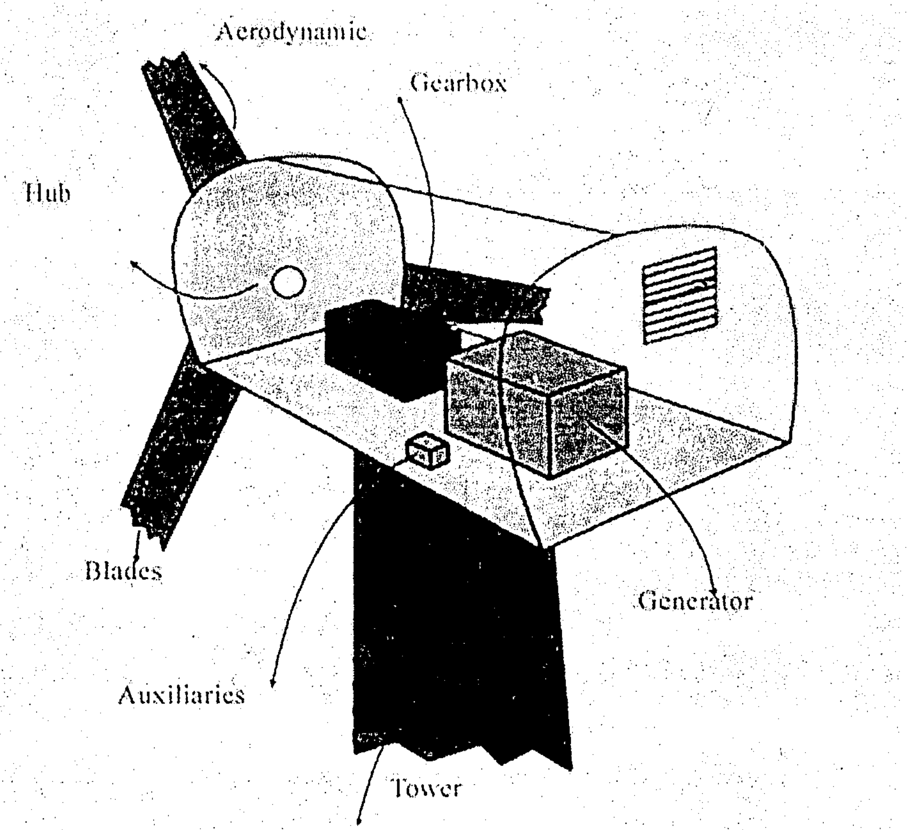


Figure 1 - (Modified from Wagner 1996)

The noise from the blades and the internal machinery are commonly categorised as mechanical and aerodynamic noise respectively.

Mechanical Noise

Mechanical noise sources are primarily associated with the electrical generation components of the turbine, typically emanating from the gear box and the generator. Mechanical noise was audible from early turbine designs, however, on modern designs, mechanical noise has been significantly reduced (Moorhouse et al., 2007).

Aerodynamic Noise

Aerodynamic noise typically dominates the noise emission of a wind turbine and is produced by the rotation of the turbine blades through the air.

Turbine blades employ an airfoil shape to generate a turning force. The shape of an airfoil causes air to travel more rapidly over the top of the airfoil than below it, producing a lift force as air passes over it. The nature of this air interaction produces noise through a variety of mechanisms (Brooks et al., 1989).

Aerodynamic noise is broadband in nature and includes acoustic energy in the infrasound, low, mid and high frequency ranges.

Whilst the aerodynamic noise from a rotating turbine blade produces energy in the infrasound range, there are natural sources of infrasound including wind and breaking waves, and a wide range of man-made sources such as industrial processes, vehicles and air conditioning and ventilation systems that make infrasound prevalent in the natural and urban environment (Howe, 2006).

Aerodynamic noise can be further separated into the following categories which are relevant to the infrasound study:

Amplitude Modulation

Amplitude modulation is most commonly described as a "swish" (Pedersen, 2005). "Swish" is a result of a rise and fall in the noise level from the moving blades. The noise level from a turbine rises during the downward motion of the blade. The effect of this is a rise in level of approximately once per second for a typical three-bladed turbine as each blade passes through its downward stroke.

It was previously thought that "swish" occurred as the blade passed the tower, travelling through disturbed airflow, however, a recent study indicates it is related to the difference in wind speed over the swept area of a blade (Oerlemans and Schepers, 2009).

Other explanations for the rise in noise level that occurs on the downward stroke relate to the slight tilt of the rotor-plane on most modern wind turbines to ensure that the blades do not hit the tower. An effect of the tilt is that when the blades are moving downwards they are moving against the wind. Conversely, when moving upwards they are moving in the same direction as the wind. Therefore, with the effective wind speed being higher on the downward stroke, it is suggested that a higher noise level is produced.

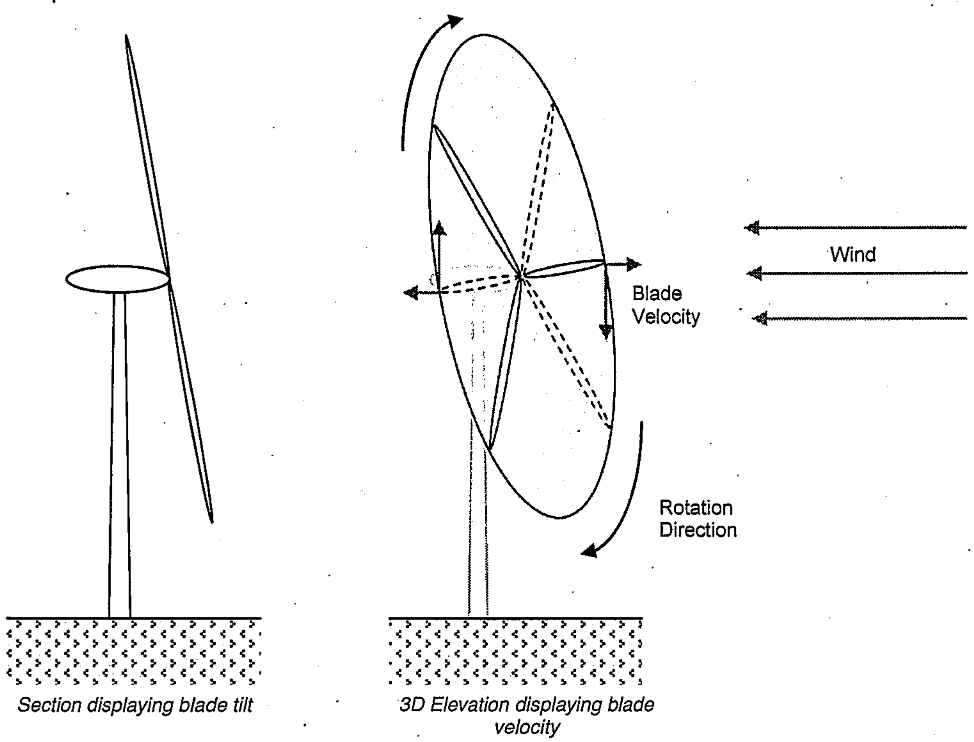


Figure 2 - Blade Velocity due to Tilt

Low Frequency Noise

Noise sources that produce low frequency content, such as a freight train locomotive or diesel engine have dominant noise content in the frequency range between 20 and 200 Hz (O'Neal et al, 2009). Low frequency noise is often described as a "rumble".

Aerodynamic noise from a wind turbine is not dominant in the low frequency range. The main content of aerodynamic noise generated by a wind turbine is often in the area known generically as the mid-frequencies, being between 200 and 1000Hz.

Noise reduces over distance due to a range of factors including atmospheric absorption. The mid and high frequencies are subject to a greater rate of atmospheric absorption compared to the low frequencies and therefore over large distances, whilst the absolute level of noise in all frequencies reduces, the relative level of low frequency noise compared to the mid and high frequency content increases. For example, when standing alongside a road corridor, the mid and high frequency noise from the tyre and road interaction is dominant, particularly if the road surface is wet. However, at large distances from a road corridor in a rural environment, the remaining audible content is the low frequency noise of the engine and exhaust.

This effect will be more prevalent in an environment that includes masking noise in the mid and high frequencies, such as that produced by wind in the trees.

Separation distances between wind farms and dwellings can be of the order of 800 to 1200m. At these distances, in an ambient environment where wind in the trees is present, it is possible that only low frequencies remain audible and detectable from a noise source that produces content across the full frequency range. This effect will become more prevalent for larger wind farms because the separation distances need to be greater in order to achieve the relevant noise standards. A greater separation distance changes the dominant frequency range from the mid frequencies at locations close to the wind farm to the low frequencies further away, due to the effects described above.

Low frequency sound produced by wind farms is not unique in overall level or content. Low frequency noise from other sources that is well in excess of that in the vicinity of a wind farm can be measured and heard at a range of suburban and rural locations.

The low frequency content of noise from a wind farm is inherently considered as part of its environmental noise assessment against relevant standards and guidelines.

Infrasound

Infrasound is generally considered to be noise at frequencies less than 20 Hz (O'Neal et al., 2009). The generation of infrasound was detected on early turbine designs, which incorporated the blades 'downwind' of the tower structure (Hubbard and Shepherd, 1990). The mechanism for the generation was that the blade passed through the wake caused by the presence of the tower.

Audible levels of infrasound have been measured from downwind blade wind turbines (Jakobsen, J., 2005). Modern turbines locate the blades upwind of the tower and it is found that turbines of contemporary design now produce much lower levels of infrasound (Jakobsen, J., 2005), (Hubbard and Shepherd 1990).

Infrasound is often described as inaudible, however, sound below 20 Hz remains audible provided that the sound level is sufficiently high (O'Neal et al., 2009). The thresholds of hearing for infrasound have been determined in a range of studies (Leventhall, 2003). These thresholds are depicted in graphical form below for frequencies less than 20 Hz (Figure 3).

Non-audible perception of infrasound through felt vibrations in various parts of the body is also possible, however, this is found to only occur at levels well above the audible threshold (Moeller and Pedersen, 2004).

Weighting networks are applied to measured sound pressure levels to adjust for certain characteristics. The A-weighting network (dB(A)) is the most common, and it is applied to simulate the human response for sound in the most common frequency range. The G-weighting has been standardised to determine the human perception and annoyance due to noise that lies within the infrasound frequency range (ISO 7196, 1995).

A common audibility threshold from the range of studies is an infrasound noise level of 85 dB(G) or greater. This is used by the Queensland Department of Environment and Resource Management's (DERM's) draft Guideline for the assessment of low frequency noise as the acceptable level of infrasound in the environment from a noise source to protect against the potential onset of annoyance.

The audibility threshold limit of 85 dB(G) is consistent with other European standards and studies, including the UK Department for Environment, Food and Rural Affairs threshold developed in 2003 (DEFRA., Leventhall, 2003), the UK Department of Trade and Industry study (DTI, Hayes McKenzie, 2006), the German Standard DIN 45680, the Denmark National Standard and independent research conducted by Watanabe and Moeller (Watanabe and Moeller, 1990).

The 85 dB(G) audibility threshold limit is shown in Figure 3 below. Other audibility thresholds have also been overlaid to provide a comparison.

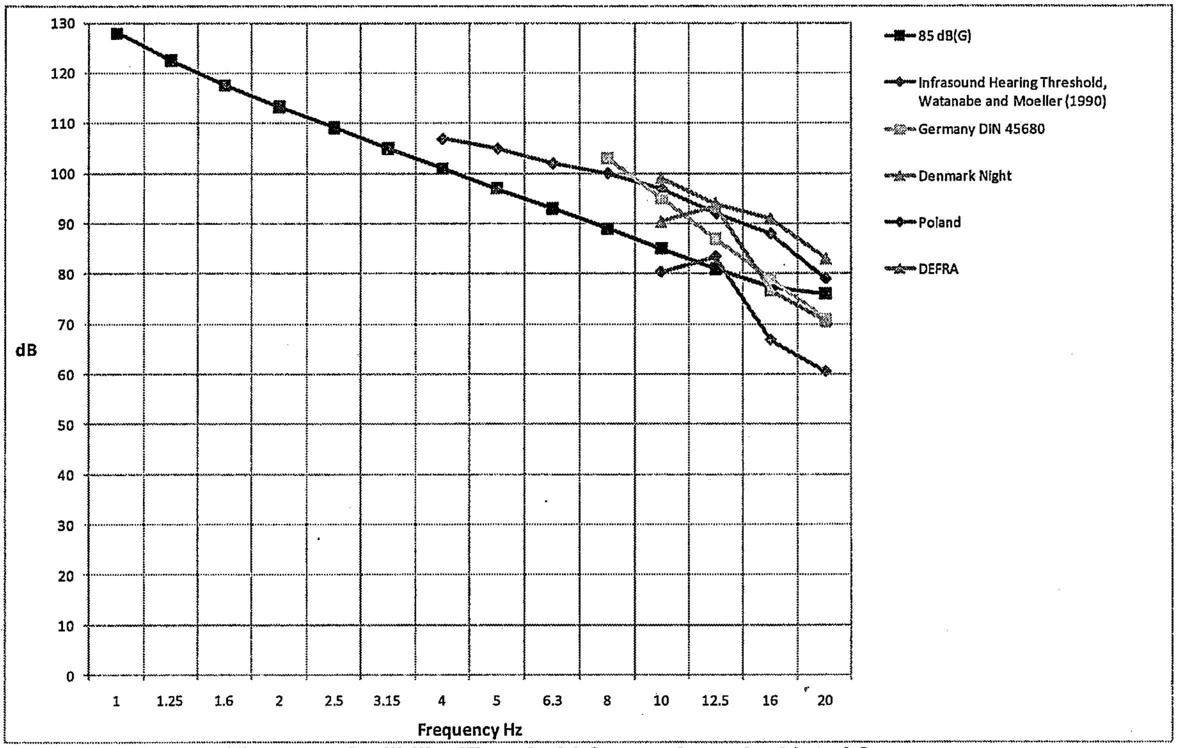


Figure 3 - Audibility Threshold Curves from the Listed Sources

DETERMINATION OF A MEASUREMENT METHODOLOGY

Microphone Mounting Method

A microphone mounting method is provided in IEC 61400-11 (IEC, 2002), as shown in Figure 4 below. The method was developed to minimise the influence of wind on the microphone for the measurement of noise in frequencies higher than those associated with infrasound. This is achieved by mounting the microphone at ground level on a reflecting surface and by protecting the microphone with two windshields constructed from open cell foam.

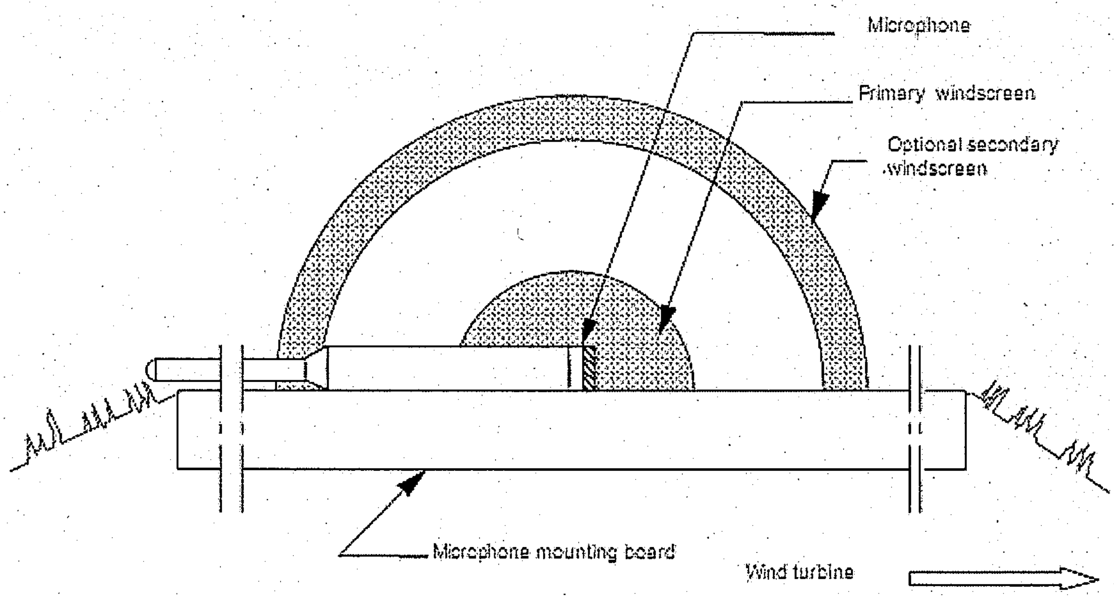


Figure 4 - Mounting of the microphone – vertical cross-section (Reproduced from Figure 1b, IEC 61400-11)

The above method was not developed specifically for the measurement of infrasound, and wind gusts can be clearly detected when measuring in the infrasound frequency range using the above method.

Therefore, this study has developed an alternative method to reduce the influence of wind on the microphone that would otherwise mask the infrasound from the turbine.

A below ground surface method was developed based on a similar methodology (Betke et al, 2002). This method has been adapted for this study, and includes a dual windshield arrangement, with a foam layer mounted over a test chamber, and a primary windshield used around the microphone.

The microphone mounting arrangement is depicted in the following schematic:

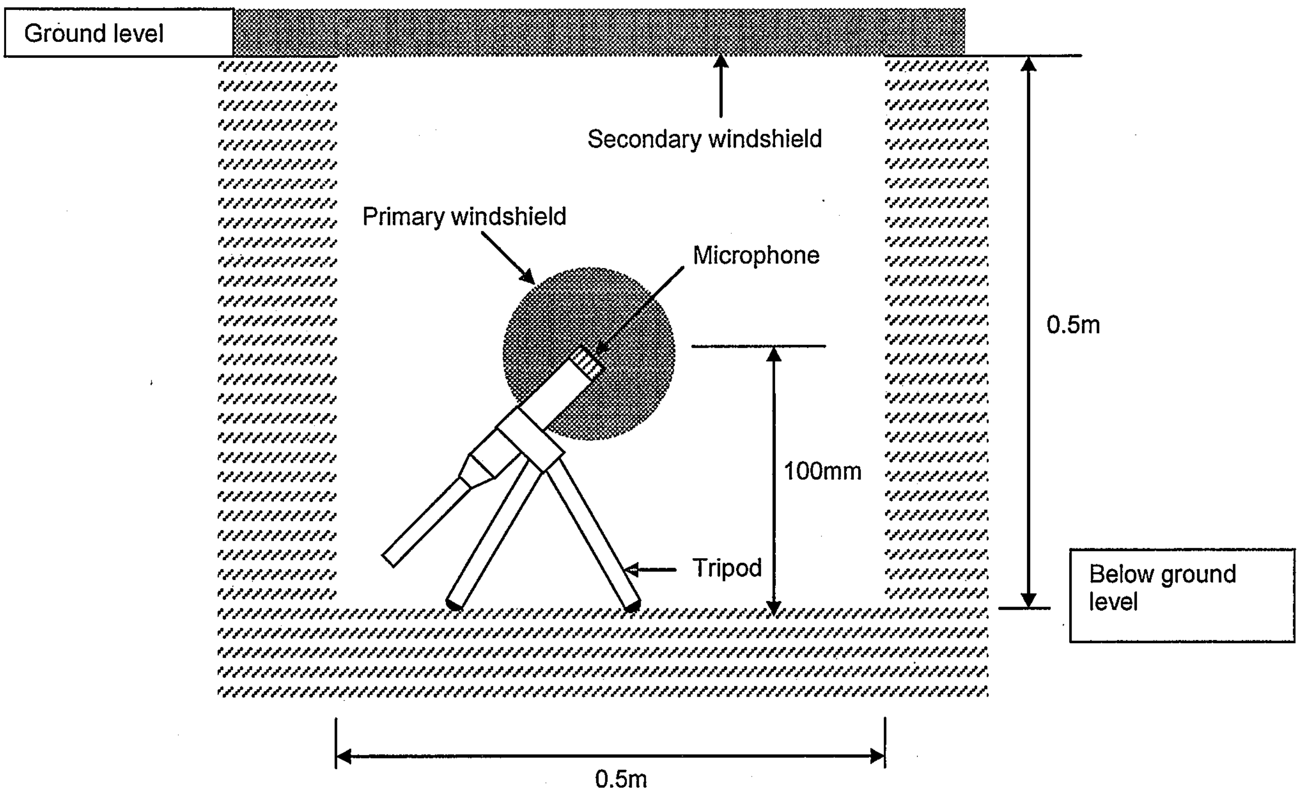


Figure 5 - Schematic of Microphone Position

Inputs

The measurement methodology was developed with the following inputs:

- Literature review related to wind turbine infrasound research;

- Measurements to determine the influence of wind on the microphone using different measurement techniques, including the IEC 61400-11 measurement procedure, placing the microphone in an enclosure above the ground, and placing the microphone in a 500mmx500mmx500mm deep (approximate) test chamber with an open cell foam (acoustically transparent) lid, based on the Betke et al method. The measurements were initially made at locations without any appreciable man made noise sources;

- Measurements to determine the level of transfer of infrasound at a range of different frequencies between 8Hz and 20Hz, from immediately outside a chamber to inside a chamber, under conditions of negligible wind and ambient noise influence. The infrasound noise source (bass speaker and tone signal generator) was placed 10m away from the chamber and 1m above the ground;

- Measurements to determine the level of transfer of infrasound at a range of different frequencies between 8Hz and 20Hz, from immediately outside a lightweight elevated dwelling with windows open, to inside a room within that dwelling, under conditions of negligible wind and ambient noise influence, comprising use of an infrasound noise source (bass speaker and tone signal generator) placed 10m from the dwelling and 1m above the ground;

- Discussions with Mr Andrew Roberts of REPower Australia Pty Ltd regarding the test measurement procedure and the preliminary results.

Based on the above, the important factors for an infrasound measurement methodology comprise:

- The ability to reduce the influence of wind on the microphone;
- Turning the noise source on and off to confirm infrasound from the source can be identified within the ambient environment;
- Measurement conditions that minimise the influence of the ambient environment whilst enabling the operation of a wind farm. This is expected to comprise a light breeze (similar to a Beaufort Scale 2 breeze of between 2 and 3 m/s at ground level) occurring on a night or early morning with a clear sky.

MEASUREMENTS

Equipment

All measurements were made with the SVANTEK 957 Type 1 NATA calibrated sound and vibration analyser. The SVANTEK 957 Type 1 meter has a measured frequency response to 0.5 Hz. A GRAS 40AZ ½" free field microphone with a frequency response of ±1dB to 1 Hz was also used. The meter and microphone arrangement is therefore suitable for measurement of noise levels in the infrasound range.

Controlled Verification

The below ground technique was analysed at a remote site away from a wind farm, transport corridor or other appreciable noise source and in very still conditions. The location was a suburban property in Blackwood, a suburb of the Adelaide Hills.

The aim of the analysis was to determine the level of transfer of infrasound from outside to inside the chamber. The following procedure was used:

- Generation of a constant level of infrasound using a tone signal generator and sub-woofer speaker, mounted 1m above the ground at a distance of 10m horizontally from the chamber. The infrasound was generated at a number of discrete frequencies between 8 and 20 Hz;
- Measurement of the infrasound using the IEC 61400-11 above ground technique;
- Measurement of the infrasound using the below ground technique;
- Measurement of the infrasound without the tone signal generator operating (ambient infrasound).

In addition, to provide additional information regarding the noise level reduction of infrasound from outside to inside a dwelling, a measurement of infrasound inside a lightweight dwelling with the windows open was also made at a number of discrete frequencies.

The testing was conducted between approximately 9pm and 11pm on two occasions in Blackwood under conditions of negligible breeze and no appreciable ambient noise sources.

The measurement results are summarised in the following tables and the ambient noise level is shown in Figure 6.

Table 1 - Measurement approximately 10m from controlled source with no wind

Frequency (Hz)		8.00	10.0	12.5	16.0	20.0
Noise Level (dB)	Inside chamber	47	50	54	60	63
	Outside chamber	47	50	54	60	63

Table 2 - Measurement of ambient conditions in test location (controlled source turned off)[1]

Frequency (Hz)	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	39	38	39	39	37	51

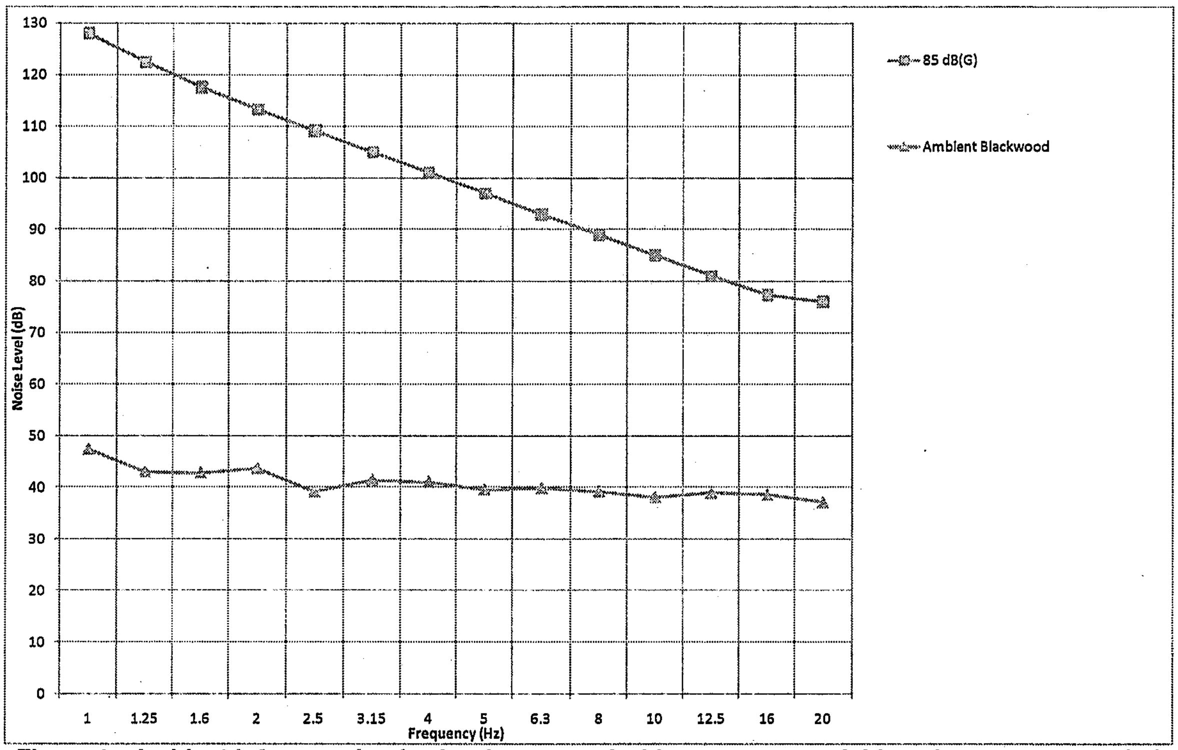


Figure 6 - Ambient infrasound noise level measured without any appreciable noise sources or wind

[1] Measurements of the ambient levels of infrasound were also made at frequencies lower than 8 Hz. These results are shown in Figure 8. The sub-woofer arrangement was not able to generate infrasound below 8 Hz. Table 7 shows the results from 8 Hz to 20 Hz for the purposes of comparison with Table 6.

The results of the testing of the effect of a lightweight facade (with the windows open) on the transfer of infrasound are presented in the following tables:

Table 3 - Measurement of facade transfer with controlled source

Frequency (Hz)		10.0	16.0	20.0
Noise Level (dB)	Inside house	47	61	54
	Outside house	54	63	56

Table 4 - Measurement of ambient conditions in house locations

Frequency (Hz)		10.0	16.0	20.0
Noise Level (dB)	Inside house	37	41	34
	Outside house	42	43	41

The above conclusions can be made from the above results and on site observations:

- The measurement of a constant source of infrasound in still conditions is the same above the ground as in the chamber using the technique described above. Therefore, the below ground technique can be used to measure the infrasound from a source;
- The results are consistent at a number of discrete frequencies between 8 Hz and 20 Hz;
- The levels of infrasound inside a dwelling will be lower than the levels of infrasound outside a dwelling for an external noise source. This information is important because there is limited research available on this transfer. These results are consistent with Jakobsen, J., 2005, who found that "the outdoor to indoor correction may be quite small in a part of the infrasound range, but it is unlikely to become negative, which would imply a higher level indoors than out of doors".

RESULTS

Infrasound was measured at Clements Gap in the mid-North of South Australia (CGWF) and Cape Bridgewater in the coastal region of south-western Victoria (CBWF), using the verified below ground methodology. At Clements Gap, measurements were also made concurrently using the above ground technique provided by IEC 61400-11.

The following sections summarise the results of the measurements at the wind farms and in the vicinity of other sources of infrasound including a beach, the coastline, a central business area and a power station.

Testing at Clements Gap Wind Farm

Testing at the Clements Gap wind farm was conducted using the following procedure:

- Measurement of infrasound using the IEC 61400-11 above ground technique at distances of 85, 185 and 360m from the base of the turbine in a downwind direction; and
- Measurement of infrasound using the below ground technique at distances of 85, 185 and 360m from the base of the turbine in a downwind direction.

The testing was conducted between approximately 7pm and 11pm on Tuesday the 11th of May under a clear night sky with a light breeze. Operational data indicates the turbines were subject to hub height wind speeds of the order of 6 to 8m/s during the period of the testing.

The measurement results in close proximity to the wind turbine are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold.

Twenty (20) continuous 1 minute measurements were made at each location. The presented results are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results. The number of continuous measurements is based on the on site observations regarding the repeatability of the results.

Table 5 - Measurement approximately 85m downwind from closest operational turbine (No. 25)

Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	68	70	73	70	71	69	68	66	64	63	63	58	57	57	72
	Outside chamber	70	71	72	70	69	69	68	67	66	63	60	57	57	56	71

Table 6 - Measurement approximately 185m downwind from closest operational turbine (No. 25)

Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	67	66	69	66	67	64	62	63	61	58	56	53	52	52	67
	Outside chamber	80	79	79	77	77	77	75	75	73	72	71	69	66	64	80

Table 7 - Measurement approximately 360m downwind from closest operational turbine (No. 25)

Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	63	60	66	59	65.	60	59	57	54	51	50	47	45	46	61
	Outside chamber	71	69	72	72	72	68	69	65	64	61	59	55	53	50	67

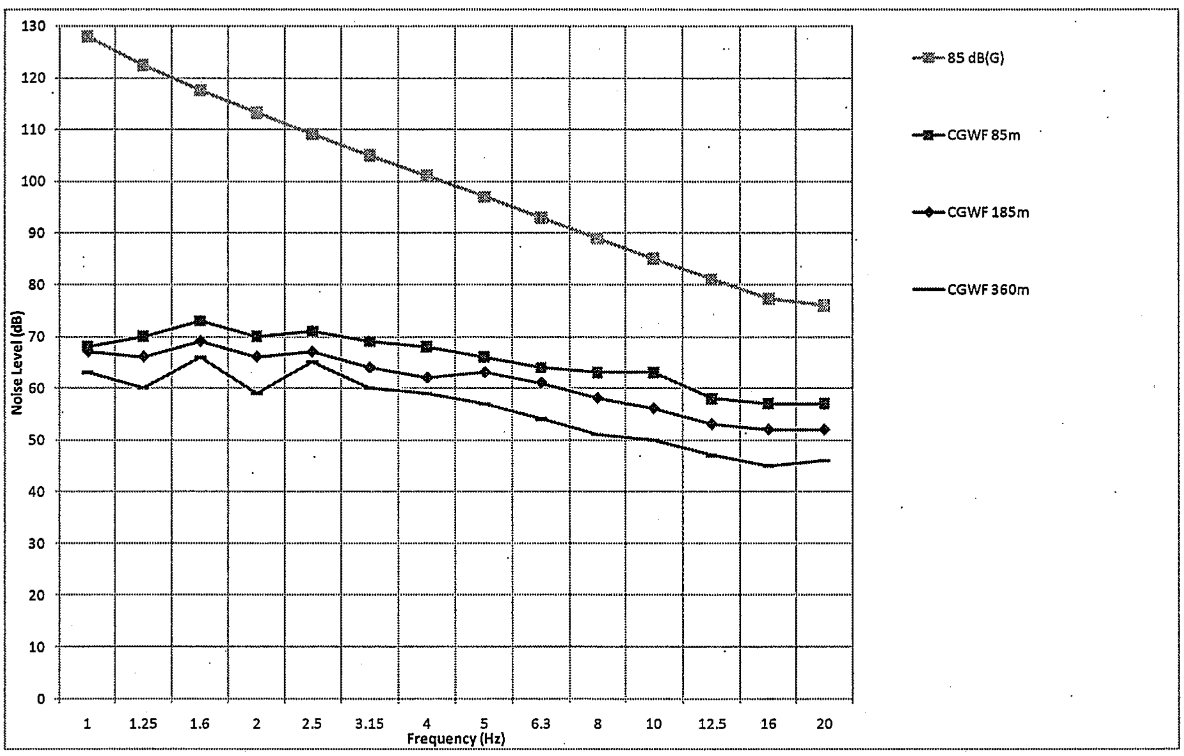


Figure 7 - Infrasound measurements below the ground at Clements Gap wind farm

The theoretical reduction in noise level from a noise source is 6dB for every doubling of the distance from that source due to the "hemispherical spreading" of the sound wave. This reduction theoretically applies to noise at all frequencies, including below 20 Hz. Tables 5, 6 and 7 indicate that a reduction in the order of 6 dB is achieved using the below ground technique, but not for the above ground technique. This is due to the above ground measurements being influenced by surface wind on the microphone.

The following conclusions can be made from the results and on site observations:

- The wind turbines generate infrasound;
- The level of infrasound is well below the audibility threshold of 85 dB(G);
- The distances at which the measurements of the operational wind farm were made are significantly less than separation distances expected between a wind farm and a dwelling, where the levels of infrasound will be correspondingly lower;
- A noise level reduction of approximately 6 dB was measured inside the chambers when doubling the distance from turbine 25. This indicates the level of infrasound measured below the ground was directly associated with turbine 25;
- The measurements above the ground surface did not reduce by 6 dB due to the presence of surface winds and their influence on the results. This indicates the IEC 61400-11 based test does not enable the infrasound from the turbines to be separated from infrasound due to the wind.

In addition to the above testing in close proximity to an individual turbine, the "Byarlea" residence was visited, which is approximately 1200m to the east of the nearest turbines in the Clements Gap wind farm.

An infrasound measurement was made within a room of the dwelling. The refrigerator was operating in the dwelling at the time of the measurement but a full survey of other operating equipment was not made. A level of the order of 51 dB(G) was measured.

Given the still conditions at the dwelling at the time of inspection, a local above ground infrasound measurement outside the dwelling was able to be made. A level of the order of 58 dB(G) was measured. The results of the measurements are presented in Tables 8 and 9 and Figure 8 below:

Table 8 - Measurement inside a room of a dwelling

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	60	49	54	54	59	52	50	45	43	41	43	38	38	33	**51**

Table 9 - Measurement outside of dwelling

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	47	45	53	47	54	54	50	50	45	44	44	43	43	43	**58**

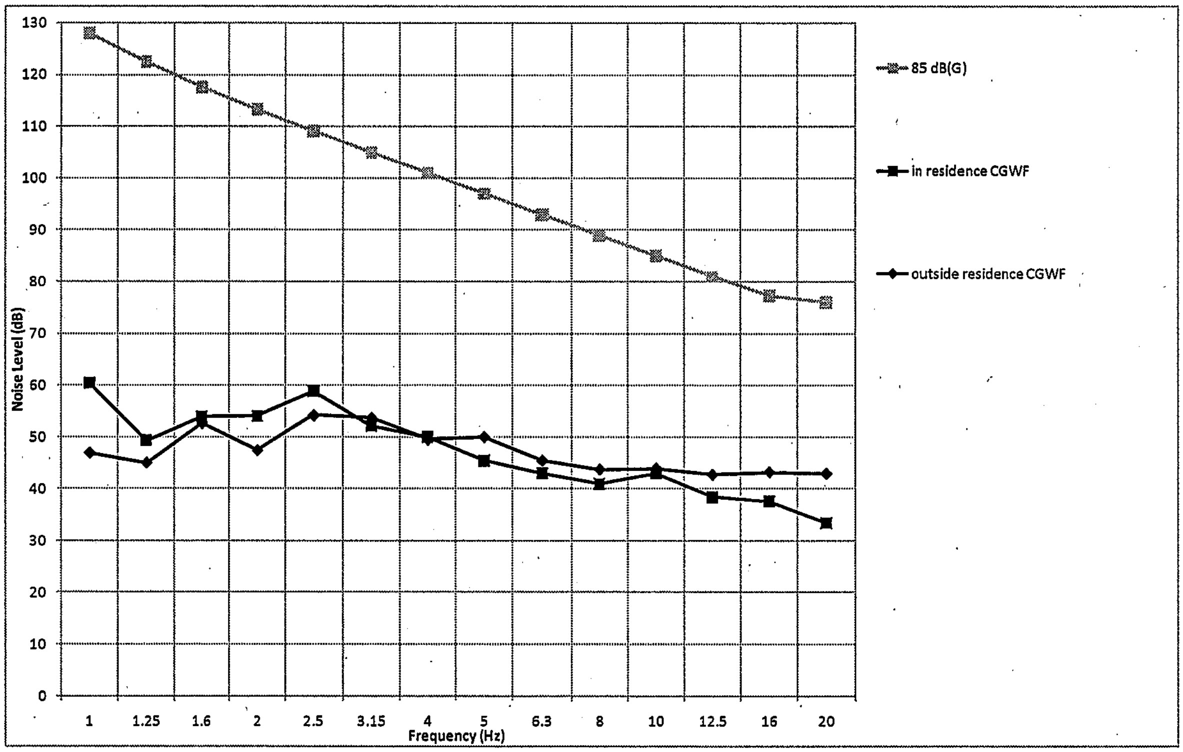


Figure 8 - Measurements of infrasound inside and outside a dwelling in the vicinity of the Clements Gap wind farm

The above conclusions can be made from the above results and on site observations:

- The levels of infrasound inside a dwelling in the vicinity of a number of turbines associated with the Clements Gap wind farm is well below the audibility threshold of 85 dB(G);
- The levels of infrasound outside a dwelling in the vicinity of a number of turbines associated with the Clements Gap wind farm is well below the audibility threshold of 85 dB(G).

Sonus

Testing at Cape Bridgewater Wind Farm

The controlled verification testing and the Clements Gap Wind Farm test confirmed that the use of the below ground technique was able to reduce the influence of wind on the microphone and identify the level of infrasound associated with a wind turbine and/or a wind farm.

Therefore, testing at the Cape Bridgewater wind farm was conducted using the following trialled and analysed procedure based around the below ground technique:

- Measurement of infrasound using the below ground technique in close proximity to an operating wind turbine at distances of 100 and 200m from the base of the turbine in a downwind direction;
- Measurement of infrasound with the wind farm not operating;
- Measurement of infrasound at the beach to the east of Cape Bridgewater;
- Measurement of infrasound in the vicinity of the coastline to the west of Cape Bridgewater;
- Measurement of infrasound in a designated forest area approximately 8km inland from the coast, under conditions of negligible wind.

The testing at the wind farm site was conducted between approximately 4am and 6am on Wednesday the 2nd of June under a clear night sky with a light breeze. During the testing, the operational status of the turbines was constantly observed and confirmed. The results in Tables 10 and 11 were taken at distances of 100m and 200m respectively from the closest operational turbine. The results in Table 12 were taken with the wind farm stationary at the 100m measurement location.

The measurement results in close proximity to the wind turbine are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold and the ambient noise result from the Adelaide Hills.

Twenty (20) continuous 1 minute measurements were made at each location. The presented results are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results.

Table 10 - Measurement approximately 100m downwind from closest operational turbine

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	61	57	59	58	58	59	55	54	54	53	51	50	54	53	**66**

Table 11 - Measurement approximately 200m downwind from closest operational turbine

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	54	52	50	54	56	55	55	54	52	52	50	49	53	49	**63**

Table 12 - Ambient infrasound measurement (with the wind farm not operating)

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	54	52	51	52	55	56	56	56	55	54	52	51	50	47	**62**

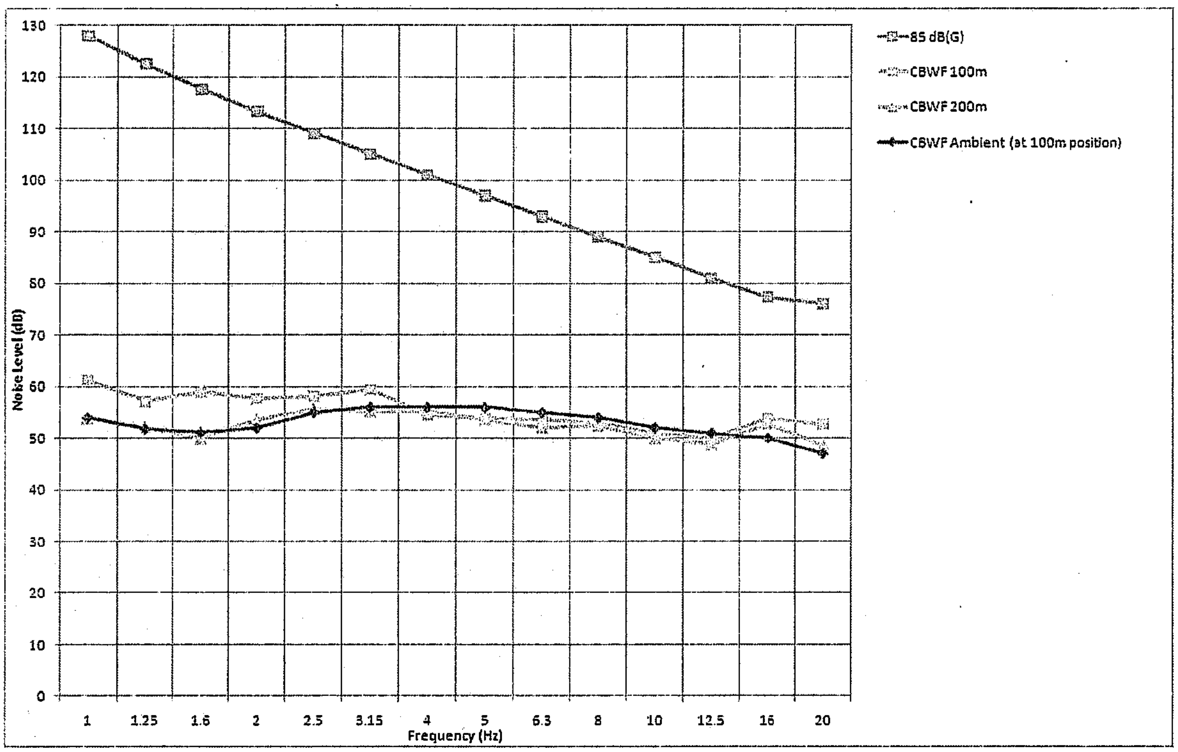


Figure 9 - Infrasound measurements below the ground at Cape Bridgewater wind farm

The above conclusions can be made from the above results and on site observations:

- The wind turbines generate infrasound;
- The level of infrasound is well below the audibility threshold of 85 dB(G);
- The distances at which the measurements of the operational wind farm were made are significantly less than separation distances between a wind farm and a dwelling, where the levels of infrasound will be correspondingly lower;
- A high level of ambient infrasound exists (infrasound in the absence of noise from the wind farm) which influences the results for the wind turbines.

Measurements were made in the vicinity of the adjacent beach and the coastline to confirm the source of the high ambient infrasound levels. In addition, a measurement was made inland to determine the extent of influence of the high ambient infrasound levels.

The results of the measurements are presented in Figure 10 below:

Table 13 – Beach at approximately 25m from the high water mark

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	53	53	65	64	66	62	70	70	67	69	63	63	63	59	**75**

Table 14 –On the cliff face at approximately 250m from the coastline

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	59	59	61	64	65	67	65	62	60	60	58	56	56	54	**69**

Table 15 – Inland at approximately 8km from the coast

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	50	46	62	61	55	50	52	52	51	47	44	44	44	43	**57**

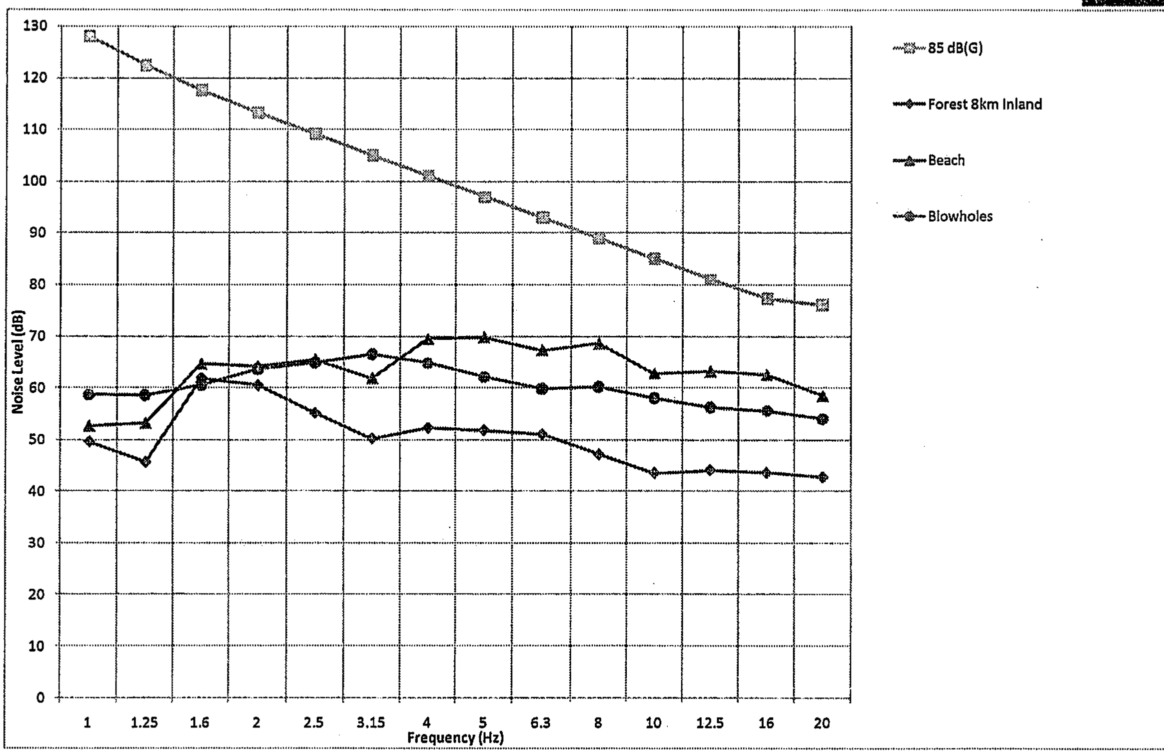
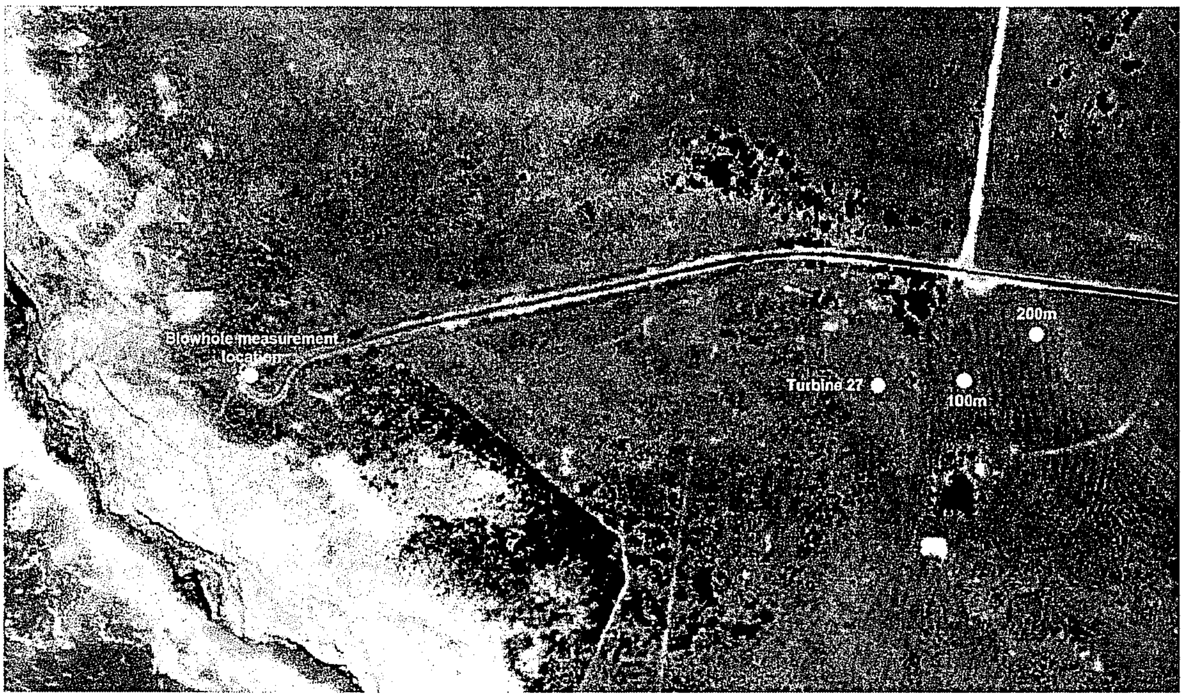


Figure 10 - Ambient noise measurements in the vicinity of Cape Bridgewater

The following conclusions can be made from the above results and on site observations:

- Natural sources generate infrasound;
- The levels of infrasound from natural sources are of the same order as those measured within 100m of a wind turbine;
- Measurable levels of infrasound that are of a similar order to that measured in close proximity to a wind farm are prevalent in the natural environment over a large area due to sources other than wind farms.

The following map depicts measurement locations relative to the turbine:



Map 1: Cape Bridgewater Wind Farm Measurement Locations

Sonus

Testing of other man-made noise sources

Testing has been conducted using the below ground technique in the vicinity of other man-made noise sources using the following procedure:

- Measurement of infrasound using the below ground technique at a distance of approximately 350m from a gas fired power station;
- Measurement of infrasound using the below ground technique within the Adelaide Central Business District at approximately 70m and 200m from two major road corridors;

The measurement results are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold and the ambient noise result from the Adelaide Hills.

The results presented are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results.

Table 16 – Power Station

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	63	57	57	54	53	50	50	49	54	55	57	62	61	61	**74**

Table 17 - CBD

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	63	60	61	62	61	58	59	56	56	53	55	60	65	63	**76**

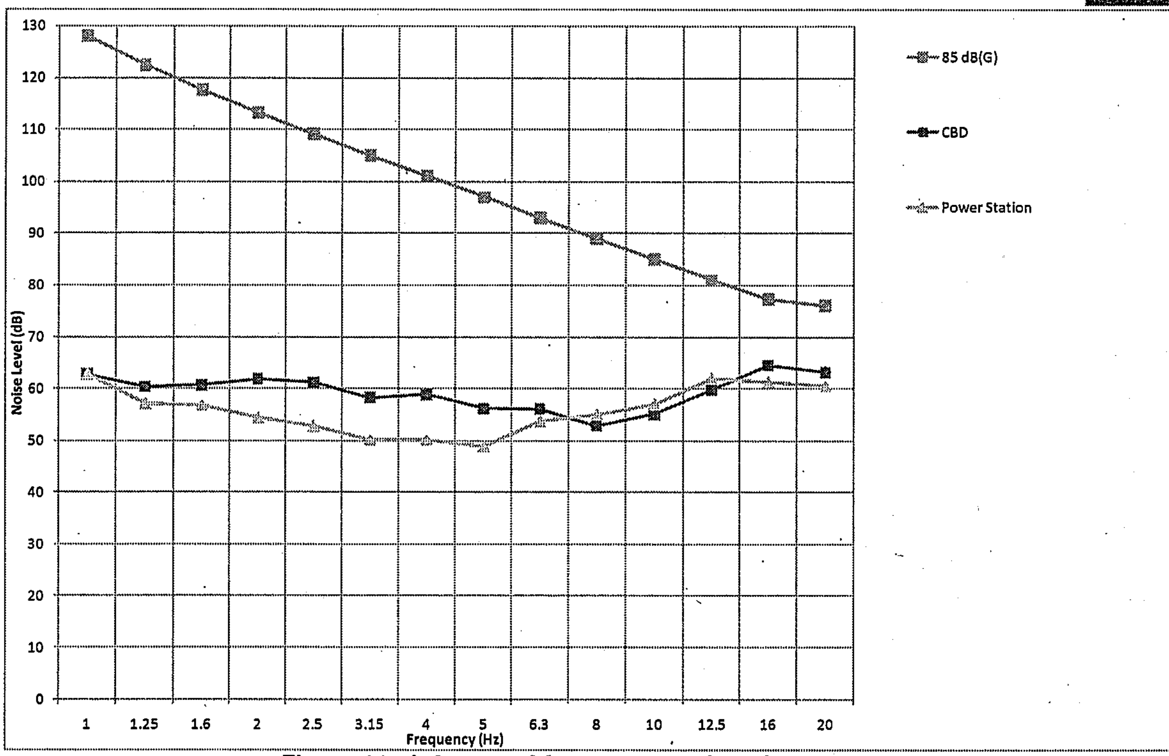


Figure 11 - Infrasound from man-made noise sources

The following conclusions can be made from the above results and on site observations:

- Man made sources generate infrasound;
- The levels of infrasound from man made sources are of the same order at those measured within close proximity of a wind turbine;
- Measurable levels of infrasound that are of a similar order to that measured in close proximity to a wind farm are prevalent in the urban environment over a large area due to sources other than wind farms.

Comparison against International results

The Canadian Wind Energy Association (Howe, 2006) and Jakobsen, J., 2005, provide a summary of results of infrasound testing at a range of sites. The data is presented as an overall dB(G) level. The methodology used to measure these data is not known and therefore the results might be influenced by wind or other sources. These data and the measured levels as part of this study are summarised in the following table:

Table 18 - Summary of Infrasound Levels

Noise source	Distance (m)	Infrasound level dB(G)	Comments
General Electric MOD-1	105	107	Downwind turbines, known to generate higher levels of infrasound compared to a modern upwind turbine
General Electric MOD-1	1000	75	Downwind turbine
Hamilton Standard WTS-4	150	92	Downwind turbine
Hamilton Standard WTS-4	250	85	Downwind turbine
Boeing MOD-5B	68	71	Upwind two bladed turbine at a limited separation distance – this shows the significant reduction between downwind and upwind turbines
US Wind Power USWP-50	500	67-79	14 downwind turbines influencing the results
WTS-3	750	68	Downwind turbine
WTS-3	2100	60	Downwind turbine
Enercon E-40	200	64	Modern upwind turbine
Vestas V66	100	70	Modern upwind turbine
Vestas V80	60	79	Influenced by wave action from the Atlantic Ocean (HGC Engineering, 2006)
GE 1.5MW	300	67	Modern upwind turbine
Nordex N-80	200	60 (7m/s)	Measurements were made downwind from 5m/s to 12m/s. The level increases by approximately 1 dB(G) for each 1m/s increase in wind speed from 5m/s
DTI Wind Farm	1000	65	Details of the turbine type were not provided in the DTI study. The wind farm included seven turbines (DTI, Hayes McKenzie, 2006)
Siemens SWT 2.3-93	300	73	Measured as part of the "Epsilon" study (O'Neal, 2009)
GE 1.5sle	300	70	Measured as part of the "Epsilon" study (O'Neal, 2009)
Clements Gap	85	72	Modern upwind turbine
Clements Gap	180	67	Modern upwind turbine
Clements Gap	360	61	Modern upwind turbine
Cape Bridgewater	100	66	Modern upwind turbine, influenced by the ambient noise environment
Cape Bridgewater	200	63	Modern upwind turbine, influenced by the ambient noise environment

The main source of uncertainty associated with the measurement of infrasound is the influence of wind on the microphone. The methodology used by the international studies is not explicitly nominated, and therefore the contribution of wind on the microphone in the above results is not known. However, the infrasound associated with the turbines will be at most the same and more likely less than the results in the above table.

This study employs a specific methodology that aims to reduce the influence of wind on the microphone and therefore the extent of the uncertainty in the infrasound attributable to the turbines. However, the influence of wind and the presence of infrasound in the ambient environment when measuring in the vicinity of the coast, as is the case at Cape Bridgewater, are still expected to influence the results. Therefore, as for the international studies, the uncertainty predominantly relates to the extent that the infrasound from the turbines is below the results presented in this report.

Jakobsen, J. 2005 notes the following with respect to review of the data available for the 2005 works:

> *....the level from an upwind turbine of contemporary design at 100m distance would be about 70 dB(G) or lower, while the level from a downwind machine can be 10 to 30 dB higher.*

The results of this study show infrasound noise levels of the order of 60 to 70 dB(G) in close proximity to wind turbines. Based on the above table, these levels show consistency with other International measurements of modern upwind turbines. In addition, the measured noise levels in this study are provided by a detailed methodology that reduces the influence of the wind and therefore the uncertainty for the results.

CONCLUSION

The following conclusions can be made from the results of the study:

- Wind turbines generate infrasound, however, measurements made both outside and inside and at a variety of distances significantly less than separation distances between wind farms and dwellings, indicate the infrasound produced by wind turbines is well below established guideline perception thresholds;
- The level of infrasound that has been measured in both a rural coastal and an urban environment is of the same order as that measured within 100m of a wind turbine.

The following figure overlays the compiled results of the study:

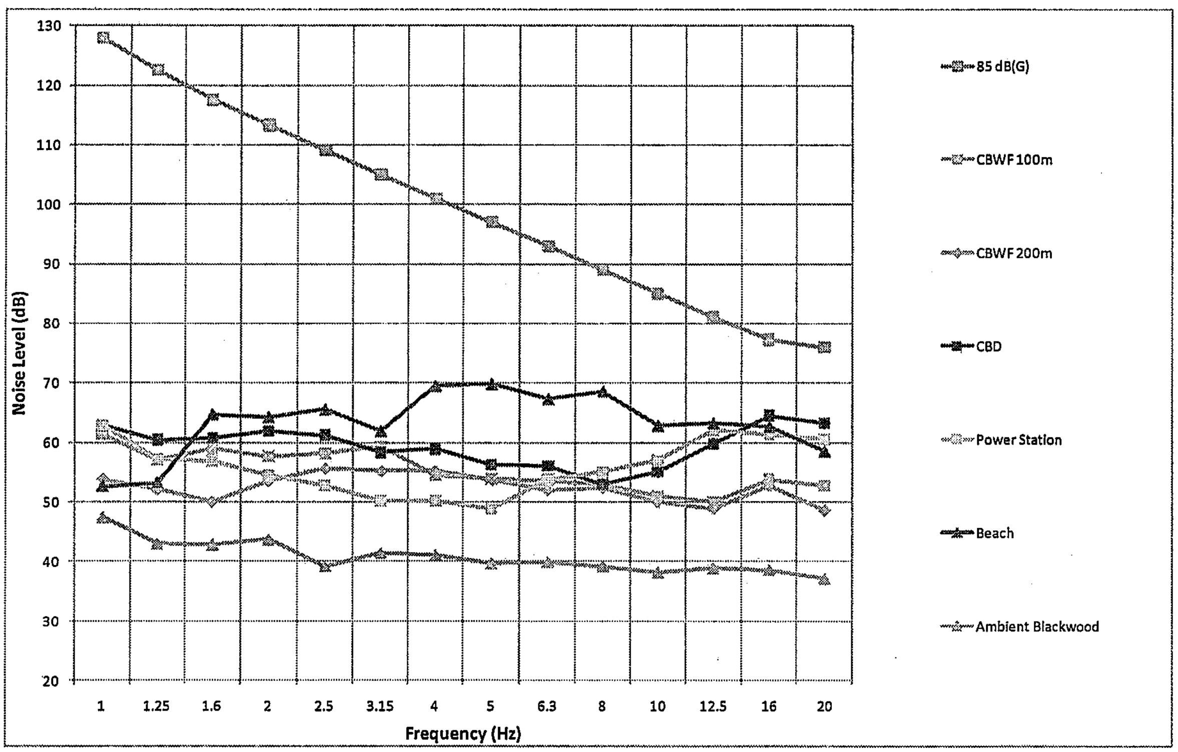


Figure 12 - Summary of Measurements Cape Bridgewater Wind Farm (CBWF)

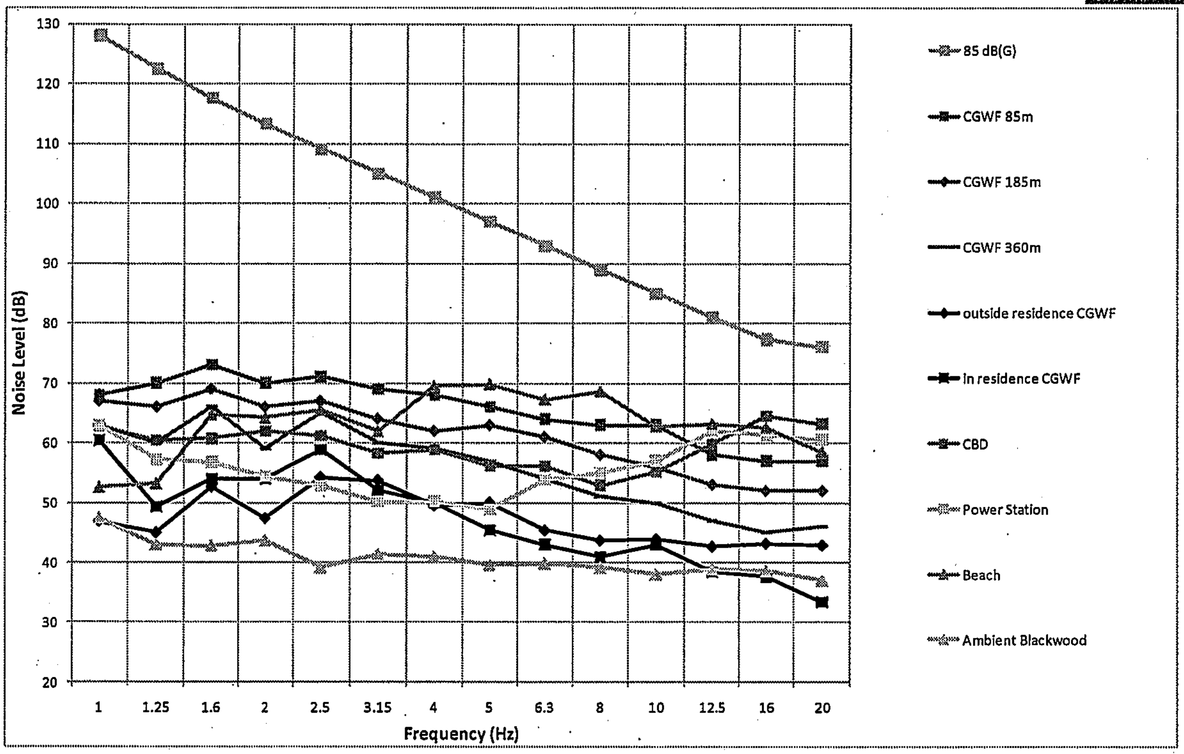


Figure 13 - Summary of Measurements Clements Gap Wind Farm (CGWF)

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INFRASOUND FROM WIND TURBINES – FACT, FICTION OR DECEPTION

Geoff Leventhall
Noise and Vibration Consultant, 150 Craddocks Avenue Ashtead Surrey KT21 1NL UK, geoff@activenoise.co.uk

ABSTRACT

Infrasound is discussed in terms of what it actually is, how the media has dealt with it and what those with limited knowledge say about it. The perception of infrasound occcurs at levels higher than the levels produced by wind turbines and there is now agreement amongst acousticians that infrasound from wind turbines is not a problem. Statements on infrasound from objectors are considered and it is shown how these may have caused avoidable distress to residents near wind turbines and also diverted attention from the main noise source, which is the repeating sound of the blades interacting with the tower. This is the noise which requires attention, both to reduce it and to develop optimum assessment methods

RÉSUMÉ

L'infrason est discuté en termes de ce qu'il est réellement, son traitement dans les médias et par ceux avec des connaissances limitée à son sujet. La perception de l'infrason est qu'il existe à des niveaux plus hauts que ceux produits par des éoliennes, mais il y a maintenant accord parmi les acousticiens que l'infrason des éoliennes n'est pas un problème. Des rapports sur l'infrason par des protestataires sont considérés et on montre comment ceux-ci ont pu causer de la détresse évitable aux résidants près des éoliennes et également divertir l'attention de la source principale de bruit: le son répétitif de l'interaction des lames avec la tour. C'est ce bruit qui exige de l'attention, pour le réduire et pour développer des méthodes optimales d'évaluation.

1. INFRASOUND

A definition of infrasound is: Acoustic oscillations whose frequency is below the low frequency limit of audible sound (about 16Hz). (IEC 1994)

This definition is incorrect, as sound remains audible at frequencies well below 16Hz. For example, measurements of hearing threshold have been made down to 4Hz for exposure in an acoustic chamber (Watanabe and Møller 1990b) and down to 1.5 Hz for earphone listening (Yeowart, Bryan et al. 1967)

The limit of 16Hz, or more commonly considered as 20Hz, arises from the lower frequency limit of the standardized equal loudness hearing contours measured in units of phons, which is a difficult measurement at low frequencies, not from the lower limit of hearing.

2. THE AUDIBILITY OF INFRASOUND

Hearing sensation does not suddenly cease at 20Hz when the frequency is reduced from 21Hz to 19Hz, but continues from 20Hz down to very low frequencies of several Hertz. It is not possible to define an inaudible infrasound range and an audible audio range as separate regions, unless the infrasound range is limited to naturally occurring infrasound of very low frequencies. The range from about 10Hz to 100Hz can be considered as the low frequency region, with possible extensions by an octave at each end of this range, giving 5Hz to 200Hz. There is a very fuzzy boundary between infrasound and low frequency noise, which often causes confusion.

Hearing thresholds in the infrasonic and low frequency region are shown in Fig 1. The solid line above 20Hz is the low frequency end of the ISO standard threshold (ISO:226 2003). The dashed curve, 4Hz to 125Hz, is from Watanabe and Møller (Watanabe and Møller 1990b). There is good correspondence between the two threshold measurements in the overlap region.

The slope of the hearing threshold reduces below about 15Hz from approximately 20dB/octave above 15 Hz to about 12dB/octave below. (Yeowart, Bryan et al. 1967). The common assumption that "infrasound" is inaudible is incorrect, arising from an unfortunate choice of descriptor. "Real" infrasound, at levels and frequencies below audibility are largely natural phenomena, although human activities, such as explosions, also produce infrasound. Microphone arrays for the detection of airborne infrasound are a component of the monitoring for the Nuclear Test Ban Treaty

The median hearing threshold is not a simple delineation between "Can hear - Can't hear", but the threshold is rather variable between individuals, depending on their genetics, prior noise exposure and age (ISO7029 2000). The standard deviation of threshold measurements is typically about 6dB.

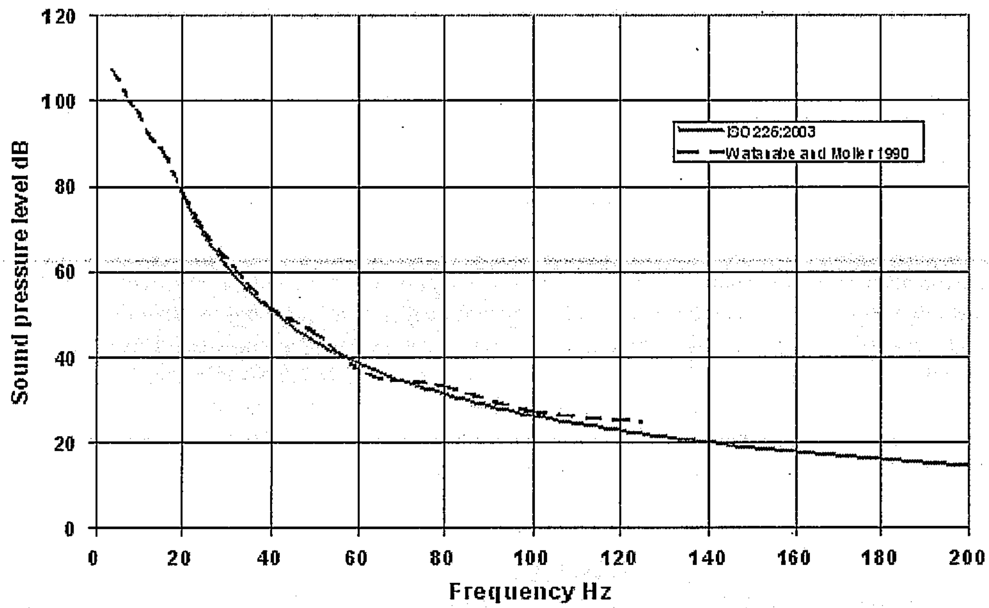

Figure 1. Infrasonic and low frequency threshold

Therefore, it is most unlikely that anyone will be able to hear sound at any frequency which is more than, say, 20dB below its median threshold.

The false concept that infrasound is inaudible, when coupled with the many common misconceptions about its subjective effects, has spawned concerns, particularly expressed in popular publications, which are best described as mythology, rather than fact.

A report reviewing low frequency noise (Leventhall, Benton et al. 2003) is available on the internet.

High levels at very low frequencies: These may result in aural pain, which is not a hearing sensation, but arises from displacements of the middle ear system beyond its comfortable limits. Persons with both hearing ability and hearing loss, and with normal middle ears, exhibit aural pain at a similar stimulus level, which is at about 165dB at 2Hz, reducing to 145dB at 20Hz. Static pressure produces pain at 175 -180dB, whilst eardrum rupture occurs at 185 -190dB (von Gierke and Nixon 1976). A pressure of 5 x 104 Pa, which is about half atmospheric pressure, falls in the 185 -190dB range. A child on a swing experiences infrasound at a level of around 110dB and frequency 0.5Hz, depending on the suspended length and the change in height during the swing.

Natural infrasound: We are enveloped in naturally occurring infrasound, which is in the range from about 0.01 Hz to 2Hz and is at inaudible levels. The lower limit of one cycle in a hundred seconds separates infrasound, as a propagating wave, from all but the fastest fluctuations in barometric pressure. There are many natural sources of infrasound, including meteors, volcanic eruptions, ocean waves, wind and any effect which leads to slow oscillations of the air. Man made sources include explosions, large combustion processes, slow speed fans and machinery. Much natural infrasound is lower in frequency than 1 Hz and below the hearing threshold. (Bedard and George 2000). Our evolution has been in the presence of natural infrasound.

Alternative receptors: The question arises of whether there is a hierarchy of receptors, of which the ear is the most sensitive except at the lower frequencies, when other receptors may come into prominence. Several vibration and contact detectors reside in the skin, covering different frequency ranges (Johnson 2001). The Pacinian corpuscles are the most sensitive, with a threshold displacement of about 0.002mm in the region of 200Hz,. Their sensitivity into lower frequencies reduces at approximately 50dB per decade from the maximum sensitivity.

The threshold displacement of 0.002mm at 200Hz is similar to the particle displacement in air of a 200Hz sound wave of 94dB (1 Pa) pressure. Since the particle displacement in a sound wave of fixed pressure doubles as the frequency is halved (20dB per decade) inaudible sound waves will not excite these subcutaneous receptors.

There is no reliable evidence that infrasound at levels below its hearing threshold has an adverse effect on the body (Berglund and Lindvall 1995). A recent French study of wind turbine noise confirms that infrasound from wind turbines is not a problem. (Chouard 2006)

Body vibrations: It is known that high levels of low frequency noise excite body vibrations (Leventhall, Benton et al. 2003). The most prominent body response is a chest resonance vibration in the region of 50Hz to 80Hz, occurring at levels above about 80dB, which are audible in this frequency range. The low frequency perception thresholds of normal hearing and profoundly deaf subjects have also been investigated (Yamada, Ikuji et al. 1983), when it was shown that the profoundly deaf subjects perceived noise through their body only at levels which were in excess of normal thresholds. The threshold of sensation of the deaf subjects was 40-50dB above the hearing threshold of those with normal hearing up to a frequency of 63Hz and greater at higher frequencies. For example about 100dB greater at 1 kHz, at which level perception was by the subjects' residual hearing. Deaf subjects experienced chest vibration in the same frequency range as normal hearing subjects.

The much repeated statement that "infrasound can be felt but not heard" is not supported by these measurements. The erroneous thought processes which led to this confusion are possibly:

Infrasound causes body vibrations - (correct at very high levels)
But infrasound is inaudible - (not correct at very high levels)
Therefore infrasound can be felt but not heard - (not correct)

neglecting that the levels to produce body vibrations are well above the hearing threshold. But, as will be shown later, infrasound is not a problem for modern wind turbines.

The dimensions of noise: Noise is multidimensional. A one dimensional view of noise is the A - weighting, which considers only levels and neglects frequencies. Another one-dimensional view is to consider only frequencies and neglect levels. Developing the dimensions further, two dimensions include both frequency and level (the spectrum), three dimensions adds in the time variations of the noise, whilst higher dimensions include subjective response.

Many lay people take the one dimensional view of infrasound, which is based on frequency alone. They express concern at the presence of any infrasound, irrespective of its level. This is a significant failure of understanding.

Public Perceptions: The Public has been misled by the media about infrasound, resulting in needless fears and anxieties, which possibly arise from confusion of the work on subjective effects, which has been carried out at high, audible levels with the popular mindset that infrasound is inaudible. There have also been misunderstandings fostered in publications and popular science books, considered later.

Early work on low frequency noise and its subjective effects was stimulated by the American space program. Launch vehicles produce high noise levels with maximum energy in the low frequency region. Furthermore, as the vehicle accelerates, the crew compartment is subjected to boundary layer turbulence noise for about two minutes after lift-off. Experiments were carried out in low frequency noise chambers on short term subjective tolerance to bands of noise at very high levels of 140 to 150dB, in the frequency range up to 100Hz (Mohr, Cole et al. 1965). It was concluded that the subjects, who were experienced in noise exposure and who were wearing ear protection, could tolerate both broadband and discrete frequency noise in the range 1 Hz to 100Hz at sound pressure levels up to 150dB. Later work suggests that, for 24 hour exposure, levels of 120 -130dB are tolerable below 20Hz. These limits were set to prevent direct physiological damage, not for comfort. (Mohr, Cole et al. 1965; Westin 1975; von Gierke and Nixon 1976).

The American work did not attract media attention, but in the late 1960's two papers from France led to much publicity and speculative exaggerations. (Gavreau, Condat et al. 1966; Gavreau 1968). Although both papers carry "infrasound" in their titles, there is very little on frequencies below 20Hz (Leventhall 2005). Some rather casual and irresponsible experiments of the "try it and see" variety were carried out on exposure of the laboratory staff, primarily using high intensity pneumatic sources at frequencies mainly at the upper end of the low frequency range, or above. For example, 196Hz at 160dB sound level and 340Hz at 155dB sound level. A high intensity whistle at 2600Hz is also included in the "infrasound" papers.

Infrasounds are not difficult to study but they are potentially harmful. For example one of my colleagues, R Levavasseur, who designed a powerful emitter known as the 'Levavasseur whistle' is now a victim of his own inventiveness. One of his larger whistles emitting at 2600Hz had an acoustic power of 1 kW. . ... This proved sufficient to make him a lifelong invalid. (Gavreau 1968)

Of course, 2600Hz is not infrasound, but the misleading implication is that infrasound caused injury to Levavasseur. A point source of sound of power 1 kW will produce a sound level of about 140dB at 1 m, which is a very undesirable exposure at 2600Hz.

Referring to the exposure of 160dB at 196Hz:

...after the test we became aware of a painful 'resonance' within our bodies - everything inside us seemed to vibrate when we spoke or moved. What had happened was that this sound at 160 decibels........ acting directly on the body produced intense friction between internal organs, resulting in sever irritation of the nerve endings. Presumably if the test had lasted longer than five minutes, internal haemorrhage would have occurred. (Gavreau 1968)

96 Hz is not infrasound, but the unpleasant effects at 160dB are described in a paper which is said to be about "Infrasound". Internal haemorrhage is often quoted as an effect of exposure to infrasound. Exposure levels were not given for frequencies of 37Hz and 7Hz, although the 7Hz caused subjective disturbance and vibrations of the laboratory walls. Unfortunately, these papers by Gavreau were seized upon by the press and presented to claim that infrasound was dangerous . For example "The silent killer all around us", London Evening News, 25 May 1974. When work by other investigators detected moderate levels of infrasound in, for example, road vehicles, the press was delighted, leading to "The silent sound menaces drivers" - Daily Mirror, 19 October 1969.

"Danger in unheard car sounds" The Observer, 21 April 1974.

The most deplorable example, in a book which claimed to have checked its sources, was in "Supernature" by Lyall Watson (Coronet 1973). In this it is claimed that the technician who gave one of Gavreau's high power infrasound sources its trial run "fell down dead on the spot" and that two infrasonic generators "focused on a point even five miles away produce a resonance that can knock a building down as effectively as a major earthquake".

T hese ficticious statements are, of course, totally incorrect but are clear contributors to some of the unfounded concerns which the public feels about infrasound. One can detect a transition from Gavreau and his colleague feeling ill after exposure to the high level of 196Hz to "fell down dead on the spot" and a further transition from laboratory walls vibrating to "can knock a building down", transitions which resulted from repeated media exaggerations over a period of five or six years.

The misunderstanding between infrasound and low frequency noise continues to the present day. A newspaper article on low frequency noise from wind turbines (Miller 24 January 2004) , opens with:

Onshore wind farms are a health hazard to people living near them because of the low-frequency noise that they emit, according to new medical studies. A French translation of this article for use by objectors' groups opens with:

De nouvelles etudes medicales indiquent que les eoliennes terrestres representent un risque pour la sante des gens habitant a proximite, a cause d'emission d'infrasons.

The translation of low frequency noise into infrasons continues through the article. This is not a trivial misrepresentation because, following on from Gavreau, infrasound has been connected with many misfortunes, being blamed for problems for which some other explanation had not yet been found e.g., brain tumours, cot deaths of babies, road accidents.

Infrasound, and its companion low frequency noise, now occupy a special position in the national psyche of a number of countries, where they lie in wait for an activating trigger to re-generate concerns of effects on health. Earlier triggers have been defence establishments and gas pipelines. A current trigger is wind turbines.

3 INFRASOUND AND LOW FREQUENCY NOISE FROM WIND TURBINES

Early designs of downwind turbines produced pressure pulses at about once per second, which were high enough to cause vibrations in lightweight buildings nearby. (Shepherd and Hubbard 1991). A series of pulses occurring at one per second analyses into a harmonic series in the infrasound region, which is the origin of the link between wind turbines and infrasound One could discuss whether the Fourier time-frequency duality is misleading on this point, since it was the effects of peaks of the pulses which caused the building vibration, not a continuous infrasonic wave. Similar vibration would have occurred with a faster stream of pulses, with the limiting condition that the pulse repetition rate was lower than the period of the vibration.

Modern up-wind turbines produce pulses which also analyse as infrasound, but at low levels, typically 50 to 70dB, well below the hearing threshold. Infrasound can be neglected in the assessment of the noise of modern wind turbines (Jakobsen 2004)

Fig 2 shows the infrasonic and low frequency noise at 65m from a 1.5MW wind turbine on a windy day. The fol-

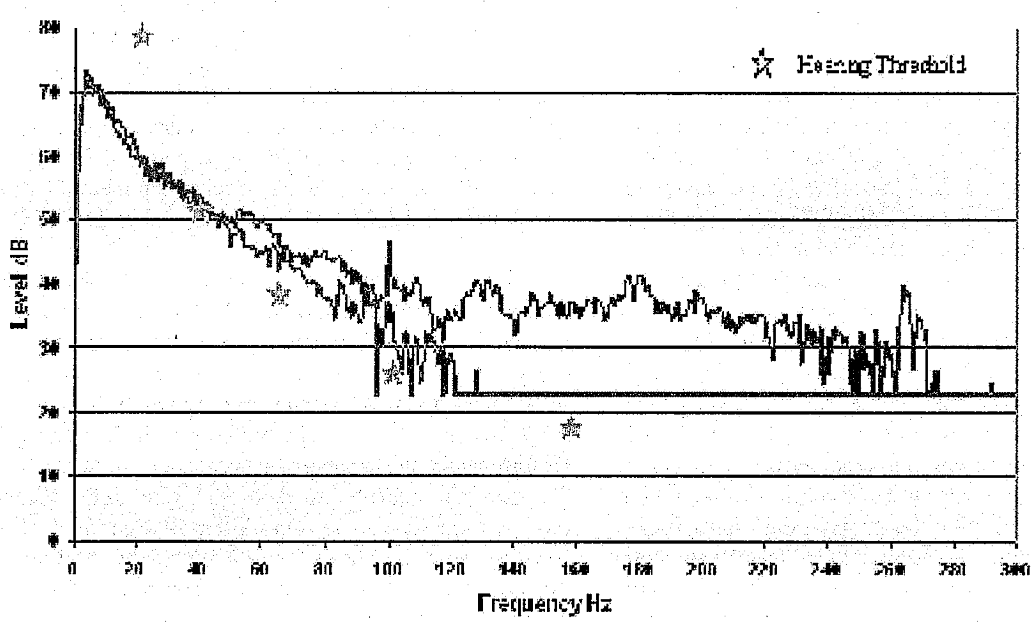

Figure 2. Spectrum of a modern upwind wind turbine - Upper trace Wind Turbine Noise. Lower trace Background noise.

lowing should be noted.

- The fall off below about 5Hz is an instrument effect. The background noise actually increases down to the frequencies of atmospheric pressure variations .
- Frequencies below 40Hz cannot be distinguished from background noise due to wind.
- The wind turbine noise and background noise separate above about 40Hz and both rise above the median hearing threshold.
- The measurements were taken at 65m. Levels are likely to be about 15dB lower at normal separation distances

On the occasions, such as unusually turbulent inflow conditions, when low frequency noise is produced by wind turbines, it may not be perceived as a noise, but rather as an unidentified adverse component in the environment, which disappears if the turbines stop, or if the inflow conditions change. This is because we are not accustomed to listening to low levels of broad band low frequency noise and, initially, do not always recognise it as a "noise", but more as a "disturbance" in the environment. An analogy is with air-conditioning rumble noise, which is noticed when it stops.

What Objectors Say Objectors have eagerly grasped the media hype on infrasound and low frequency noise and used it to engender concerns about wind turbine developments. In this they have, possibly, done a disservice to the communities they were established to help, through raising false concerns and diverting attention from more important aspects of the development. Two examples are as follows.

In the UK there is an Advertising Standards Authority(ASA), to which deceptive adverts can be referred for assessment. An objectors' group (Ochils Environmental Protection Group) issued a leaflet "FACTS ABOUT WIND POWER". containing a number of assertions including:

. "... wind turbines still create noise pollution, notably 'infra sound' - inaudible frequencies which nevertheless cause stress-related illness ..."

In their Judgment (April 02, 2004), the ASA concluded that the objectors had not produced evidence to substantiate their claim.

In the USA, a high profile objector (Nina Pierpont of Malone NY) placed an advertisement in a local paper, consisting entirely of selected quotations from a previously published technical paper by van den Berg (Van den Berg 2004). However the comment "[i.e. infrasonic]", as shown in Fig 3, was added in the first line of the first quotation in a manner which might mislead naive readers into believing that it was part of the original.

The van den Berg paper was based on A-weighted measurements and had no connection with infrasound. So, not only is the advertisement displaying the advertiser's self deception, but this has also been propagated to others who have read it. To mistakenly connect the noise to infrasound, which has unpleasant associations is, however, a way to gather support . (When a person has adopted a particular mindset, new information is processed to support that mindset. We all do this.)

It takes little technical knowledge to be aware that a modulated high frequency wave does not contain the modulation components. For example, an amplitude modulated radio wave contains the carrier wave and sidebands, which are close in frequency to the carrier. The fluctuations of wind turbine noise (swish – swish) are a very low frequency modulation of the aerodynamic noise, which is typically in the region of 500 - 1000Hz. The modulation occurs from a change in radiation characteristics as the blade passes the tower, but the modulating frequencies do not have an independent and separate existence.

The comment, [i.e. infrasonic], added into Fig 3 gives incorrect information. Claims of infrasound are irrelevant and possibly harmful, should they lead to unnecessary fears.

PAID ADVERTISEMENT

Wind Turbines & Infrasound:
What the latest research says

"At night the wind turbines cause a low pitched thumping [i.e., infrasonic] sound superimposed on a broadband 'noisy' sound, the 'thumps' occurring at the rate at which blades pass a turbine tower.... The number and severity of noise complaints near the wind park are at least in part explained by the two main findings of this study: actual sound levels are considerably higher than predicted, and wind turbines can produce sound with an impulsive character."

-- Professor Frits G.P. van den Berg, University of Groningen, the Netherlands, November 2004 (see excerpts from research articles, below)

Figure 3 Part of an advertisement placed by an objector in the Malone (NY) Telegram, 25th February 2005.

It has been shown that fear of a noise source, for example that aircraft might crash, increases the extra annoyance of a person with a high fear of a crash by up to 19dB DNL equivalent, compared with a person who has no fear (Miedema and Vos 1999).

Fear of a source is not the same as fear of the noise itself, but it is understandable that those who fear the effects of a noise upon their health will be less tolerant of the noise than those who do not fear it. We can only speculate upon the harm which objectors might have done by, for example, taking a one dimensional view of infrasound and publicising the subjective effects of high levels of both infrasound and low frequency noise in a manner which implies that the effects may also be caused by the low levels produced by wind turbines.

4 WIND TURBINE NOISE

It has been shown above that there is insignificant infrasound from wind turbines and that there is normally little low frequency noise. Turbulent air inflow conditions cause enhanced levels of low frequency noise, which may be disturbing, but the overriding noise from wind turbines is the fluctuating audible swish, mistakenly referred to as "infrasound" or "low frequency noise". Objectors uninformed and mistaken use of these terms (as in Fig 3), which have acquired a number of anxiety-producing connotations, has led to unnecessary fears and to unnecessary costs, such as for re-measuring what was already known, in order to assuage complaints.

Attention should be focused on the audio frequency fluctuating swish, which some people may well find to be very disturbing and stressful, depending on its level. The usual equivalent level measurements and analyses are incomplete, as these measurements are taken over a time period which is much longer than the fluctuation period and information on the fluctuations is lost. A time varying sound is more annoying than a steady sound of the same average level and this is accounted for by reducing the permitted level of wind turbine noise. However, more work is required to ensure that the optimum levels have been set.

5 CONCLUSIONS

- Infrasound from wind turbines is below the audible threshold and of no consequence.
- Low frequency noise is normally not a problem, except under conditions of unusually turbulent inflow air.
- The problem noise from wind turbines is the fluctuating swish. This may be mistakenly referred to as infrasound by those with a limited knowledge of acoustics, but it is entirely in the normal audio range and is typically 500Hz to 1000Hz. It is difficult to have a useful discourse with objectors whilst they continue to use acoustical terms incorrectly. This is unfortunate, as there are wind turbine installations which may have noise problems.
- It is the swish noise on which attention should be focused, in order to reduce it and to obtain a proper estimate of its effects. It will then be the responsibility of legislators to fix the criterion levels, However, although the needs of sensitive persons may influence decisions, limits are not normally set to satisfy the most sensitive.

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Primer for

Addressing Wind Turbine Noise

Revised Oct. 2006

by Daniel J. Alberts

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Table of Contents

Introduction

Michigan is proceeding to develop renewable energy policies. The Energy Office of Michigan, in their 2004 Annual Report to the Michigan Public Service Commission on Michigan's Renewable Energy Program, recommended that the State of Michigan adopt the following policies:

- Set a goal of installing 800 MW of wind power by the year 2010.
- Adopt statewide policies to encourage the development of wind energy in Michigan.
- Adopt a Renewable Portfolio Standard (RPS) that requires 1.0% of all energy sold within the state of Michigan be generated from renewable sources (including wind) by December 2006.
- Increase the RPS requirement by 0.5 % each year to reach a total of 10% by 2015.

Although the State of Michigan may encourage renewable energy development, local governments within the state will be responsible for zoning and permitting wind turbines. To develop zone and permit wind turbines, local governments will need to examine a variety of issues, including the impact of wind turbine noise on land use compatibility.

To help wind energy advocates and Michigan's policy makers better understand this issue, Michigan's Energy Office asked Lawrence Technological University to research the noise issue and present their findings to Michigan's Wind Working Group. The formal research documents are available at Lawrence Technological University's web site:

http://www.ltu.edu/engineering/mechanical/delphi_wind.asp

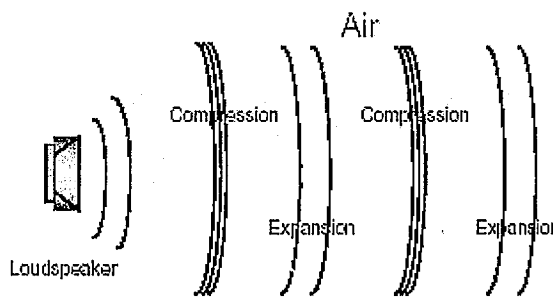
This paper consolidates the education material on noise concepts and assessment distributed through the two formal phases of the research with additional material on engineering standards for noise measurement. The author hopes this paper will help decision makers understand wind turbine noise well enough to develop beneficial permitting procedures and zoning ordinances, and permit wind energy development with minimal conflicts.

Noise Concepts and Definitions

The dictionary defines noise as unwanted sound. But to understand noise measurement and assessment, it is necessary to examine noise from an engineering perspective. This means defining several characteristics of sound, and redefining noise based on these definitions.

Sound is a defined as rapid fluctuations of air pressure which create a repeating cycle of compressed and expanding air.

Figure 1. Sound



Sound power is the energy converted into sound by the source. Sound power is not measured directly, it is calculated from measurements, and is used to estimate how far sound will travel and to predict the sound levels at various distances from the source. Several wind turbine manufacturers provide sound power with their turbine brochures. For example, Vestas' V80, 1.8 MW turbine emits between 98 and 109 dB(A) of sound power depending on configuration.

As sound energy travels through the air, it creates a sound wave that exerts pressure on receivers such as an ear drum or microphone. *Sound pressure* is typically measured in micropascals (μPa) and converted to a *sound pressure level* in decibels (dB) for reporting. The decibel scale is a logarithmic scale relative to the human threshold of hearing. Sound pressure level is used to determine loudness, noise exposure, and hazard assessment. (The next section covers sound pressure scales in more detail.) ANSI, the EPA, ISO, OSHA, and the WHO[1] all base their recommendations for maximum noise exposure on sound pressure levels.

As stated above, sound is a repeating cycle of compressed and expanding air. The *frequency* is the number of times per second, or Hertz (Hz), that this cycle repeats. An *octave* is a range where the lowest frequency is exactly half the highest frequency. A Concert A is 440 Hz, the next higher A is 880 Hz.

Sounds are often classified by the number of frequency components they contain. A *tone* is a sound that contains only one frequency. Musical notes are tones. Mechanical systems often emit noise that contains a noticeable tone. *Narrowband* sounds contain two or more frequency components, but the frequencies are very close to each other, within 1/3 of an octave. *Broadband* sounds contain multiple frequency components, and the frequencies span more than 1/3 of an octave. Cars, lawn equipment, jet engines and wind turbines all produce broadband noise.

[1] American National Standards Institute (ANSI), US Environmental Protection Agency (EPA), International Standards Institute (ISO), Occupational Safety and Health Administration (OSHA) and the World Health Organization (WHO)

Table 1 lists some important frequency ranges for studying the impact of wind turbine noise.

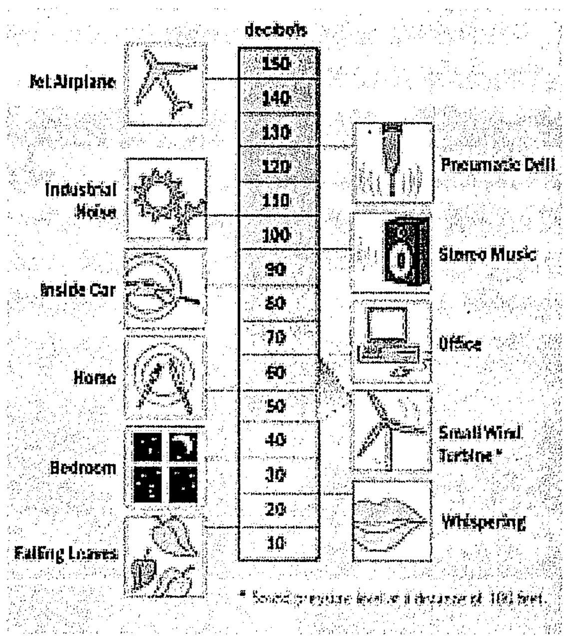
Table 1. Important Frequency Ranges

	Range
Normal Hearing	20 Hz – 20 kHz
Normal Speech	100 Hz – 3 kHz
Low Frequency	20 – 200 Hz
Infra Sound	< 16 Hz

Sound Pressure Level Scales

The human ear can detect and respond to sound pressures, from 20 μPa to over 200,000,000 μPa. (beyond 200,000,000 μPa the response becomes pain.) Engineers wanted a scale with a smaller range, so they mapped sound pressure on logarithmic scale which they defined as the decibel (dB). Zero decibels is the lowest pressure (20 μPa) that a person with normal hearing can detect. One hundred forty decibels is the pressure (20,000,000 μPa) that causes most people physical pain. Figure 2 shows how this scale relates to some common noise sources.

Figure 2. The Decibel Scale[2]



[2] Source: The American Wind Energy Association, http://www.awea.org/faq/noisefaq.html

Because decibels are a logarithmic scale, values do not add the same as they would for a linear scale. Doubling the sound power increases the sound pressure level by 3 dB. For example, two wind turbines each generating 110 dB of noise would produce a combined noise of 113 dB. However, doubling the sound pressure will increase the sound level by 6 dB.

A few additional things to remember about the decibel scale:

- Outside the laboratory most people cannot notice a volume change of less than 3 dB.
- A volume change of 3–5 dB is clearly noticeable.
- Most people subjectively perceive volume increase of 10 dB as twice as loud.

Peoples' perception of noise, however, do not always correspond with the dB scale. Sounds created with the same energy, but with different frequencies are not perceived to be equally loud. A lower frequency sound will seem quieter than a higher frequency sound of the same sound level. Noise control engineers wanted scales that reflected peoples' perception of noise. So they created 'weighting' scales.

In one sense, noise scales are like temperature scales. A thermometer measures the amount of heat in the air. The heat measurement is then compared to a reference scale such as Fahrenheit or Celsius. When we measure noise, we are actually measuring the amount of pressure that sound exerts on the receiver. We then compare that pressure to a decibel scale. However, the decibel scales are also adjusted by frequency. Engineers specify adjusted values by appending the scale name to the units, i.e., dB(A) or dB(C). Unadjusted values are reported as simply dB. Three of the scales, A, C, and G, have been identified as potentially relevant to addressing wind turbine noise.

The A scale is the most commonly used for community noise assessment and for specifying exposure limits. Designed to reflect the way people perceive sounds, the A scale divides the range of possible frequencies into octaves, and for each octave adjusts the decibel level so that a specified decibel level will seem to have the same loudness in each range. Table 2 shows how to adjust a sound pressure level for each frequency range to report a sound pressure level on the A, C, and G scales.

Table 2. Decibel Weighting Scales

Octave-center frequency (Hz)	Weighted response (dB) A scale*	C scale*	G scale**
4			-16.0
8			-4.0
16			+7.7
31.5	-39.4	-3.0	-4.0
63	-26.2	-0.8	
125	-16.1	-0.2	
250	-8.6	0.	
500	-3.2	0.	
1,000	0.0	0.	
2,000	+1.2	-0.2	
4,000	-1.0	-0.7	

*From IEC 60651
**From ISO 7196

Many noise control texts state that the A scale is insufficient for determining the impact of noise or the level of annoyance when the frequency is below 100 Hz. Other texts state that the A scale is insufficient for any sound above 60 dB. These texts recommend the C scale which more closely resembles the actual sound pressure. However, the US Department of Labor based their noise exposure standards on the A scale. ANSI, the EPA, ISO, OSHA and WHO all provide their health impact data and their recommended noise exposure limits on the A scale; so it is likely the A scale will remain predominant.

As Table 2 shows, the difference between the A scale and the actual sound pressure varies significantly from one frequency range to another. So in order to ensure compliance with limits specified on the A scale, engineers specify non-adjusted limits for each range. Table 3 shows how Mundy Township in Michigan specified non-adjusted noise limits for each octave band to achieve the desired A scale limits.

Table 3. Octave Band Noise Limits

Frequency at center of octave band	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz
Non-adjusted dB level	72 dB	71 dB	65 dB	57 dB	51 dB	45 dB
Equivalent dB(A)	32.6 dB(A)	44.8 dB(A)	49 dB(A)	48.4 dB(A)	47.8 dB(A)	45 dB(A)

The G scale is used only for infrasound, i.e., sounds below 20 Hz. A few studies show that wind turbines do generate infrasound. However, the practicality and the importance of using the G scale for measuring this noise is still being debated.

For additional information on noise measurement, visit:

http://www.phys.unsw.edu.au/~jw/dB.html

http://www.dataphysics.com/support/library/downloads/articles/DP-Aweight.pdf

Wind Turbine Noise

Wind turbines generate two types of noise: aerodynamic and mechanical. A turbine's sound power is the combined power of both. Aerodynamic noise is generated by the blades passing through the air. The power of aerodynamic noise is related to the ratio of the blade tip speed to wind speed. Table 4 shows how the sound power of two small wind turbines vary with wind speed.

Table 4. Sound Power of Small Wind Turbines[3]

Make and Model	Turbine Size	Wind Speed (meters/second)	Estimated Sound Power
Southwest Windpower Whisper H400	900 W	5 m/s	83.8 dB(A)
		10 m/s	91 dB(A)
Bergey Excel BW03	10 kW	5 m/s	87.2 dB(A)
		7 m/s	96.1 dB(A)
		10 m/s	105.4 dB(A)

Depending on the turbine model and the wind speed, the aerodynamic noise may seem like buzzing, whooshing, pulsing, and even sizzling. Turbines with their blades downwind of the tower are known to cause a thumping sound as each blade passes the tower. Most noise radiates perpendicular to the blades' rotation. However, since turbines rotate to face the wind, they may radiate noise in different directions each day. The noise from two or more turbines may combine to create an oscillating or thumping "wa-wa" effect.

Wind turbines generate broadband noise containing frequency components from 20 – 3,600 Hz. The frequency composition varies with wind speed, blade pitch, and blade speed. Some turbines produce noise with a higher percentage of low frequency components at low wind speeds than at high wind speeds.

Utility scale turbines must generate electricity that is compatible with grid transmission. To meet this requirement, turbines are programmed to keep the blades rotating at as constant a speed as possible. To compensate for minor wind speed changes, they adjust the pitch of the blades into the wind. These adjustments change the sound power levels and frequency components of the noise. Table 5 lists the sound power for some common utility scale turbines.

Table 5. Sound Power of Utility Scale Wind Turbines

Make and Model	Turbine Size	Sound Power
Vestas V80	1.8 MW	98 – 109 dB(A)
Enercon E70	2 MW	102 dB(A)
Enercon E112	4.5 MW	107 dB(A)

A turbine's sound power represents the sound energy at the center of the blades, which propagates outward at the height of the hub. While writing this paper, I visited the Bowling Green Wind Farm Project, in Bowling Green, OH. At the base of 1.8 MW turbine, we measured the noise level at 58–60 dB(A). However, the turbines stand in a corn field, and depending on our position relative to the turbines, it was very difficult to distinguish the sound of the turbine from the rustling of the corn stalks.

Mechanical noise is generated by the turbine's internal gears. Utility scale turbines are usually insulated to prevent mechanical noise from proliferating outside the nacelle or tower. Small turbines are more likely to produce noticeable mechanical noise because of insufficient insulation. Mechanical noise may contain discernable tones which makes it particularly noticeable and irritating.

The amount of annoyance that wind turbine noise is likely to cause can be related to other ambient noises. One study in Wisconsin[4] reported that turbine noise was more noticeable and annoying at the cut-in wind speed of 4 m/s (9 mph) than at higher wind speeds. At this speed, the wind was strong enough to turn the blades, but not strong enough to create its own noise. At higher speeds, the noise from the wind itself masked the turbine noise. This could be of significance to Michigan communities where the average wind speeds very from 0 to 7 m/s (0–16.7 mph).

Health Impacts of Noise Exposure

Excessive exposure to noise has been shown to cause a several health problems. The most common impacts include:

- Hearing loss (temporary and permanent)
- Sleep disturbance

[3] Source: P. Migliore, J. van Dam and A. Huskey. Acoustic Tests Of Small Wind Turbines http://www.bergey.com/Technical/AIAA%202004-1185.pdf

[4] http://www.ecw.org/ecw/productdetail.jsp?productId=508&numPerPage=100&sortA

Exposure to extremely high noise levels can also cause headaches, irritability, fatigue, constricted arteries, and a weakened immune system[5]. However, there is no evidence that wind turbines generate the level of noise needed to create these problems.

Induced Hearing Loss

Noise exposure can induce two types of hearing loss: threshold shifts, which refers to the lowest volume a person can detect, and frequency loss, which means an inability to hear specific frequencies.

A person with normal hearing can detect any sound above 0 dB. Exposure to loud noises can temporarily desensitize nerve endings so that the lowest volume a person could hear might increase to 6 or 10 dB. With this shift, the person's entire perception of noise changes so that what was previously perceived as a normal volume seems too quiet to understand. If exposure is brief and the noise is removed, most people's hearing will return to normal. Long-term exposure, however, can cause permanent damage.

Hearing loss is related to the total sound energy to which a person is exposed. This is a combination of the decibel level and the duration of exposure. The Environmental Protection Agency (EPA), The American National Standards Institute (ANSI), and the US Occupational Safety and Health Administration (OSHA) have issued separate recommendations for maximum noise exposure to prevent hearing loss. Table 6 summarizes ANSI's recommendations.

Figure 3 shows how ANSI's recommendations compare to those of the EPA and OSHA.

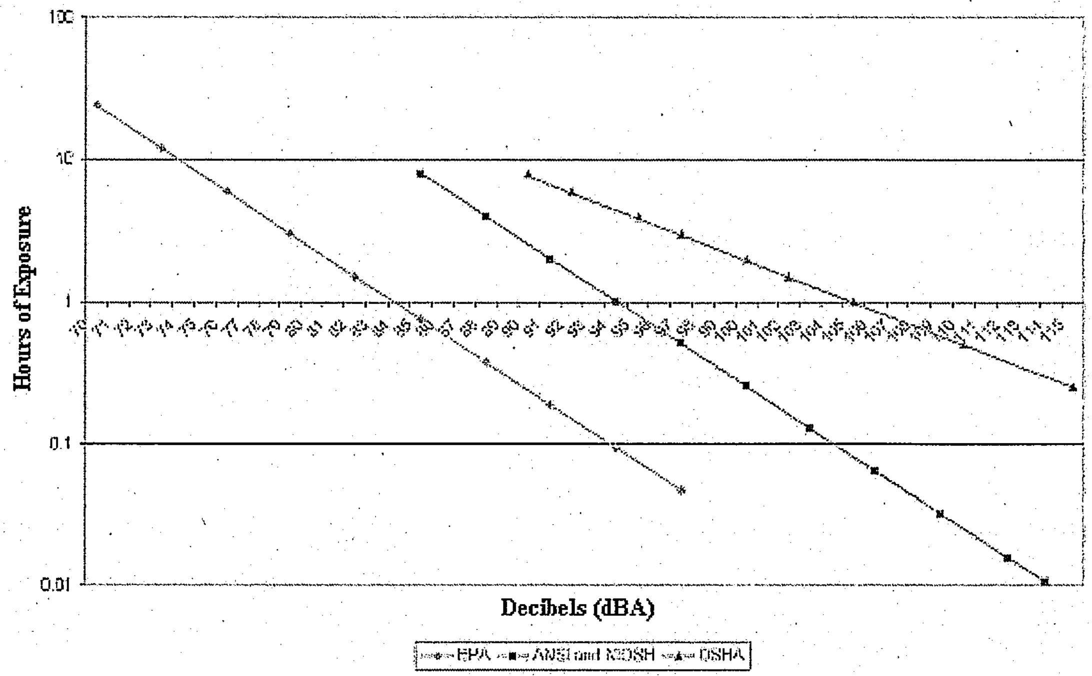
Table 6. ANSI Recommendations for Max Noise Exposure

Sound level dB(A)	Max exposure
90	8 hours
95	4 hours
100	2 hours
110	1/2 hour
115	1/4 hour

[5] Bragdon, Clifford. (19710Noise Pollution The Unquiet Crisis. (pg 69-71) University of Pennsylvania Press.

Stephens, Dafydd and Rood, Graham (1978) The Nonauditory Effects of Noise on Health (pg 285-312)in Handbook of Noise Assessment Edited by Daryl May Van Nostrand Reinhold Company New York

Figure 3. Comparison of Maximum Noise Exposure Standards[6]



Hearing loss can occur in specific frequencies. Elderly people tend to loose the ability to perceive higher frequencies before lower frequencies. Wind turbine noise, however, has not been linked to frequency loss.

Sleep Disturbance

The Institute of Environmental Medicine at Stockholm University prepared an extensive volume for the World Health Organization (WHO) on the impact of community noise on people's health. They report that noise exposure can affect sleep in several ways, including:

- increasing the time needed to fall asleep,
- altering the cycle of sleep stages, and
- decreasing the quality of REM sleep.

Over extended periods of time, any one of these problems could lead to more serious health issues.

[6]Source: http://www.nonoise.org/hearing/exposure/standardschart.htm

Sleep disturbances have been linked to three characteristics of noise exposure, including:

- the total noise exposure (including daytime exposure)
- the peak noise volume
- for intermittent noise, the number of volume peaks

The study reports that:

- Noise levels of 60 dB wakes 90% of people after they have fallen asleep.
- Noise levels of 55 dB affects REM cycles and increases time to fall asleep.
- Noise of 40-45 dB wakes 10% of people.

WHO recommends that ambient noise levels be below 35 dB for optimum sleeping conditions. These recommendations are significant because of a Dutch study[7] that showed noise from a 30 MW wind farm becomes more noticeable and annoying to nearby residents at night. This study noted that although the noise is always present, certain aspects of turbine noise, such as thumping and swishing, were not noticeable during the day, but became very noticeable at night. Residents as far as 1900 meters from the wind farm complained about the nighttime noise.

Intermittent peaks of 45 dB occurring more than 40 times per night, or peaks of 60 dB occurring more than 8 times per night will disturb most people's sleep. Intermittent starts and stops may be an issue for small, residential scale wind turbines (< 500 kW), and medium sized commercial turbines (500 kW – 1 MW) but are not likely to be an issue for utility scale turbines.

Many people (but not all) develop the ability to fall asleep regardless of the sound levels. Studies, however, show that this is only a partial adaptation. The presence of noise continues to negatively affect the sleep cycles and the quality of REM sleep.

Noise Assessment and Exposure Indicators

In many areas, noise levels change several times per day. So a noise that might seem loud at some times might be barely noticeable at other times. To account for these differences, many noise specifications use statistical limits. Table 7 lists some of the most commonly used indicators and their meanings.

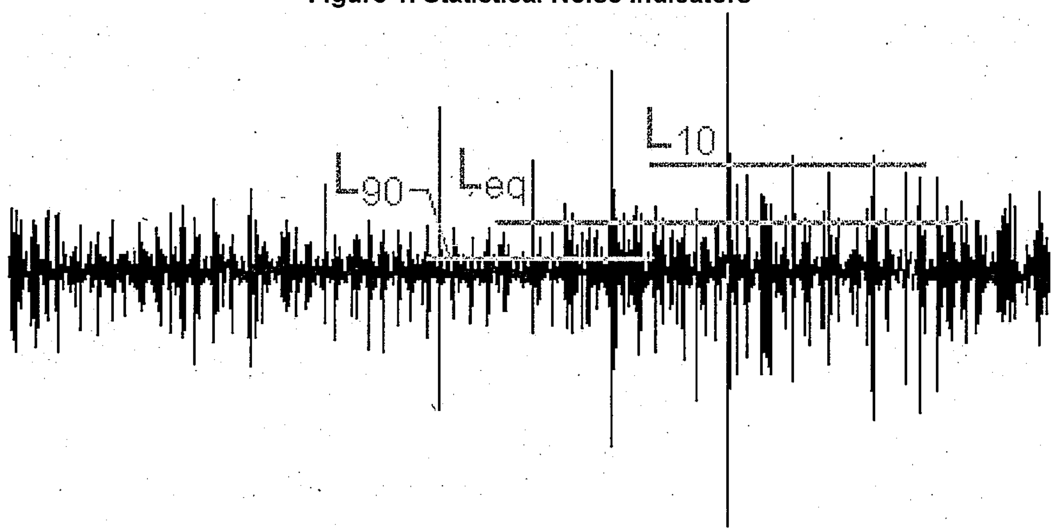
[7] G.P. van den Berg (2003) Effects of the wind profile at night on wind turbine sound. Journal of Sound and Vibration 277 (2004) 955–970

Table 7. Statistical Indicators

Indicator	Meaning
L_{max}	The maximum sound level measured.
L_{eq}	Equivalent continuous sound. An average sound energy for a given time
L_{10}	Sound level exceeded 10 percent of the time. Generally considered to be the sound level that will annoy most people.
L_{90}	Sound level exceeded 90 percent of the time. Generally considered to be a measure of ambient background noise.
L_{dn}	Day-night average sound level, or the average sound level for a 24-hour period

Figure 4 shows how sound levels vary over 1.5 minutes, and shows the relationship between L_{10}, Leq, and L_{90}.

Figure 4. Statistical Noise Indicators



With the exception of L_{max}, statistical indicators are not used to determine the effects of noise exposure on hearing or sleep. Community planners, however, often use these statistics to determine the existing noise levels and predict the impact or community responses of adding a new source of noise.

For example, the Oregon Noise Control Regulation[8] requires the operator of noise producing equipment to determine the L_{10} and L_{50} of a community prior to installing the equipment.

[8] http://www.energy.state.or.us/siting/noise.htm. (This web site also discusses some of the difficulty of measuring statistical noise levels for wind turbines.)

Operating the new equipment must not raise the statistical levels L_{10} or L_{50} by more than 10 dB in any one hour.

Kolano and Saha Engineers[9] especially recommend using statistical limits for regulating noise in hospital and school zones:

> For residential, community park, school, or hospital receiving zones the maximum wind turbine noise limit should be 10 dB greater than the preexisting statistical background sound level (L_{90}) of the community, or 3 dB less than the preexisting statistical high sound level of the community (L_{10}), whichever is lower. The preexisting L_{10} and L_{90} should be measured over a minimum of 3 continuous days that reasonably represents the community over the course of a year. For other zones, such as commercial, industrial and public rights of way the wind turbine noise limit should be 15 dB greater than the L_{90}, or equal to the L_{10}, whichever is less.

Sound Propagation and Attenuation

Propagation refers to how sound travels. Attenuation refers to how sound is reduced by various factors. Many factors contribute to how sound propagates and is attenuated, including air temperature, humidity, barriers, reflections, and ground surface materials. ISO 9613, "Predictive Modeling Standard," provides a standard method for predicting noise propagation and attenuation. This paper summarizes three of the most influential factors:

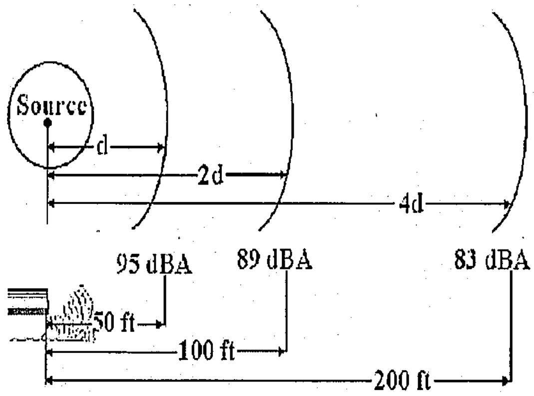
- distance
- wind direction
- building material absorption

Distance

As stated earlier, the decibel scale is logarithmic. Doubling the sound energy increases the sound pressure level by three decibels. But doubling the distance from a stationary source reduces the sound level by six decibels.

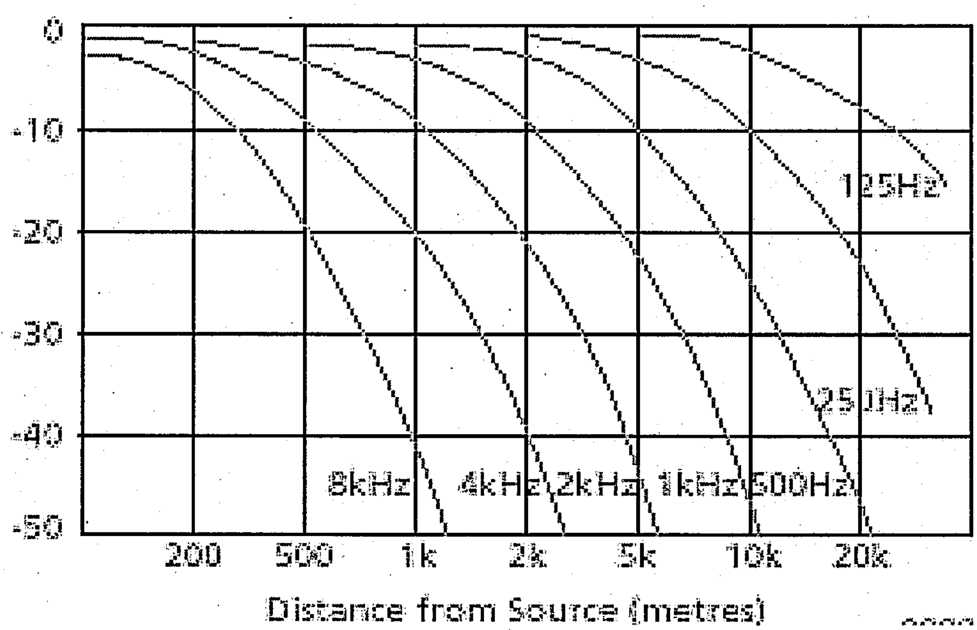
[9] Unpublished correspondence.

Figure 5. Attenuation by Distance[10]



Low frequencies travel further than high frequencies. An 8 kHz tonal sound will be attenuated (reduced in volume) about 40 dB per kilometer. By comparison, a 4 kHz tonal sound will be attenuated only about 20 dB per kilometer. For broadband noise, such as wind turbines produce, the low frequency components may travel further than the higher frequency components. Since low-frequency noise is particularly annoying to most people, it is important to specify limits for low frequency noise.

Figure 6. Frequency Attenuation[11]



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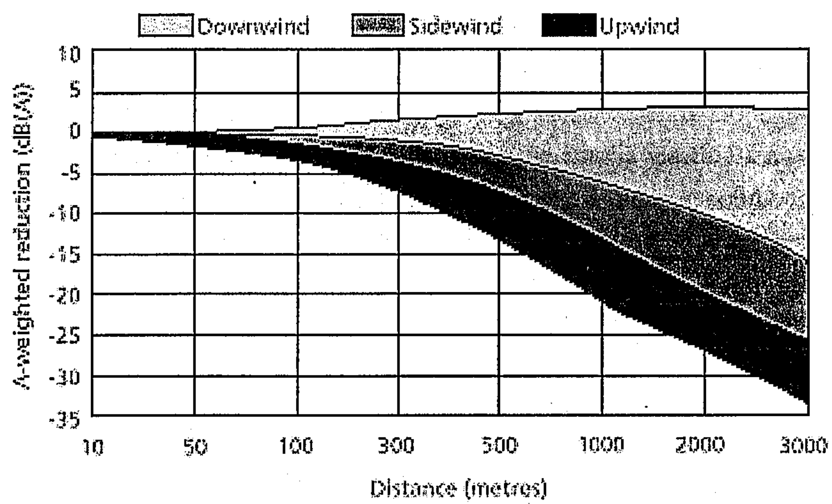
[10] Image source unknown.

[11] Source: Environmental Noise Booklet from Brüel & Kjær Sound & Vibration Measurement A/S. Retrieved from http://www.nonoise.org/library/envnoise/index.htm

Wind Direction

Wind direction also has an influence on sound propagation. Within 900 ft of a sound source, the wind direction does not seem to influence the sound. But after about 900 ft., the wind direction becomes a major factor in sound propagation. Downwind (meaning the wind is moving from the noise source towards the receiver) of the source, sound volume will increase for a time before decreasing. Upwind (the wind is moving from the receiver to the noise source), sound volumes decrease very quickly.

Figure 7. Wind Attenuation of Sound[12]



Building Materials

General home construction, with stud walls and windows in consideration, reduces noise differently for each frequency range. The EPA estimates that in cold climates, such as we have in Michigan, these types of homes attenuate 27 dB of noise. However, this estimate was based on traffic noise which consists of different frequency components than wind turbine noise.

Wind turbine noise, especially at lower wind and blade speeds, will contain more low frequency components than traffic noise. Light weight building home structures will not attenuate these frequencies components as well as higher frequency components. Table 8 lists the estimated attenuation for three octave bands in the low frequency range.

[12] Source: Environmental Noise Booklet from Brüel & Kjær Sound & Vibration Measurement A/S. Retrieved from http://www.nonoise.org/library/envnoise/index.htm

Table 8. Low Frequency Attenuation by Homes

Center of Octave Range	Estimated Attenuation
250 Hz	20 dB
125 Hz	10-15 dB
63 Hz	5-10 dB

Noise Ordinances

There are several methods to specifying noise limits:

- specifying a single all-encompassing maximum limit
- determining preexisting ambient noise levels and specifying that a new noise source may not increase the ambient noise by more than a particular amount
- setting a base limit, with adjustments for district types and time of day or night
- specifying maximum sound levels for each octave range

The American Wind Energy Association (AWEA) and the State of California recommend that noise from small turbines be limited to 60 dB(A) at the closest inhabited dwelling[13]. However, many people feel these simple limits are insufficient to protect people from noise's harmful effects, or even to address the annoyance level.

As mentioned before, the State of Oregon requires that turbine operators determine the preexisting L_{10} and L_{50} of a community. Operating the new equipment must not raise the statistical levels L_{10} or L_{50} by more than 10 dB in any one hour[14]. This method is adopted to address noise as a public nuisance, and takes into consideration the fact that each community will find different noise levels acceptable. However, many people consider it insufficient to account for low frequency noise or to protect people's sleep.

The International Standards Organization (ISO) recommends setting a base limit of 35–40 dB(A) and adjusting the limit by district type and time of day. Table 9 lists the adjusted limits from a base of 35 dB(A).

[13] Permitting Small Wind Turbines: Learning from the California Experience http://www.energy.ca.gov/renewables/

[14] http://egov.oregon.gov/ENERGY/RENEW/Wind/docs/OAR340-035-0035.pdf

Table 9. ISO 1996-1971 Recommendations for Community Noise Limits

District Type	Daytime Limit	Evening Limit (7 -11 PM)	Night limit (11 PM – 7 AM)
Rural	35 dB(A)	30 dB(A)	25 dB(A)
Suburban	40 dB(A)	35 dB(A)	30 dB(A)
Urban residential	45 dB(A)	40 dB(A)	35 dB(A)
Urban Mixed	50 dB(A)	45 dB(A)	40 dB(A)

The most comprehensive method combines the district method with specific limits for frequency components in each octave range. The Charter Township of Mundy, MI's noise ordinance contains two tables; one specifying an overall limit, and one specifying octave band limits for each type of district. Table 10 shows an excerpt from Mundy's ordinance.

Table 10. Mundy Township Octave Band Noise Limits

		Frequency at center of octave band					Total Noise Limit
District Type		31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	
Residential	Day	72 dB	71 dB	65 dB	57 dB	51 dB	55 dB(A)
	Night	67 dB	66 dB	60 dB	52 dB	46 dB	50 dB(A)
Agricultural	Day	82 dB	81 dB	75 dB	67 dB	61 dB	65 dB(A)
	Night	72 dB	71 dB	65 dB	57 dB	51 dB	55 dB(A)

Note: The standard practice among noise control engineers is to specify limits for octave band components as unadjusted dB, and limits for total noise exposure as dB(A).

Engineering Standards

Several organizations have issued recommendations and standards related to noise measurement, assessment and control. Table 11 lists some of the applicable engineering standards.

Table 11. Noise Control Engineering Standard

Standard	Title
ASTM E1014-84	Standard Guide for Measurement of Outdoor A-Weighted Sound Level
ISO 9613	Predictive Modeling Standard
IEC 61400-11	Wind turbine generator systems –Part 11: Acoustic noise measurement techniques
ISO 1996-1971	Recommendations for Community Noise Limits
ANSI S1.4-1983	Specifications for Sound Level Meters
ANSI S12.18-1994	Procedures for Outdoor Measurement of Sound Pressure Levels

Referencing these standards in noise control ordinances will help clarify many aspects of community noise control that might otherwise be left open to interpretation.

Example Ordinance Language

> Prior to installing the turbines, establish the existing ambient noise level according to ANSI S12.18-1994 with a sound meter that meets or exceeds ANSI S1.4-1983 specifications for a Type I sound meter.
>
> Use the sound propagation model of ISO 9613 to micro site the turbines within a wind farm so that the turbines will not emit noise above the limits specified in Table 9 and Table 10 beyond the property line of the wind farm.

Conclusions

Community noise assessment and control is a land compatibility issue which must be carefully addressed. A few years ago, the city of Sterling Hts., MI permitted an outdoor concert venue adjacent to a residential neighborhood. The noise became a nuisance, neighbors filed law suits, and the city spent more than $31 million trying to settle the conflict.

With good preparation, however, similar conflicts with wind energy development can be avoided. This paper provides a foundation which should help decision makers develop beneficial permitting procedures and zoning ordinances, and permit wind energy development with minimal conflicts.

About the Author

Daniel J. Alberts is a senior member of the Society for Technical Communication. He holds a BS in Engineering from the University of Michigan and a Master of Science in Technical and Professional Communication from Lawrence Technological University (LTU). Mr Alberts was a founding member of LTU's Alternative Energy Student Group and served as the group's Vice President for the 2004-05 school year.

Mr. Alberts can be reached through http://www.daniel-alberts.info or dja1701@nethere.com.

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HOWE GASTMEIER CHAPNIK LIMITED
2000 Argentia Road
Plaza 1, Suite 203
Mississauga, ON
L5N 1P7 Canada

Tel: (905) 826-4044
Fax: (905) 826-4940

WIND TURBINES AND SOUND: REVIEW AND BEST PRACTICE GUIDELINES

SUBMITTED TO:
CanWEA
Canadian Wind Energy Association
Suite 320, 220 Laurier Avenue West
Ottawa, Ontario
Canada K1P 5Z9

SUBMITTED BY:
Howe Gastmeier Chapnik Limited
(HGC Engineering)
2000 Argentia Road Plaza 1, Suite 203
Mississauga, Ontario
Canada L5N 1P7

Contact: Brian Howe, MEng, MBA, PEng
Bill Gastmeier, MASc, PEng
Nick McCabe, PEng

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1. INTRODUCTION

Howe Gastmeier Chapnik Limited (HGC Engineering) was retained by the Canadian Wind Energy Association (CanWEA) to develop a best practice guide for the development of wind turbine generation facilities in Canada with respect to noise.

Wind power generation has become an accepted industry in Canada, with large scale wind farms involving 20 or more wind turbines now operating in most provinces. Today, Canada has over 1,000 MW of installed wind energy capacity, and the federal government and some provincial governments have programs in place to promote further wind energy projects. Wind is a renewable resource, and with the potential economic and environmental advantages, the prevalence of wind farms in Canada is sure to increase.

The rate of growth of wind farms in Canada brings more people into closer proximity to the wind turbine generators, and it is important that any potential impact from future projects be well assessed. CanWEA has commissioned this study as a review of current practices with regard to noise assessment and to develop a guide for future efforts. The study has been based on a review of relevant literature, discussions with wind farm developers and environmental regulators in different Canadian jurisdictions, and on the experience of HGC Engineering and others pertaining to the assessment of noise associated with wind farms in Canada.

The report begins with a discussion of noise in general, its descriptors and assessment methods, and moves to a discussion of wind turbine generators and the noise they produce. A review of various guidelines and standards used as criteria for assessment of noise in Canada are described, together with a review of international and Canadian experience with the assessment of wind turbine generator noise, based on the results of the surveys and interviews. The report ends with the presentation of the best practice guideline.

2. ACOUSTIC PRIMER

Sound is a complex phenomenon with temporal, spatial and psychological dimensions. Noise is simply unwanted sound. Sounds vary in many ways including loudness, character, temporal pattern, and are audible to different extents by different people in different environments. In order to have a meaningful discussion of sound, it is productive to consider some basic terminology.

One of the most basic descriptors of sound is the sound level, or more accurately, the sound pressure level (SPL). The SPL of a sound indicates little about the source of the sound, its character or what it sounds like, but describes only its magnitude. Sound pressure levels are most commonly measured and described in decibels, denoted dB or A-weighted decibels, denoted dBA. A-weighted decibels more closely correlate with the subjective loudness of a sound, as discerned by the human ear.

Another basic descriptor of sound is the Sound Power Level (PWL). This is a basic quantity directly describing the amount of acoustic power radiated by a source. It is the fundamental quantity which produces a sound pressure level (SPL) at a distance. It is used define the source for assessment purposes, and to calculate the SPL at a receptor. The PWL is also usually described in decibels or A-weighted decibels.

The frequency content (or spectrum) is the property we perceive as pitch, which gives a sound its unique character. A sound can be a purely high frequency sound (a treble note), or a purely low frequency sound (a bass note), or more commonly is made up of a complex mixture of frequencies. A spectral analysis breaks a measured sound into a number of frequency bands of a defined width, like the notes on a musical scale. In acoustics, frequency is most commonly measured in cycles per second, or Hertz, designated Hz.

Human sensitivity to sound can vary considerably between individuals, typically decreasing with age and past exposure to noise. In general, young people are sensitive to sound in the range of

20 to 20,000 Hz. Sounds predominantly outside of this range are difficult to detect except in extreme cases. Also, very quiet sound, measurable with appropriate instrumentation, can be completely inaudible to people, being below the threshold of hearing.

Ambient sound, or background sound, can strongly affect the audibility of a particular sound in a particular environment. In a very noisy environment, such as a factory floor, one must often shout to be heard. Similarly, on a windy day, a nearby industry can be made inaudible (masked) by the natural sounds produced by the wind in the trees, or other environmental noise such as traffic.

The acceptability of sound from an industrial source by an individual depends on many factors. The sound level is an important factor, but is certainly not the only one. The background sound in an area is also important as it directly affects audibility through masking. As background sound levels typically change from moment to moment, as when vehicles pass nearby, aircraft fly overhead, birds chirp and the wind gusts, the sound is less noticeable , possibly inaudible at times, and may not attract an individual's attention. The character of a sound (does it buzz, rattle, hum, whine, swoosh or thump) can also significantly affect the audibility and potential annoyance. The activities that an observer is engaged in also impact the relative acceptability; someone playing or walking on a busy afternoon will generally notice or be irritated by a noise much less than someone woken up in the middle of the night.

The list below provides definitions of various acoustic terminology used in this report.

Octave Band: A filter with a bandwidth of one octave, or twelve semi-tones on the musical scale representing a doubling of frequency.

1/3-Octave Band: A filter with a bandwidth of one-third of an octave representing four semitones, or notes on the musical scale. This relationship is applied to both the width of the band, and the centre frequency of the band.

A-Weighting: This is a filter, often applied to a pressure signal or to a *SPL* or *PWL* spectrum, which decreases or amplifies certain frequencies in accordance with international standards to approximate the frequency dependence of average human hearing.

Amplitude Modulated Sound: A sound which noticeably fluctuates in loudness over time.

Audible Frequency Range: Generally assumed to be the range from about 20 Hz to 20,000 Hz, the range of frequencies which our ears perceive as sound.

C-Weighting: This is an international standard filter, which can be applied to a pressure signal or to a *SPL* or *PWL* spectrum, and which is essentially a pass-band filter in the frequency range of approximately 63 to 4000 Hz. This filter provides a more constant, flatter, frequency response, providing significantly less adjustment than the A-scale filter for frequencies less than 1000 Hz.

L_{EQ} (Energy Equivalent or Average Sound Level): A sound level, which if constant over a measurement period, would contain the same acoustic energy as a varying sound level actually measured over the period.

Frequency: The rate of oscillation of a sound, measured in units of Hertz (Hz) or kilohertz (kHz). One hundred Hz is a rate of one hundred times per second. The frequency of a sound is the property we perceive as pitch: a low-frequency sound (such as a bass note) oscillates at a relatively slow rate, and a high-frequency sound (such as a treble note) oscillates at a relatively high rate.

G-Weighting: A filter used to represent the infrasonic components of a sound spectrum.

Infrasound: Sound with a frequency content below the threshold of hearing, generally held to be about 20 Hz. Infrasonic sound with sufficiently large amplitude can be perceived, and is both heard and felt as vibration. While perceptible levels of infrasound can be unsettling and objectionable, there does not appear to be any reliable evidence that adverse impacts on the body occur when amplitudes are below the threshold of hearing. Natural sources of infrasound are waves, thunder and wind.

Linear Weighting: This is a term used to indicate that a measurement does not have *A-weighting* or any other frequency weighting applied to it.

Overall Sound Level: For the measurements in this report, indicates that the reported level (*SPL, SL*, etc.) is the summation of measurements of all audible frequencies (20 Hz to 20 kHz), whether or not A-weighted. Analogous to and alternately implemented as a passband filter from 20 Hz to 20 kHz.

Sound Power, *w*: This is the acoustic power output of a sound source, expressed in Watts. It is a function of the source parameters itself and is virtually independent of the environment in which it is located.

Sound Power Level, *PWL* or L_W: Reported in dB (or dBA if A-weighted), this is 10 times the logarithmic ratio of the acoustic power output of a source to 1 picoWatt. A sound power level is an attribute of a source of noise, virtually independent of both the environment in which it is located and the location of any observer. A sound pressure level meter does not directly measure sound power.

Sound Pressure, *P*: Reported in rms Pascals, is the dynamic variation in atmospheric pressure.

Sound Pressure Level, *SPL*: A sound pressure level is equivalent to 20 times the logarithmic ratio of the instantaneous sound pressure (in Pascals) of the sound being measured to that at the threshold of hearing, defined as 20 microPascals. Accordingly, the sound pressure level changes from place to place and time to time. The sound pressure level is generally what is meant by the term 'noise level'. Sound pressure levels are expressed in decibels (dB), or A-weighted decibels (dBA).

Spectrogram: A chart used to visually illustrate a time-varying sound spectrum. The vertical axis represents frequency, the horizontal axis represents time, and colours used to represent amplitude.

Spectrum: Sound Pressure signals may be passed through a parallel series of filters (e.g. *1/3-octave band*) to produce *SPL*s in each filter band. When these are presented in sequential order of filter band, a Sound Pressure Level spectrum is produced. A similar process may be applied to produce Sound Power Level or Sound Intensity Level spectra.

Time Weighting: This is an exponential time response function applied to the pressure signal being measured, effectively dampening the signal's response to quickly and highly varying sound pressures.

Tonal: A tonal sound is a sound with a significant portion of its energy confined to a narrow frequency band. A highly tonal sound is often described as a buzz, whine, or hum.

Ultrasound: Frequencies of sound above the audible range (generally considered to be greater than 20,000 Hz) are not audible or perceptible to humans, but can be perceived by some animals.

3. WIND TURBINES, TURBINE SOUND PRODUCTION AND PROPAGATION

A wide variety of wind turbine designs have been developed and constructed in the world and in Canada in recent decades. These have included designs incorporating a vertical axis of rotation, with which the National Research Centre of Canada was involved, and designs incorporating a horizontal axis of rotation which are more common today. Horizontal-axis turbines have been designed in many ways usually using a two or three bladed rotor, but sometimes with rotors using as few as one blade or more than three. Designs have placed the rotor blades both upwind and downwind of the tower. A wide variety of sizes and rated generating capacities have also been developed. Today, most wind turbine generators are horizontal-axis systems with a nacelle housing the gearbox, generator and rotation equipment at the top of the tower connected to the three-bladed rotor, as illustrated in Figure 1. The nacelle rotates to face the wind. These systems have blades with a variable pitch meaning that the blades themselves can rotate around their own radial axis to catch either more or less wind, controlling the speed of the turbine.

Canada today has over 1,000 MW of installed wind turbine generator capacity, and has wind farms dating back to the mid 1990s. The most common turbines installed in the last couple of years appear to be horizontal-axis systems in the 1 to 2 MW range, usually with a nacelle height of about 80 metres, and a blade diameter of about 80 metres. The rotation speed is usually in the range of about 10 to 20 rpm with tip speeds in the subsonic range of 150 to 300 km/hr, with systems allowing for some flexibility in the rotation speed.

Wind turbine generators produce noise through a number of different mechanisms which can be roughly grouped into mechanical and aerodynamic sources. The major mechanical components including the gearbox, generator and yaw motors each produce their own characteristic sounds. Other mechanical systems such as fans and hydraulic motors can also contribute to the overall acoustic emissions. Mechanical noise is radiated by the surfaces of the turbine, and by openings in the nacelle casing. The interaction of air and the turbine blades produces aerodynamic noise through a variety of processes as air passes over and past the blades. Generally, wind turbines radiate more noise as the wind speed increases.

Modern wind turbine generators are considerably quieter than earlier versions, with some investigators showing a reduction in recent years of about 10 dB over earlier versions. Different models and different manufacturer's systems have their own acoustic characteristics, although various investigations indicate that the radiated sound power levels form a fairly consistent band as shown in Figure 2. Sound power levels of 105 dBA re 10^{-12} W are typical for modern turbines in the 1 to 2 MW range at moderate wind speeds.

The noise produced by a wind turbine generator can include tonal components produced by the gearbox and generator. The noise produced by air interacting with the turbine blades tends to be broadband noise, but is amplitude modulated as the blades pass the tower, resulting in a characteristic 'swoosh'. The spectrograph attached as Figure 3 illustrates the swoosh measured near a typical wind turbine generator, showing an amplitude modulation of about 0.8 Hz, most audible in the 250 to 1000 Hz range.

There appears to be some confusion between this low speed temporal modulation of sound and low-frequency or low-pitched sounds. To avoid misunderstanding, it should be realized that any sound, with predominantly low, middle, or high-pitched frequency content, can be modulated in time, without changing the pitch of the sound. Low frequency modulation of audible sound does not imply the presence of infrasound.

Some older turbines, with blades arranged downwind of the tower, resulted in infrasonic noise being generated through changes in the airflow pressure near the tower. In modern turbines with upwind blades, this issue has been minimized. While a great deal of discussion about infrasound in connection with wind turbine generators exists in the media there is no verifiable evidence for infrasound production by modern turbines.

Because modern horizontal axis turbines can vary rotor speed and blade pitch, there is some ability to control the aerodynamic noise of the turbines, and this creates some variability in the sound of a wind turbine generator.

There has been discussion about the appropriate weighting network for the assessment of a wind turbine noise. While there are a variety of weighting networks in use for various technical purposes, an A-weighted spectrum provides a better indicator of the spectral makeup of a sound as perceived by the human ear than any other frequency weighting network than any other commonly in use today. For this reason, it is used worldwide in the assessment of the impact of environmental noise on people, and has been widely adopted in assessment guidelines and criteria. While the use of another weighting network, such as the C-weighting network would generate a higher single-number sound level descriptor than the equivalent A-weighting level, it is unclear what it would represent in terms of human perception, and it is equally unclear what the appropriate criterion for a C-weighted sound level would be. There does not appear to be any technical justification for the use of the C-weighting network in the assessment of the acceptability of noise from wind turbine generators on people.

Mechanical issues such as yaw motor supports or power train design can result in anomalous sounds such as periodic booming or tonal noises. Experience in Canada suggests that often these matters can generally be corrected through maintenance.

Sound radiating from a sound source to a receptor location is attenuated through a number of mechanisms in addition to the simple geometric spreading with distance. These include viscous losses in the air, interaction with the ground and any intervening structures, topography or vegetation. Sound from a wind turbine generator is no different. Various calculation methodologies are used to predict sound levels at a specified point. One such model which currently sees wide application in Canada is ISO standard 9613-2, *Acoustics – Attenuation of sound during propagation outdoors*. This model uses as and input the total acoustic energy radiated by the operating wind turbine generator (the sound power level), and predicts the sound pressure level at any given point, taking into account the natural propagation mechanisms discussed above.

Atmospheric conditions play a large role determining the sound level due to a wind turbine generator at any given location at any given time. Different prediction models consider atmospheric effects in different ways. ISO 9613-2 considers propagation conditions equivalent to a moderate downwind condition in all directions simultaneously (ie, the model favors the propagation of sound from a source to any receptor to some degree). However, it does not purport to consider the absolute worst case environmental situation, and consequently, there may be times when the actual impact exceeds that predicted, due to infrequent or extreme environmental conditions. While ISO 9613-2 has this and other limitations it remains a widely applied and recognized assessment methodology.

The subjective audibility of a wind turbine generator is also highly dependant on the background sound level. The sound from a wind turbine generator generally increases with wind speed, but so too does the background sound. Interestingly, both the experience of HGC Engineering and published articles suggest that the greatest apparent intrusion of sound of a modern wind turbine over the background sound typically occurs at relatively low wind speeds. At high wind speeds, the wind tents to generate significant background sound by moving trees, grasses, etc. in most environments, masking the sound of a wind turbine.

4. ASSESSMENT CRITERIA

The assessment of the acceptability of a sound is complex. In Canada, a number of assessment guidelines, methodologies and criteria are currently in use. The standards generally recognise that different acceptability criteria should apply in different circumstances, often offering different criteria during different times of the day, and for different acoustical environments (such as urban settings, as well as rural or natural settings). Many standards are explicitly based on background sound levels, often qualified with minimum levels for use in very quiet areas. Audibility is generally not an assessment criterion for industrial noise under the provincial documents; it is not expected that a receptor should be entirely free of industrial noise.

Several provincial jurisdictions do not have specific sound level guideline policies for environmental noise published by the provincial ministries of the environment. Included in this group are the Maritime Provinces, Saskatchewan and British Columbia. Other provinces have guidelines governing the assessment of industrial sound developed to various degrees. At present, Ontario is the only provincial jurisdiction with a noise assessment guideline specifically intended for wind turbine generators, recognising that the maximum sound power output generally corresponds with high background sound levels. The provincial noise guidelines are briefly discussed below:

Manitoba

The Manitoba Department of Environment has published *Guidelines for Sound Pollution Prepared by Environmental Management Division*". That document provides separate limits for residential areas, commercial areas and industrial areas. For a residential area, the Maximum Acceptable sound levels are 60 dBA and 50 dBA during daytime (07:00 to 22:00) and nighttime (22:00 to 07:00) hours respectively. The Maximum Desirable sound levels are 55 and 45 dBA for daytime and nighttime hours respectively. The Maximum Acceptable levels are to be reduced by 5 dBA if the sound source under assessment contains predominant discrete tones or impulsive character. Definitions of tonal and impulsive character are provided in the guideline. There is no guideline or document specific to wind turbine generator noise.

Quebec

Instruction note 98-01, published by *Ministère du Développement durable, de l'Environnement et des Parcs* provides criteria and a methodology for assessing noise from industrial sound sources, including power related facilities. The standard provides different sound level criteria for different areas, and for nighttime and daytime hours. For a residential area with a light density, the limits are 40 dBA and 45 dBA during the nighttime and daytime respectively, and for denser areas the limits increase by 5 dBA.

Alberta

The Alberta Energy & Utility Board publishes noise guidelines for energy related industrial installations. The noise guidelines are contained in Directive ID99-08. The limits depend on the background sound at the point of reception, as well as several other factors including the dwelling density per quarter section. In areas where the background sound and dwelling density are low, the Permissible Sound Level (PSL) is 40 dBA at night and 50 dBA during the day. (Daytime is 07:00 to 22:00 and night is 22:00 to 07:00). In some cases of very low sound level the limits could be slightly lower than these, but are typically somewhat greater. The PSL applies to the combined level of the background sound and the source under assessment. There is no specific technical guideline for assessing the acoustic impact of wind turbine generators, although such a document is currently under discussion.

Ontario

The Ontario Ministry of Environment (MOE) publishes a fairly comprehensive series of guideline documents for assessing industrial noise. Two of the MOE guideline documents, NPC-205 *Sound Level Limits for Stationary Sources in Class 1 and 2 Areas (Urban)*, and NPC-232 *Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)* provide general assessment guidelines for industrial noise impacting a sensitive land use such as a residence or residential area. An acoustically urban area is defined as one with man-made sounds such as traffic dominating the acoustic environment. Rural areas have sound levels generally dominated by natural sounds, other than the industrial noise source under consideration.

Both NPC-205 and NPC-232 indicate that in general, the applicable sound level limit for a stationary source of sound is the background sound level. However, where background sound levels are low, exclusionary minimum criteria apply, with an exclusionary limit of 40 dBA specified for quiet nighttime periods in rural areas, and 45 dBA specified for quiet daytime periods in rural areas. In urban areas, these limits are 45 dBA and 50 dBA for nighttime and daytime periods.

Because wind turbines generate more sound as the wind speeds increase, and because increasing wind speeds tend to cause greater background sound levels, wind turbine generators have been identified by the MOE as a unique case, and they have provided supplementary guidance for the assessment of wind turbine generator noise in publication *Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators* (hereafter, *Interpretation*). This publication, while consistent with NPC-232 at low wind speeds, provides criteria for the combined impact of all wind turbine generators in an area as a function of wind speed, thus adjusting to some degree the criteria of NPC-232. The criteria are presented in A-weighted decibels, as follows.

Table 1. MOE Criteria for Wind Turbines.

Wind Speed [m/s]	4	5	6	7	8	9	10	11
Wind Turbine Noise Criteria [dBA]	40	40	40	43	45	49	51	53

This guideline publication specifies an analytical method of assessment; the manufacturers sound power data is used as input to a model which predicts the acoustic impact at a point of reception over a full range of wind speeds. The publication further specifies that the calculation methodology of ISO 9613-2, *Acoustics-Attenuation of sound during propagation outdoors* be used. Consequently, the MOE guidelines share the limitations of ISO 9613-2, and yield a receptor sound level under a single assumed propagation condition that does not reflect a realistic meteorological situation, but is generally favourable to the propagation of sound from a source to a receptor (essentially a moderate downwind condition in all directions). Consequently, there may be times when the actual impact exceeds that predicted.

It is important to note that the MOE guidelines do not require inaudibility of a sound source. In fact, even if the sound levels from a source are less than the criteria, the spectral and temporal characteristics of a sound often result in audibility.

Federal Government

Health Canada, Natural Resources Canada, the Canadian Environmental Assessment Agency all have experience and capability in the assessment of noise from wind turbine generators, and are actively involved with their assessment. However, for the most part, these Ministries and agencies rely on provincial regulations where they apply.

5. REVIEW OF CANADIAN EXPERIENCE

During the preparation of this survey, environmental assessments for several wind farm projects were reviewed. Eight different wind farm developers were contact to discuss their experiences with noise assessment and other acoustic issues in different jurisdictions in Canada. Altogether, developers of wind farms in Nova Scotia, Quebec, Ontario, Saskatchewan and Alberta were interviewed. British Columbia does not yet have an operating wind farm, but some are under consideration at present.

Each of the wind farms had a substantial number of large wind turbine generators in place and operational. A number of the wind farms are sited such that residences are located between 300 and 400 metres, and this is generally the minimum setback encountered. Often, residences this close or closer are associated with a landowner leasing land to the wind farm and experiences with this situation appear positive. However, particularly where no financial relationship exists, complaints amongst people living this close to a wind turbine generator are not uncommon.

In populated areas, typical sound level impacts from turbines tend to be 40 to 50 dBA at the closest homes, although atmospheric conditions have a significant effect on the actual sound level at any given moment.

Some areas of Canada with very light population densities have seen wind farm projects. In such areas, plans placing no wind turbine generator closer to a residence than about 1000 metres have been feasible. Not surprisingly, complaints at this distance are very rare.

A realistic expectation of the acoustic impact of the potential audibility of a proposed wind farm appears to be critical. Public consultation and dialog is of course important at all stages of a project, but without an accurate understanding of wind turbine noise such consultation can be counterproductive. One developer discussed a site which had had a pilot turbine installed early on in the development process. This allowed local residents to see and hear the turbine, creating a realistic expectation to the eventual impact of the completed farm. A similar effect occurs in areas with pre-existing wind farms. Conversely, where the expectation of inaudibility was suggested, the ensuing audible wind turbine noise was deemed unacceptable by affected residences.

Mechanical problems with wind turbine generators tend to produce identifiable sounds, increasing the potential for annoyance and complaints among nearby residents. For example, mechanical issues such as yaw motor supports or power train designs can result in anomalous sound producing periodic booming or tonal noises. Developer's experience suggested that such problems can be correctable.

Neither a review of published technical literature, nor the experience of HGC Engineering indicates that infrasound in connection with wind turbine generators is a problem in Canada.

6. CONCLUSIONS AND BEST PRACTICE GUIDELINES

With its potential for environmental and economic advantages, wind power generation has quickly become an accepted industry in Canada with over 1,000 MW of installed wind energy capacity. Large scale wind farms with 20 or more wind turbines are now operating in most of the provinces, and their prevalence is sure to increase. However, when wind farms come close to residences, consideration must be given to ensuring a compatible co-existence. The residences should not be adversely affected and yet, at the same time the wind farms need to reach an optimal scale in terms of layout and number of units.

Wind turbines produce sound, primarily due to mechanical operations and aerodynamics effects at the blades. Modern wind turbine manufacturers have virtually eliminated the noise impact caused by mechanical sources, and instituted measures to reduce the aerodynamic effects. But, as with many activities in society, the wind turbines emit sound power at a level that does impact areas at some distance away. When residences are nearby, care must be taken to ensure that the operations at the wind farm do not unduly cause annoyance or otherwise interfere with the quality of life of the residents. This is not to suggest that the sound should be inaudible under all circumstances – this is an unrealistic expectation that is not required or expected from any other agricultural, commercial, industrial or transportation related noise source – but rather that the sound due to the wind turbines should be at a reasonable level in relation to the ambient sound levels.

Discussions with a variety of wind farm operators and regulators across the country leave no doubt that the above goal can be achieved, and very often is. There have been some situations where issues related to sound have arisen. Lessons can and should be learned from these situations and assimilated by the wind farm developers in future endeavours. With this in mind, the following are suggested as best practices for future wind farm developments, presented somewhat in order of implementation.

1. At the initial stage of planning for a potential wind farm site, it is important to identify all potentially critical receptors for noise. These include residences, but could also include institutional uses such as hospitals, schools or places of worship, or First Nations sacred sites. In addition, the zoning and official plans for the jurisdictions should be considered to determine if future receptors are currently allowed. Needless to say, the wind farms have to make themselves aware of and comply with any local, provincial and federal approvals processes.

2. Good public relations are essential, and at the early stage this principally consists of educating the public with respect to the sound generated by wind turbines. The information presented to the public should be factual and should not set unrealistic expectations. It is counterproductive to suggest that the wind turbines will be inaudible, or to use vague terms like "quiet". Modern wind turbines produce a sound due to the aerodynamic interaction of the wind with the turbine blades, audible as a "swoosh", which can be heard at some distance from the turbines. The magnitude of the sound will depend on a multitude of variables and will vary from day to day and from place to place with environmental and operational conditions. Audibility is distinct from the sound level, since it depends on the relationship between the sound level from the wind turbines and the ambient background sound level. As wind farms are becoming common across the country, arranging visits to existing operations or using pilot installations is an excellent means of allowing community members to hear and judge the situation for themselves.

3. Community involvement needs to continue throughout the project. Annoyance is a complicated psychological phenomenon; as with many industrial operations, expressed annoyance with sound can reflect an overall annoyance with the project, rather than a rational reaction to the sound itself. Wind projects offer a benefit to the environment and the energy supply for the greater population, and offer economic benefits to the land owners leasing installation sites to the wind farm. A positive community attitude

throughout the greater area should be fostered, particularly with those residents near the wind farm, to ensure they do not feel taken advantage of.

4. While dealing with the public in a straightforward and honest fashion, it is important for the wind farm proponents to dispel inaccurate concerns and rumours that sometimes arise. For example, infrasound is often cited as a concern despite the fact that numerous studies, along with HGC Engineering's own research, show that it is not an issue for modern wind turbines.

5. In certain jurisdictions and situations there is pressure to introduce guidelines that require a certain minimum distance between the placement of turbines and any residential receptors. In fact, distances of up to 1,000 m have been proposed in an attempt to eliminate complaints. While this would likely achieve that goal, it is not well founded and would unduly hamper the wind power industry. It is far more appropriate to deal with each application on its own merits, taking into account the topography in the area, the number and placement of the wind turbine, the sound power produced by the particular model of wind turbine, and the ambient sound levels at the receptors. For example, based on a review of operating wind farms in rural areas with 10 or more turbines rated in the range of 1 to 2 MW, acceptable separation distances for sound are generally found to be in the neighbourhood of 300 to 600 m, depending on the particulars for the site. For residences near single low noise models of turbines, separation distances of less than 250 m may achieve acceptable sound levels. Strict enforcement of a large separation distance would also not make sense for installations in high density urban areas or near busy highways, or in instances where the resident has ownership in the turbine and prefers a lower separation distance.

6. A technical assessment of the sound impact of a wind farm project should be undertaken if there are any potentially sensitive receptors within a kilometre or so, even if one is not specifically required during the approval process. The assessment should be completed

by an engineer qualified in the area of acoustics, following accepted engineering practices, and be based on reliable data.

7. Ambient sound levels should be monitored at the receptors to assist in defining criteria and to provide a benchmark for any sound measurements following start-up of the operations. It is important to note that, particularly in quiet rural areas, the ambient sound levels are influenced by wind – as the wind speed increases the ambient sound levels increase. Therefore, it is appropriate to correlate ambient sound levels to wind speed.

8. Accurate sound power data for the wind turbines is necessary for the predictions, and is readily available from leading manufacturers. The sound power data should be based on measurements conducted in accordance with IEC 61400-11, *Wind turbine generator systems – Part 11: Acoustic noise measurement techniques,* and be provided as a function of wind speed.

9. Predictions of the sound levels should be made using an accepted methodology that takes into account the layout of the wind farm and the topography of the surrounding area. ISO 9613-2, *Acoustics-Attenuation of sound during propagation outdoors* is the internationally recognized standard recommended by the Ontario Ministry of the Environment under their assessment protocol, is implemented in the most of the leading environmental acoustical modelling packages, and is currently under review by the Canadian Standards Association (CSA) for adoption in Canada. It is important to recognize that ISO 9613-2 is only one of several possible prediction standards, and that while it is considered conservative in that it relies on an assumed atmospheric condition that favours the propagation of sound to the receptor, it does not necessarily predict the absolute worst case. Thus, it must be anticipated that some degree of statistical variability will occur in practice.

10. The specific numeric criteria for the sound pressure level produced by wind turbines vary from jurisdiction to jurisdiction. Many provinces do not currently provide numeric sound level criteria. Some, such as Alberta and Quebec provide applicable environment sound level limits from industrial sources, but these have not necessarily been specifically developed for wind turbines. The Ontario Ministry of the Environment provides the most comprehensive guidance relevant to wind turbines in their publications NPC-232 *Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)* and PIBS 4709 *Interpretation of Applying MOE NPC Technical Publications to Wind Turbine Generators. Interpretation* is an analytical, prediction-based standard that relies on sound powers from IEC 61400-11 using the propagation model of ISO 9631-2. It is well suited for wind turbines because it starts with criteria similar to Alberta and Quebec, 40 dBA at night in quiet rural areas, but adjusts the limit for acceptability as a function of wind speed, reflecting the fact that the ambient sound levels increase with wind speed. The criteria are presented in A-weighted decibels, as follows.

Table 1. Recommended Sound Criteria for Wind Turbines.

Wind Speed [m/s]	4	5	6	7	8	9	10	11
Wind Turbine Noise Criteria [dBA]	40	40	40	43	45	49	51	53

In all likelihood, given the relatively early stage of large scale wind energy production in Canada, guidelines and criteria will develop further in the various jurisdictions. In the meantime, and in the absence of locally applicable assessment criteria, it is suggested that an approach similar to that put forward in the Ontario Ministry of the Environment guidelines be used. Even still, it should be appreciated by all parties that adhering to these guidelines does not necessarily ensure that there will be no complaints from area residents. Under selected circumstances, further investigation may be in order. For instance, it may be appropriate to give special consideration to residences in quiet valleys that are affected by wind to a lesser degree than nearby wind turbines.

Good public relations during the construction and following start-up can be just as important as during the planning stages. The wind farm should maintain a commitment to the community and respond to concerns in an expedient fashion. Sporadic and legitimate noise complaints could develop. For example, sudden and sharp increases in sound levels could result from mechanical malfunctions or perforations or slits in the blades. Problems of this nature can be corrected quickly, and it is in the wind farm developer's interest to do so.

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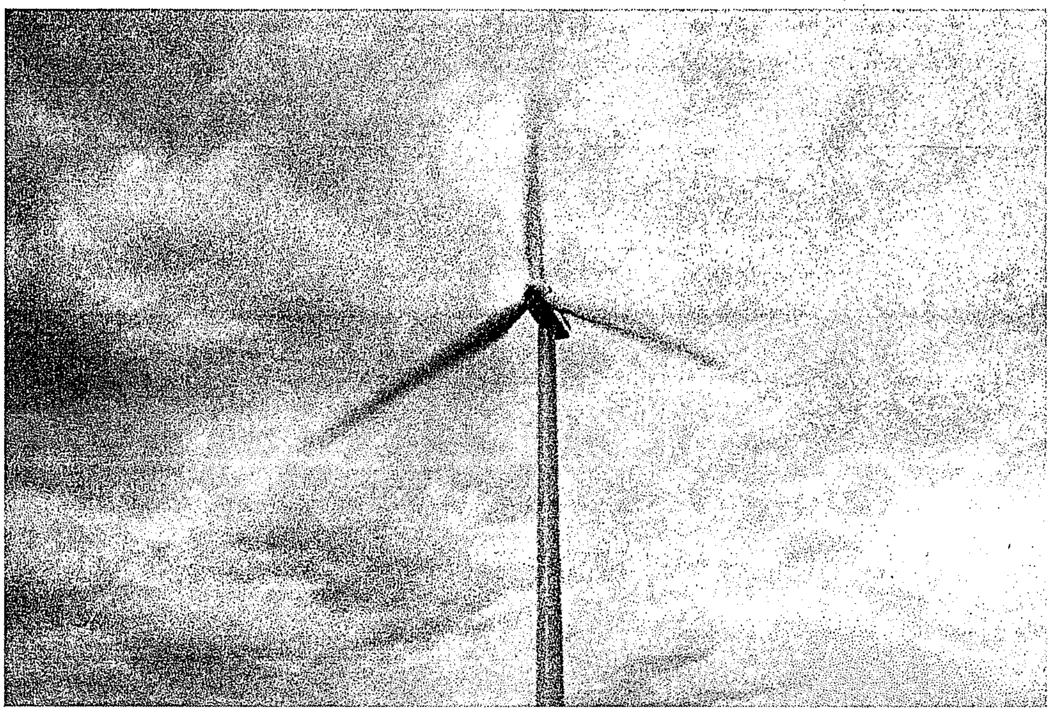


Figure 1: A Typical Modern Horizontal-Axis, Upwind Turbine in Use Throughout Canada Today.

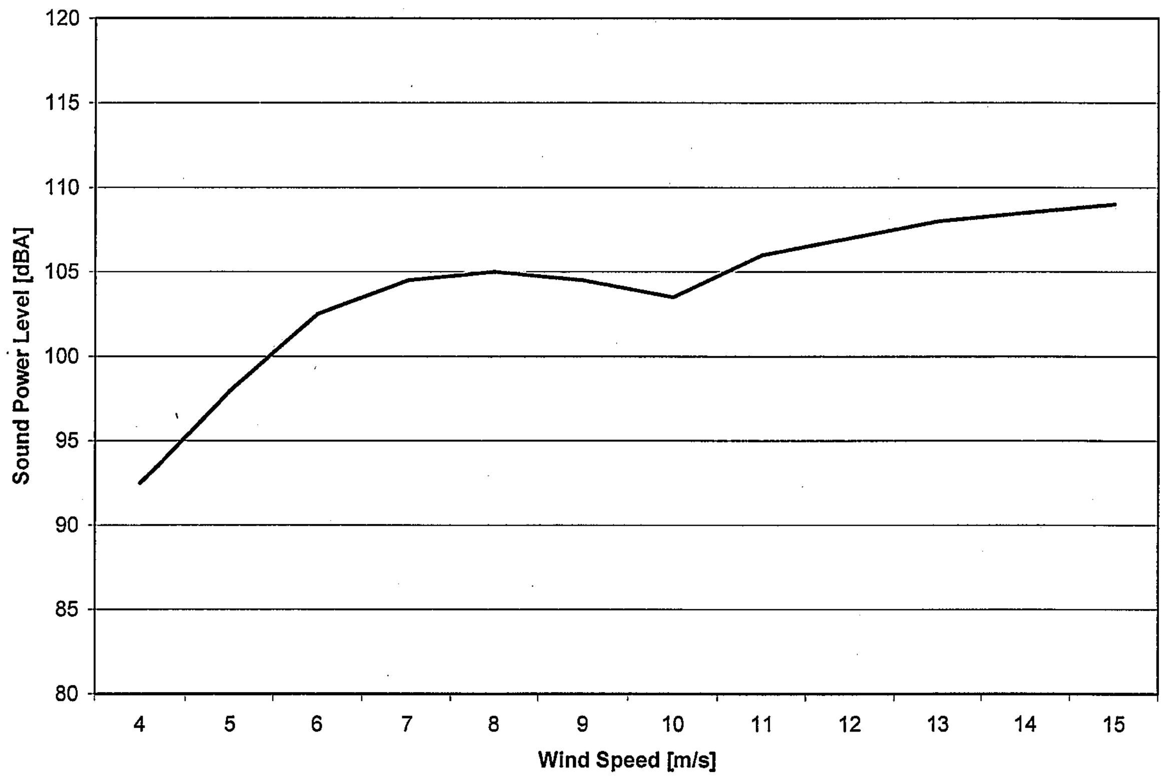
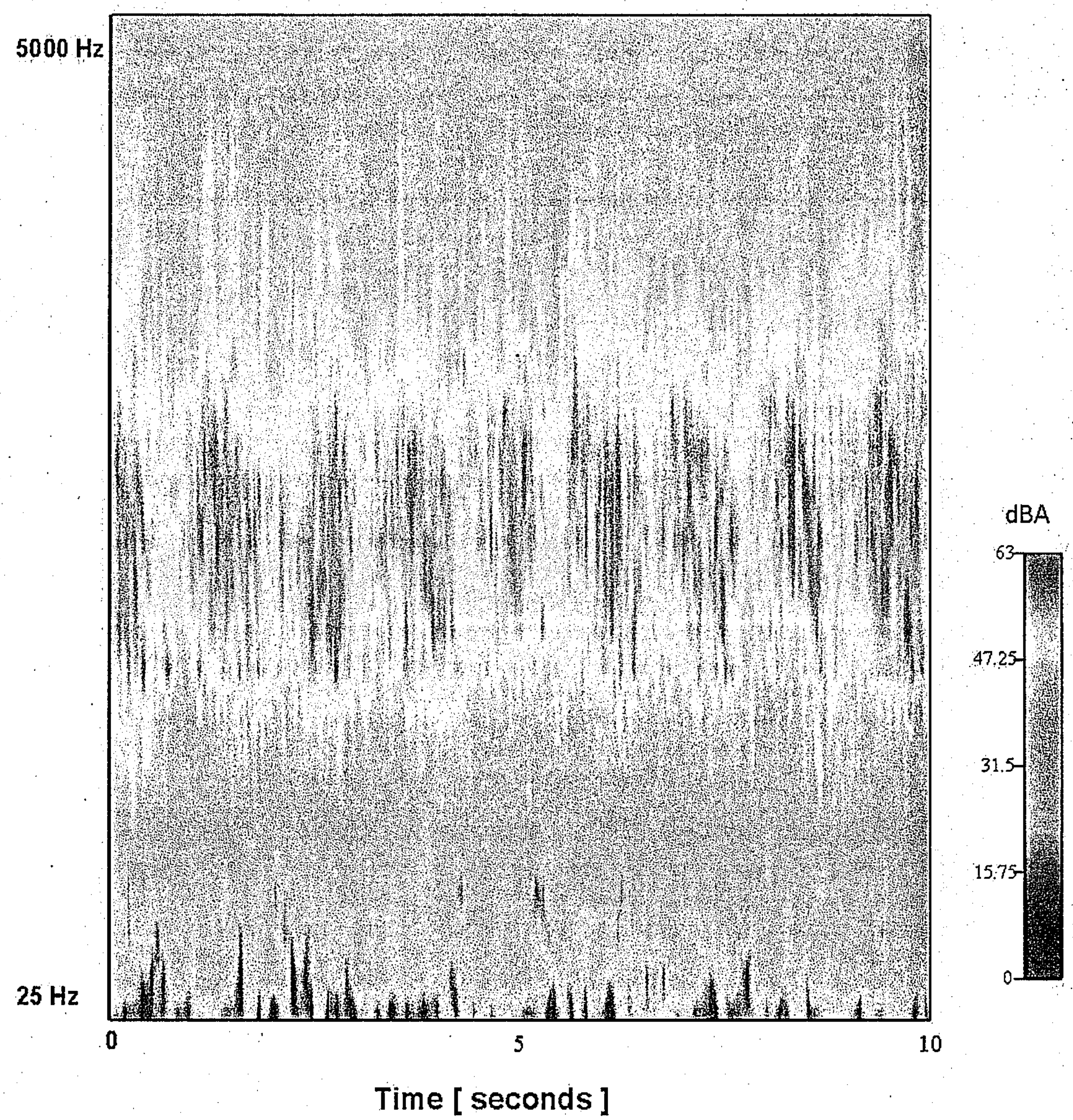


Figure 2: Typical Sound Power Levels of Modern 2 MW Wind Turbine



Colours Represent A-Weighted Sound Pressure Levels

Figure 3: Spectrogram of Sound Pressure Level Measured at 70 metres from a Modern 1.5 MW Wind Turbine Generator

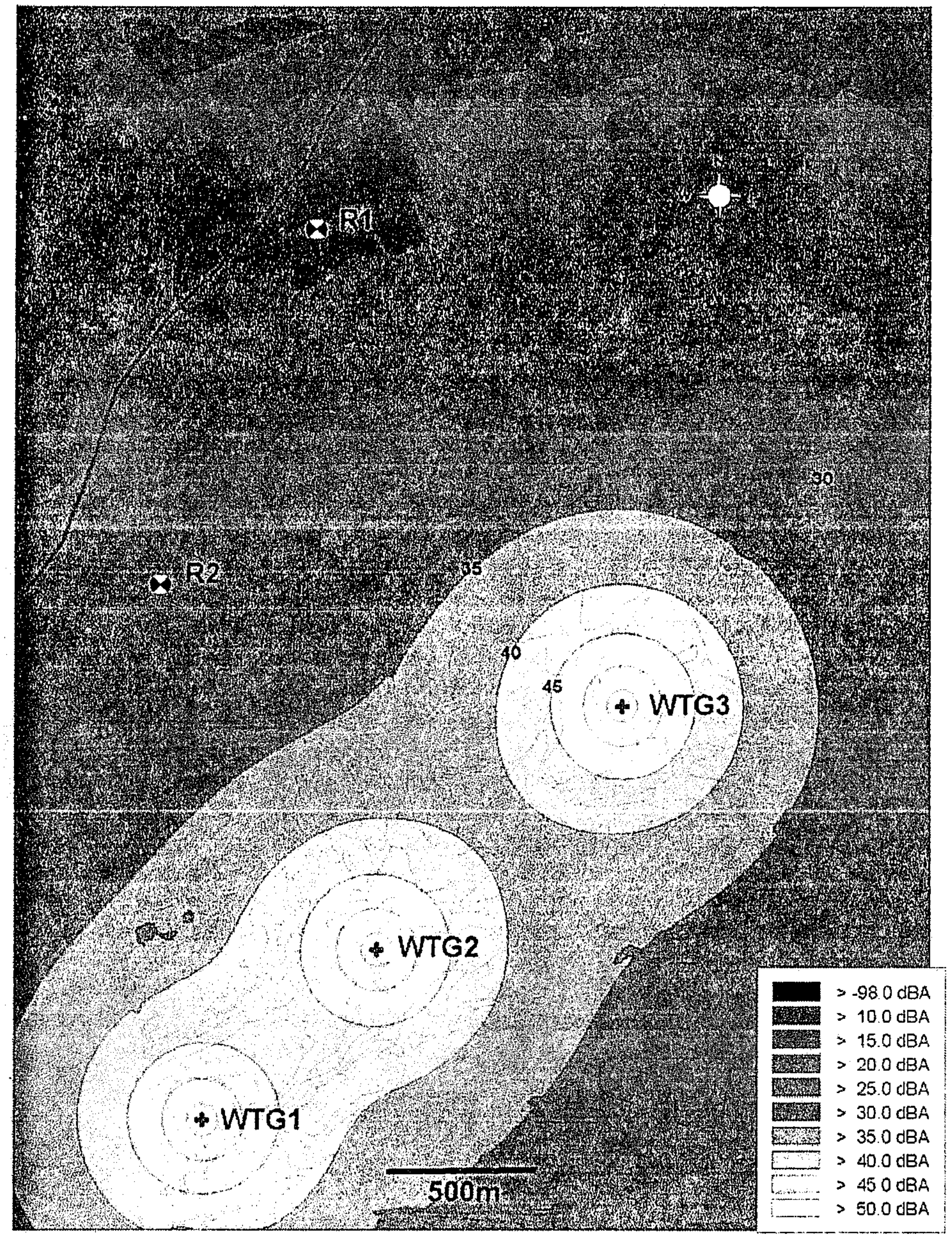


Figure 4: Representative Acoustic Model showing the Propagation of Sound from Typical Wind Turbine Generators

Wind Turbine Acoustic Noise

A white paper

Prepared by the

Renewable Energy Research Laboratory
Department of Mechanical and Industrial Engineering
University of Massachusetts at Amherst
Amherst, MA 01003
413-545-4359
www.ceere.org/rerl

Anthony L. Rogers, Ph.D.
arogers@ecs.umass.edu

James F. Manwell, Ph.D.

Sally Wright, M.S., PE

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Introduction

Wind turbines generate sound via various routes, both mechanical and aerodynamic. As the technology has advanced, wind turbines have gotten much quieter, but sound from wind turbines is still an important siting criterion. Sound emissions from wind turbine have been one of the more studied environmental impact areas in wind energy engineering. Sound levels can be measured, but, similar to other environmental concerns, the public's perception of the acoustic impact of wind turbines is, in part, a subjective determination.

Noise is defined as any unwanted sound. Concerns about noise depend on:

1. the level of intensity, frequency, frequency distribution and patterns of the noise source;
2. background sound levels;
3. the terrain between the emitter and receptor
4. the nature of the receptor; and
5. the attitude of the receptor about the emitter.

In general, the effects of noise on people can be classified into three general categories:

1. Subjective effects including annoyance, nuisance, dissatisfaction
2. Interference with activities such as speech, sleep, and learning
3. Physiological effects such as anxiety, tinnitus, or hearing loss.

In almost all cases, the sound levels associated with wind turbines large & small produce effects only in the first two categories, with *modern* turbines typically producing only the first. The third category includes such situations as work inside industrial plants and around aircraft. Whether a sound is objectionable will depend on the type of sound (tonal, broadband, low frequency, or impulsive) and the circumstances and sensitivity of the person (or receptor) who hears it. Because of the wide variation in the levels of individual tolerance for noise, there is no completely satisfactory way to measure the subjective effects of noise or of the corresponding reactions of annoyance and dissatisfaction.

Operating sound produced from wind turbines is considerably different in level and nature than most large scale power plants, which can be classified as industrial sources. Wind turbines are often sited in rural or remote areas that have a corresponding ambient sound character. Furthermore, while noise may be a concern to the public living near wind turbines, much of the sound emitted from the turbines is masked by ambient or the background sounds of the wind itself.

The sound produced by wind turbines has diminished as the technology has improved. As blade airfoils have become more efficient, more of the wind energy is converted into rotational energy, and less into acoustic energy. Vibration damping and improved mechanical design have also significantly reduced noise from mechanical sources.

The significant factors relevant to the potential environmental impact of wind turbine noise are shown in Figure 1 [Hubbard and Shepherd, 1990]. Note that all acoustic technology is based on the following primary elements: Sound sources, propagation paths, and receivers. In the following sections, after a short summary of the basic principles of sound and its measurement, a review of sound generation from wind turbines, sound propagation, as well as sound prediction methods is given.

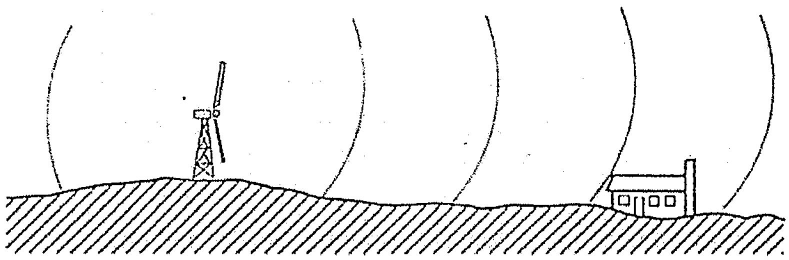

Figure 1: Examples of sources, receivers, and propagation paths

Noise and Sound Fundamentals

Sound and Noise

Sounds are characterized by their magnitude (loudness) and frequency. There can be loud low frequency sounds, soft high frequency sounds and loud sounds that include a range of frequencies. The human ear can detect a very wide range of both sound levels and frequencies, but it is more sensitive to some frequencies than others.

Sound is generated by numerous mechanisms and is always associated with rapid small scale pressure fluctuations, which produce sensations in the human ear. Sound waves are characterized in terms of their amplitude or magnitude (see below), wavelength (λ), frequency (f) and velocity (v), where v is found from:

$$v = f\lambda$$

The velocity of sound is a function of the medium through which it travels, and it generally travels faster in more dense mediums. The velocity of sound is about 340 m/s (1115 ft/s) in air at standard pressures.

Sound frequency denotes the "pitch" of the sound and, in many cases, corresponds to notes on the musical scale (Middle C is 262 Hz). An octave is a frequency range between a sound with one frequency and one with twice that frequency, a concept often used to define ranges of sound frequency values. The frequency range of human hearing is quite wide, generally ranging from about 20 to 20 kHz (about 10 octaves). Finally, sounds experienced in daily life are usually not a single frequency, but are formed from a mixture of numerous frequencies, from numerous sources.

Sound turns into noise when it is unwanted. Whether sound is perceived as a noise depends on subjective factors such as the amplitude and duration of the sound. There are numerous physical quantities that have been defined which enable sounds to be compared and classified, and which also give indications for the human perception of sound. They are discussed in numerous texts on the subject (e.g., for wind turbine sound see Wagner, et al., 1996) and are reviewed in the following sections.

Measurement Scales: Sound Power, Pressure and Intensity

It is important to distinguish between the various measures of the magnitude of sounds: sound power level and sound pressure level. Sound power level is the power per unit area of the sound pressure wave; it is a property of the source of the sound and it gives the total acoustic power emitted by the source. Sound pressure is a property of sound at a given observer location and can be measured there by a single microphone.

Because of the wide range of sound pressures to which the ear responds (a ratio of 10^5 or more for a normal person), sound pressure is an inconvenient quantity to use in graphs and tables. In addition, the human ear does not respond linearly to the amplitude of sound pressure, and, to approximate it, the scale used to characterize the sound power or pressure amplitude of sound is logarithmic [see Beranek and Ver, 1992]. Whenever the magnitude of an acoustical quantity is given in a logarithmic form, it is said to be a level in decibels (dB) above or below a zero reference level.

Sound intensity, I, is defined as the power of the sound per unit area, and so can be measured in watts/m^2, but is more commonly measured in units of decibels, as:

$$I = 10 \log_{10}\left(-I/I_0\right)$$

where the reference intensity, I_0, is often the threshold of hearing at 1000 Hz: $I_0 = 10^{-12}$ W/m^2.

Because audible sound consists of pressure waves, sound power is also quantifiable by its relation to a reference pressure. The sound power level of a source, L_W, in units of decibels (dB), and is given by:

$$L_W = 10 \log_{10}\left(P/P_0\right)$$

with P equal to the sound power level in units of power density and P_0 a reference sound power (often $P_0 = 2 \times 10^{-5}$ N/m^2).

The sound pressure level (SPL) of a sound, L_P, in units of decibels (dB), is given by:

$$L_p = 20 \log_{10}\left(p/p_0\right)$$

with p equal to the effective (or root mean square, RMS) sound pressure and p_0 a reference RMS sound pressure (usually 2×10^{-5} Pa). [See Nave, 2005. This Hyperphysics website, by Georgia State University, is an excellent introduction to sound and hearing.]

The human response to sounds measured in decibels has the following characteristics:

- Except under laboratory conditions, a change in sound level of 1 dB cannot be perceived.
- Doubling the energy of a sound source corresponds to a 3 dB increase

- Outside of the laboratory, a 3 dB change in sound level is considered a barely discernible difference.
- A change in sound level of 5 dB will typically result in a noticeable community response.
- A 6 dB increase is equivalent to moving half the distance towards a sound source
- A 10 dB increase is subjectively heard as an approximate doubling in loudness
- The threshold of pain is an SPL of 140 dB

Figure 2 illustrates the relative magnitude of common sounds on the dB scale. For example, The threshold of pain for the human ear is about 200 Pa, which has an SPL value of 140 dB.

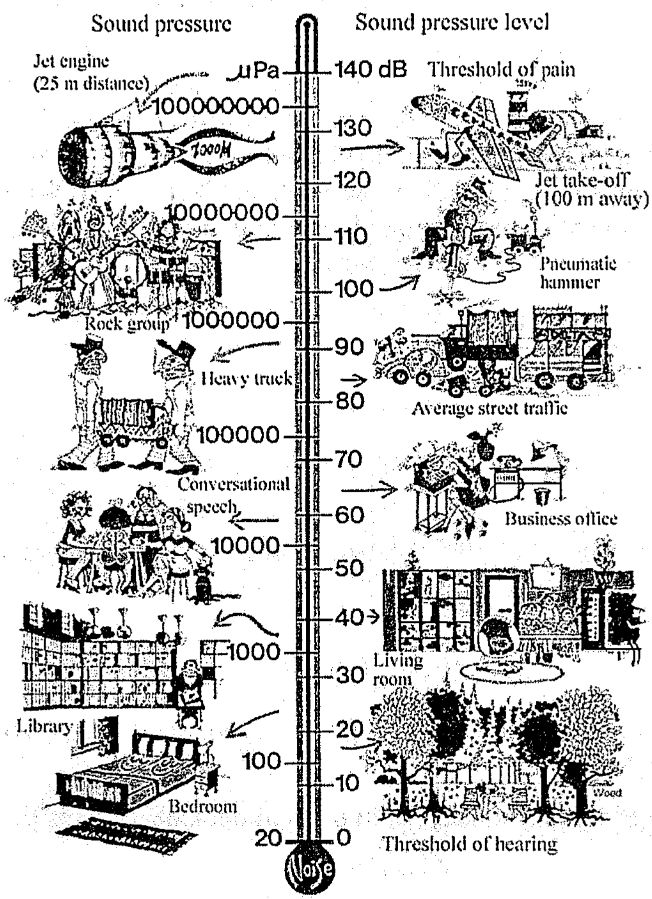

Figure 2: Sound Pressure Level (SPL) Examples (Bruel and Kjaer Instruments)

Measurement of Sound or Noise

Sound pressure levels are measured via the use of sound level meters. These devices make use of a microphone that converts pressure variations into a voltage signal which is then recorded on a meter (calibrated in decibels). As described above, the decibel scale is logarithmic. A sound level measurement that combines all frequencies into a single weighted reading is defined as a broadband sound level. For the determination of the human ear's response to changes in sound, sound level meters are generally equipped with filters that give less weight to the lower frequencies. As shown in Figure 3, there are a number of filters that accomplish this:

- A-Weighting: This is the most common scale for assessing environmental and occupational noise. It approximates the response of the human ear to sounds of medium intensity.
- B-Weighting: this weighting is not commonly used. It approximates the ear for medium-loud sounds, around 70 dB.
- C-Weighting: Approximates response of human ear to loud sounds. It can be used for low-frequency sound.
- G-Weighting: Designed for infrasound

The weighting is indicated in the unit, e.g. measurements made using A-weighting are expressed in units of dB(A). Details of these scales are discussed by Beranek and Ver [1992].

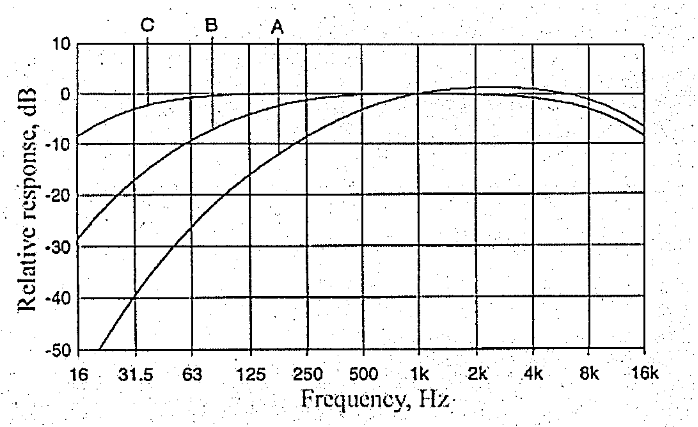

Figure 3: Definition of A, B, and C Frequency Weighing Scales [Beranek and Ver, 1992]

Once the A-weighted sound pressure is measured over a period of time, it is possible to determine a number of statistical descriptions of time-varying sound and to account for the greater community sensitivity to nighttime sound levels. Terms commonly used in describing environmental sound include:

- L_{10}, L_{50}, and L_{90}: The A-weighted sound levels that are exceeded 10%, 50%, and 90% of the time, respectively. During the measurement period L90 is generally taken as the background sound level.
- L_{eq}: *Equivalent Sound Level:* The average A-weighted sound pressure level which gives the same total energy as the varying sound level during the measurement period of time. Also referred to as $L_{A\ eq}$.
- L_{dn}: *Day-Night Level:* The average A-weighted sound level during a 24 hour day, obtained after addition of 10 dB to levels measured in the night between 10 p.m. and 7 a.m.

dB Math

From the comments above it can be seen that decibels do not add numerically as linear measures of other physical things do. Figure 4 shows how to add the decibels of two sound sources that are within 12 dB of each other.

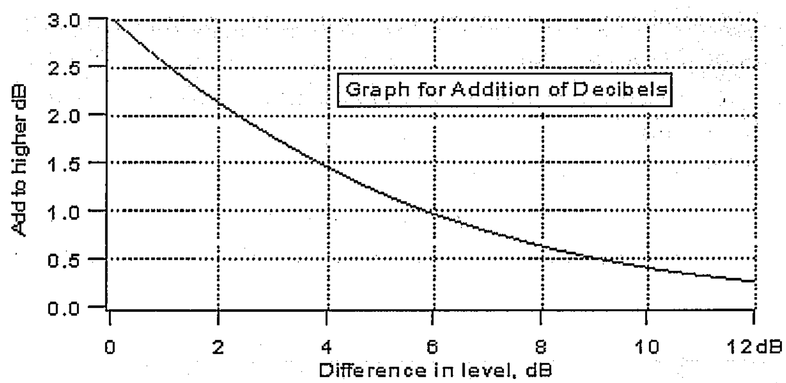

Figure 4: Addition of two sound levels.

For example, when adding two sound sources together, one being 9.5 dB(A) louder than the second, the resultant is approximately 10 dB(A) louder than the second source. It can be seen that when the sound from two sources more than 10 dB(A) apart are combined, the total sound pressure level in decibels is very close to the louder one, with little or no contribution from the softer sound.

Infrasound & Low Frequency Sound

Terminology: Low frequency pressure vibrations are typically categorized as *low frequency sound* when they can be heard near the bottom of human perception (10-200 Hz), and *infrasound* when they are below the common limit of human perception. Sound below 20 Hz is generally considered infrasound, even though there may be some human perception in that range. Because these ranges overlap in these ranges, it is important to understand how the terms are intended in a given context.

Infrasound is always present in the environment and stems from many sources including ambient air turbulence, ventilation units, waves on the seashore, distant explosions, traffic, aircraft, and other machinery[1]. Infrasound propagates farther (i.e. with lower levels of dissipation) than higher frequencies.

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[1] To place infrasound in perspective, when a child is swinging high on a swing, the pressure change on its ears, from top to bottom of the swing, is nearly 120 dB at a frequency of around 1 Hz. [Leventhall, 2004]

Some characteristics of the human perception of infrasound and low frequency sound are:

- Low frequency sound and infrasound (2-100 Hz) are perceived as a mixture of auditory and tactile sensations.
- Lower frequencies must be of a higher magnitude (dB) to be perceived, e.g. the threshold of hearing at 10 Hz is around 100 dB; see Figure 5
- Tonality can not be perceived below around 18 Hz
- Infrasound may not appear to be coming from a specific location, because of its long wavelengths.

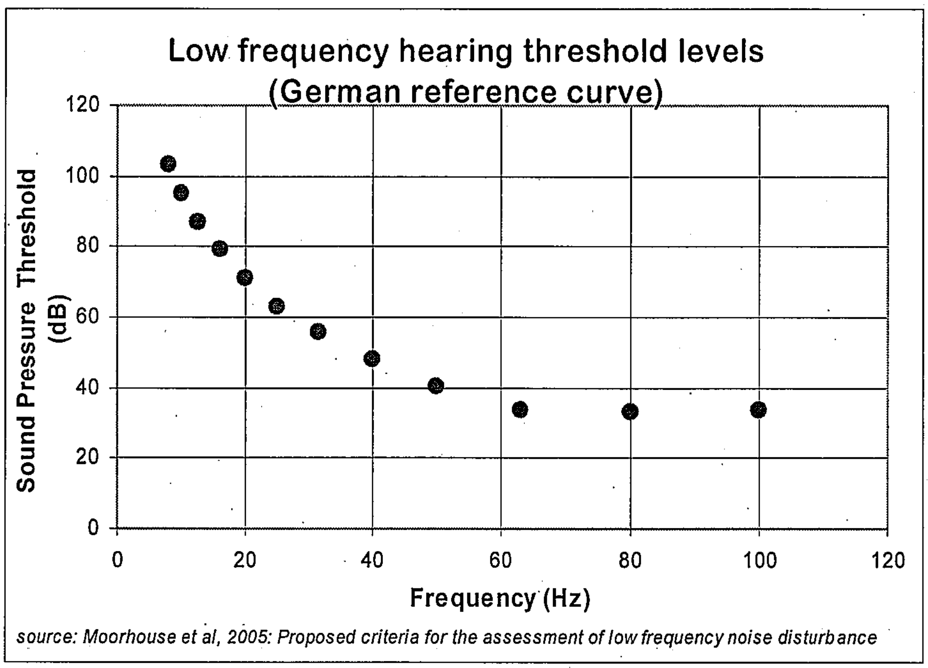

Figure 5: Typical perception threshold of human ear for low frequency sound as a function of pressure

The primary human response to perceived infrasound is annoyance, with resulting secondary effects. Annoyance levels typically depend on other characteristics of the infrasound, including intensity, variations with time, such as impulses, loudest sound, periodicity, etc. Infrasound has three annoyance mechanisms:

- A feeling of static pressure
- Periodic masking effects in medium and higher frequencies
- Rattling of doors, windows, etc. from strong low frequency components

Human effects vary by the intensity of the perceived infrasound, which can be grouped into these approximate ranges:

- 90 dB and below: No evidence of adverse effects
- 115 dB: Fatigue, apathy, abdominal symptoms, hypertension in some humans
- 120 dB: Approximate threshold of pain at 10 Hz
- 120 – 130 dB and above: Exposure for 24 hours causes physiological damage

There is no reliable evidence that infrasound below the perception threshold produces physiological or psychological effects.

Sound from Wind Turbines

Sources of Wind Turbine Sound

There are four types of sound that can be generated by wind turbine operation: tonal, broadband, low frequency, and impulsive:

1. Tonal: Tonal sound is defined as sound at discrete frequencies. It is caused by components such as meshing gears, non-aerodynamic instabilities interacting with a rotor blade surface, or unstable flows over holes or slits or a blunt trailing edge.
2. Broadband: This is sound characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is often caused by the interaction of wind turbine blades with atmospheric turbulence, and also described as a characteristic "swishing" or "whooshing" sound.
3. Low frequency: Sound with frequencies in the range of 20 to 100 Hz is mostly associated with *downwind* rotors (turbines with the rotor on the downwind side of the tower). It is caused when the turbine blade encounters localized flow deficiencies due to the flow around a tower.
4. Impulsive: This sound is described by short acoustic impulses or thumping sounds that vary in amplitude with time. It is caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine.

The sources of sounds emitted from operating wind turbines can be divided into two categories: 1) Mechanical sounds, from the interaction of turbine components, and 2) Aerodynamic sounds, produced by the flow of air over the blades. A summary of each of these sound generation mechanisms follows, and a more detailed review is included in the text of Wagner, et al. [1996].

Mechanical Sounds

Mechanical sounds originates from the relative motion of mechanical components and the dynamic response among them. Sources of such sounds include:

1. Gearbox
2. Generator
3. Yaw Drives
4. Cooling Fans
5. Auxiliary Equipment (e.g., hydraulics)

Since the emitted sound is associated with the rotation of mechanical and electrical equipment, it tends to be tonal (of a common frequency), although it may have a broadband component. For example, pure tones can be emitted at the rotational frequencies of shafts and generators, and the meshing frequencies of the gears.

In addition, the hub, rotor, and tower may act as loudspeakers, transmitting the mechanical sound and radiating it. The transmission path of the sound can be air-borne or structure-borne. Air-borne means that the sound is directly propagated from the component surface or interior into the air. Structure-borne sound is transmitted along other structural components before it is radiated into the air. For example, Figure 6 shows the type of transmission path and the sound power levels for the individual components for a 2 MW wind turbine [Wagner, et al., 1996]. Note that the main source of mechanical sounds in this example is the gearbox, which radiates sounds from the nacelle surfaces and the machinery enclosure.

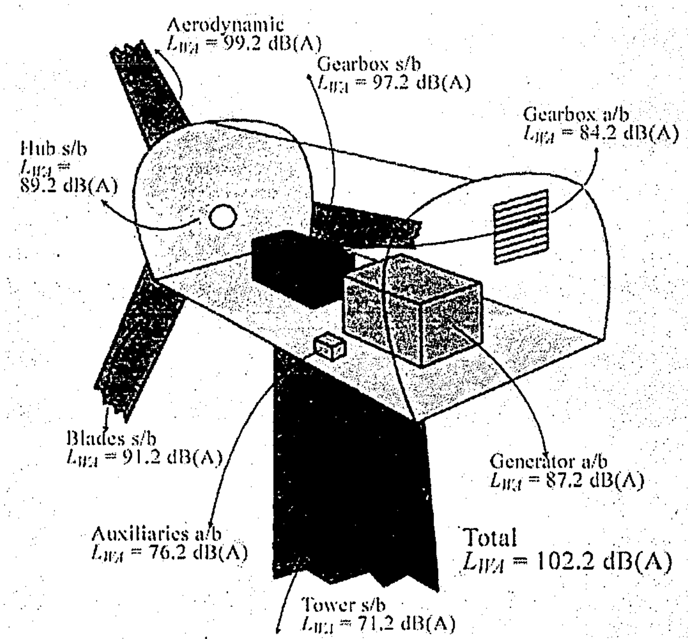

Figure 6: Components and Total Sound Power Level of a Wind Turbine, showing structure-borne (s/b) and airborne (a/b) transmission paths [Wagner, 1996].

Aerodynamic Sounds

Aerodynamic broadband sound is typically the largest component of wind turbine acoustic emissions. It originates from the flow of air around the blades. As shown in Figure 7, a large number of complex flow phenomena occur, each of which might generate some sound. Aerodynamic sound generally increases with rotor speed. The various aerodynamic sound generation mechanisms that have to be considered are shown in Table 1 [Wagner, et al., 1996]. They are divided into three groups:

1. *Low Frequency Sound:* Sound in the low frequency part of the sound spectrum is generated when the rotating blade encounters localized flow deficiencies due to the flow around a tower, wind speed changes, or wakes shed from other blades.
2. *Inflow Turbulence Sound:* Depends on the amount of atmospheric turbulence. The atmospheric turbulence results in local force or local pressure fluctuations around the blade.
3. *Airfoil Self Noise:* This group includes the sound generated by the air flow right along the surface of the airfoil. This type of sound is typically of a broadband

nature, but tonal components may occur due to blunt trailing edges, or flow over slits and holes.

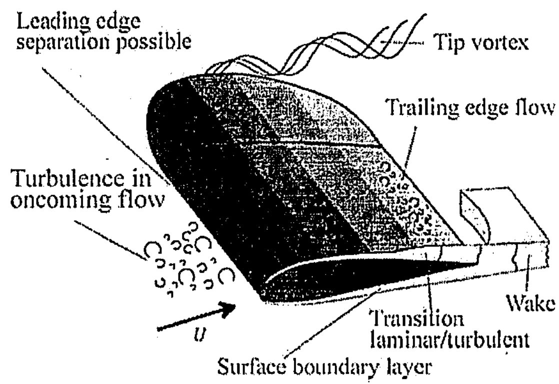

Figure 7: Schematic of Flow around a Rotor Blade [Wagner, 1996].

Table 1: Wind Turbine Aerodynamic Sound Mechanisms [Wagner et al., 1996]

Type or indication	Mechanism	Main characteristics & importance
Low-frequency sound		
Steady thickness noise; steady loading noise	Rotation of blades or rotation of lifting surfaces	Frequency is related to blade passing frequency, not important at current rotational speeds
Unsteady loading noise	Passage of blades through tower velocity deficit or wakes	Frequency is related to blade passing frequency, small in cases of upwind rotors, though possibly contributing in case of wind farms
Inflow turbulence sound	Interaction of blades with atmospheric turbulence	Contributing to broadband noise; not yet fully quantified
Airfoil self-noise		
Trailing-edge noise	Interaction of boundary layer turbulence with blade trailing edge	Broadband, main source of high frequency noise (770 Hz < f < 2 kHz)
Tip noise	Interaction of tip turbulence with blade tip surface	Broadband; not fully understood
Stall, separation noise	Interaction of turbulence with blade surface	Broadband
Laminar boundary layer noise	Non-linear boundary layer instabilities interacting with the blade surface	Tonal, can be avoided
Blunt trailing edge noise	Vortex shedding at blunt trailing edge	Tonal, can be avoided
Noise from flow over holes, slits and intrusions	Unstable shear flows over holes and slits, vortex shedding from intrusions	Tonal, can be avoided

Infrasound from Wind Turbines

When discussing infrasound from wind turbines, it is particularly important to distinguish between turbines with downwind rotors and turbines with upwind rotors. Some early wind turbines did produce significant levels of infrasound; these were all turbines with downwind rotors. The downwind design is rarely used in modern utility-scale wind power turbines.

Upwind rotors emit broad band sound emissions, which include low frequency sound and some infrasound. Note that the "swish-swish" sound is amplitude modulation at blade passing frequencies of higher frequency blade tip turbulence and does NOT contain low frequencies.

One example of low frequency sound and infrasound from a modern turbine is shown in Figure 8 . The magnitudes of these are below the perception limits of humans, which are shown in Figure 5.

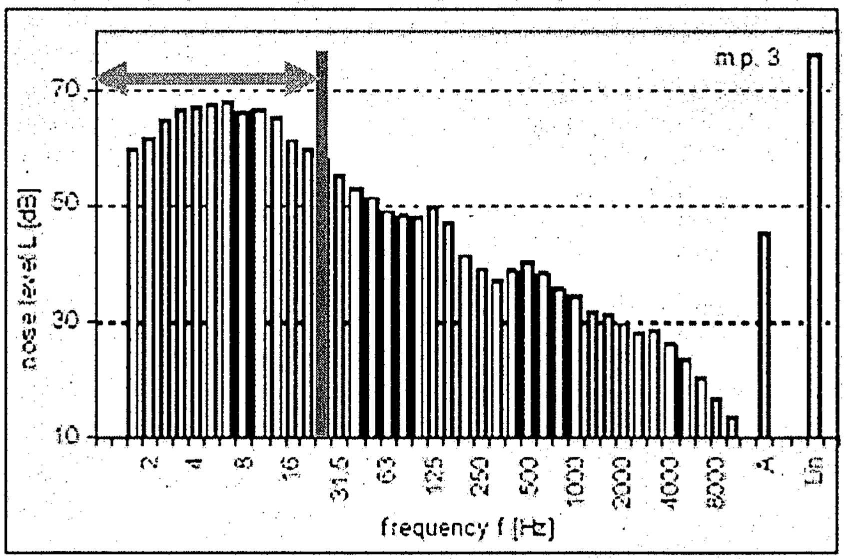

Figure 8: Example of 1/3 octave sound spectra downwind of a Vestas V80. The infrasound levels (range marked by the arrow) are below human perception level

Sound Reduction Methods for Wind Turbines

Turbines can be designed or retrofitted to minimize mechanical sound. This can include special finishing of gear teeth, using low-speed cooling fans and mounting components in the nacelle instead of at ground level, adding baffles and acoustic insulation to the nacelle, using vibration isolators and soft mounts for major components, and designing the turbine to prevent sounds from being transmitted into the overall structure. Efforts to reduce aerodynamic sounds have included [Wagner, et al., 1996] the use of lower tip speed ratios, lower blade angles of attack, upwind rotor designs, variable speed operation and most recently, the use of specially modified blade trailing edges.

Recent improvements in mechanical design of large wind turbines have resulted in significantly reduced mechanical sounds from both broadband and pure tones. Today, the sound emission from modern wind turbines is dominated by broadband aerodynamic sounds [Fégeant, 1999].

Sounds from Small Wind Turbines

Sound is likely to be one of the most important siting constraints for small wind turbines. Small wind turbines (under 30 kW capacity) are more often used for residential power or for other dedicated loads. These systems may be grid-connected or stand-alone systems. Due to the proximity of human activity, these applications could potentially result in noise complaints. Small wind turbines are in many cases louder than large turbines. Small wind turbines may also operate at higher tip speeds or turned partially out of the wind (this is known as furling, and is a common power limiting mechanism for high winds). These operating modes may aggravate sound generation. It is not always easy to obtain reliable sound measurements from the manufacturers of smaller wind turbines, especially at the wind speeds that might be a concern. For all of these reasons it is important to carefully consider sounds from small wind turbines. Below are three examples of studies of sound levels from wind small turbines.

A study of sound produced by a 10 kW Bergey wind turbine at Halibut Point State Park in Rockport, MA, includes measured sound pressure levels under a variety of wind conditions and at a variety of distances from the wind turbine base [Tech Environmental, 1998]. The study showed that under some conditions the wind turbine sound at 600 feet (182 m) from the wind turbine base increased sound levels by 13 dB(A). The study estimated that a buffer zone of 1,600 feet would be required to meet Massachusetts noise regulations (note that this model has been redesigned since that installation, so current models might not require as large a setback.) Finally, the study also mentioned that under high wind conditions in which the wind turbine sound was masked by the wind-induced background sound, as determined by the broadband sound pressure levels, the wind turbine could still be heard due to the presence of helicopter-like thumping sounds during furling. Similar sounds have been described coming from other small wind turbines [Gipe, 2001]. These low-frequency and periodic sounds are not included in the standard A-weighted sound pressure measurements prescribed in the MA DEP regulations.

In another study, sound measurements were made by the National Renewable Energy Laboratory on a 900 Watt wind turbine, the Whisper 40 [Huskey and Meadors, 2001]. This wind turbine has a rotor diameter of 2.1 m (7 ft) and was mounted on a 30 ft tower. The rotor rotates at 300 rpm at low power. The rotation speed increases to 1200 rpm as the rotor rotates out of the wind ("furls") to limit power in high winds. This operation results in a blade-tip speeds between 33 and 132 m/s. Figure 9 illustrates the sound pressure level (with the background sound removed) and the background sound levels at a distance of 10 meters (33 ft) from the wind turbine base. Between 6 and 13 m/s the sound pressure levels due to the operation of the turbine increased more than 13 dB. This is a very large increase in sound level and would be experienced as more than a doubling of the sound level. Moreover, it increased enough that the background sound level, which also increased with wind speed, was not enough to mask the wind turbine sound until the wind speed increased to over 13 m/s (30 mph).

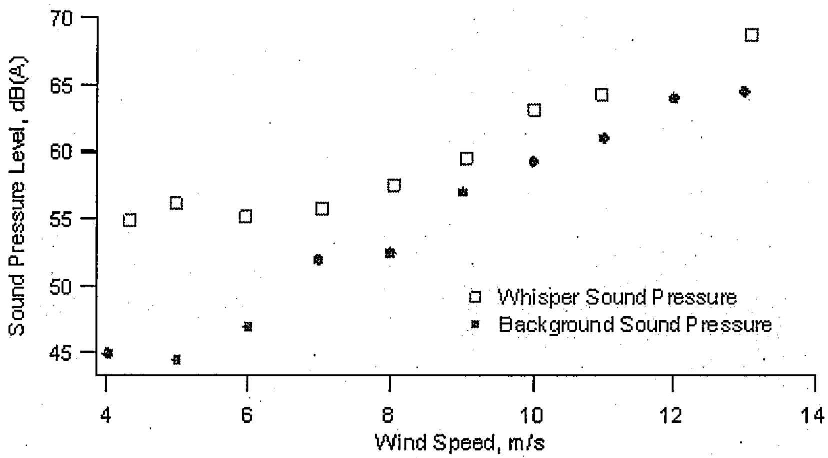

Figure 9: Measured sound power levels of a Southwest Whisper 900 wind turbine

In the third study, the National Renewable Energy Laboratory [Migliore, 2003] performed acoustic texts on eight small wind turbines ranging from 400 watts to 100 kW in rated power, using procedures based on international standards for measurement and data analysis, including wind speeds down to 4 m/s in most cases. A summary of the results are shown in Figure 10, which shows a very wide variety of sound levels. This figure illustrates that measurement in winds over 10 m/s are useful for some of the turbines considered.

Sound measurement standards for small wind turbines: The IEC 61400-11 standard (described below under Noise Standards and Regulations) may not be adequate for estimating sound levels from some small wind turbines. For instance, in contrast to the broad-band aerodynamic sounds from large wind turbines, some small wind turbine designs lead to irregular sounds that may be quite audible at higher wind speeds. Whereas the IEC standard requires the measurements at 6-10 m/s, measurements a lower and higher wind speeds should be included for small wind turbines. In addition, measurement standards do not require the measurement of thumping sounds and other irregular sounds that can be found objectionable. The possibility of irregular sounds and loud sounds in high-wind should be considered when siting small wind turbines in populated areas.

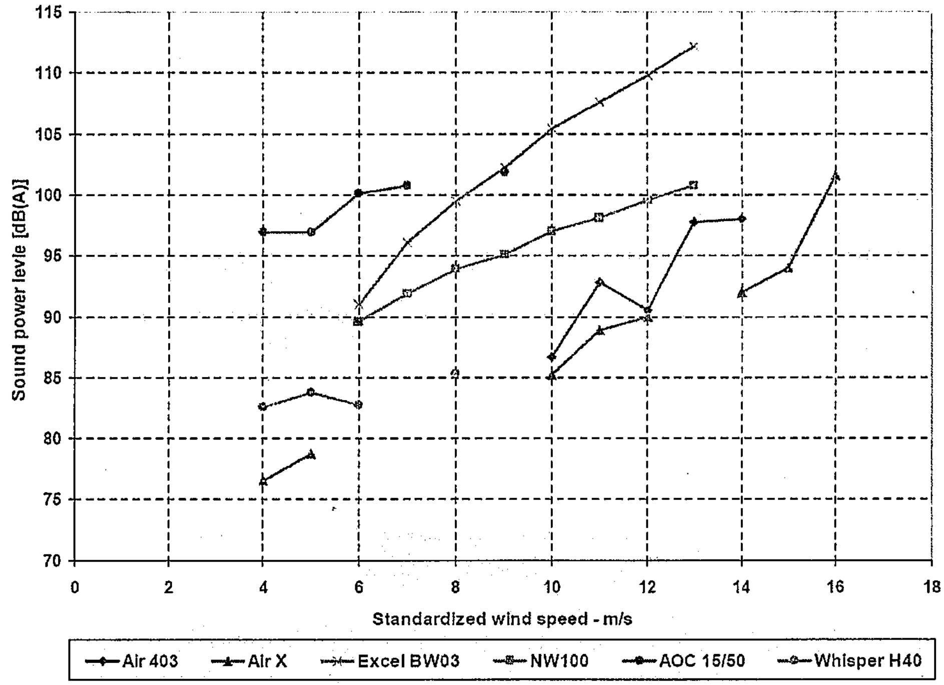

Figure 10: Summary of NREL study of small wind turbine sound: sound pressure level vs. wind speed, with the sound recorded downwind from the turbine [Migliore, 2003]

Factors that Affect Wind Turbine Sound

Wind turbine generated sound that is perceived at any given location is a function of wind speed, as well as turbine design, distance, ambient sound levels and various other factors, which are explored below.

Wind Turbine Design and Sound Emissions

All large, modern wind turbines available commercially today in the US are upwind, horizontal axis, variable pitch, and many have some variability of rotational speed. There are, however, other designs that have been used historically and may appear again in some form.

Several basic design characteristics can influence sound emissions. Wind turbines may have blades which are rigidly attached to the hub and thence to the rotor shaft. Other designs may have blades that can be pitched (rotated around their long axis). Some have rotors that always turn at a constant or near-constant speed while other designs might change the rotor speed as the wind changes. Wind turbine rotors may be upwind or downwind of the tower. Other things being equal, each of these designs might have different sound emissions because of the way in which they operate. In general, upwind rotors as opposed to downwind rotors, lower rotational speeds and pitch control result in lower sound generation.

Aerodynamic sound generation is very sensitive to speed at the very tip of the blade. To limit the generation of aerodynamic sounds, large modern wind turbines may limit the rotor rotation speeds to reduce the tip speeds. Large variable speed wind turbines often rotate at slower speeds in low winds, increasing in higher winds until the limiting rotor speed is reached. This results in much quieter operation in low winds than a comparable constant speed wind turbine.

Small wind turbines (under 30 kW) are also often variable-speed wind turbines. These smaller wind turbine designs may even have higher tip speeds in high winds than large wind turbines. This can result in greater sound generation than would be expected, compared to larger machines. This is also perhaps due to the lower investment in sound reduction technologies in these designs. Some smaller wind turbines regulate power in high winds by turning out of the wind or "fluttering" their blades. These modes of operation can affect the nature of the sound generation from the wind turbine during power regulation.

Sound Propagation

In order to predict the sound pressure level at a distance from source with a known power level, one must determine how the sound waves propagate. In general, as sound propagates without obstruction from a point source, the sound pressure level decreases. The initial energy in the sound is distributed over a larger and larger area as the distance from the source increases. Thus, assuming spherical propagation, the same energy that is distributed over a square meter at a distance of one meter from a source is distributed over 10,000 m^2 at a distance of 100 meters away from the source. With spherical propagation, the sound pressure level is reduced by 6 dB per doubling of distance. This simple model of spherical propagation must be modified in the presence of reflective surfaces and other disruptive effects. For example, if the source is on a perfectly flat and reflecting surface, then hemispherical spreading has to be assumed, which also leads to a 6 dB reduction per doubling of distance, but the sound level would be 3 dB higher at a given distance than with spherical spreading. Details of sound propagation in general are discussed in Beranek and Vers [1992]. The development of an accurate sound propagation model generally must include the following factors:

- Source characteristics (e.g., directivity, height, etc.)
- Distance of the source from the observer
- Air absorption, which depends on frequency
- Ground effects (i.e., reflection and absorption of sound on the ground, dependent on source height, terrain cover, ground properties, frequency, etc.)
- Blocking of sound by obstructions and uneven terrain
- Weather effects (i.e., wind speed, change of wind speed or temperature with height). The prevailing wind direction can cause differences in sound pressure levels between upwind and downwind positions.
- Shape of the land; certain land forms can focus sound

A discussion of complex propagation models that include all these factors is beyond the scope of this paper. More information can be found in Wagner, et al. (1996). For estimation purposes, a simple model based on the more conservative assumption of hemispherical sound propagation over a reflective surface, including air absorption is often used [International Energy Agency, 1994]:

$$L_p = L_w - 10 \log_{10}\left(2\pi R^2\right) - \alpha R$$

Here L_p is the sound pressure level (dB) a distance R from a sound source radiating at a power level, L_w, (dB) and α is the frequency-dependent sound absorption coefficient. This equation can be used with either broadband sound power levels and a broadband estimate of the sound absorption coefficient (α = 0.005 dB per meter) or more preferably in octave bands using octave band power and sound absorption data. The total sound produced by multiple wind turbines would be calculated by summing up the sound levels due to each turbine at a specific location using the dB math mentioned above.

An example of the sound that might be propagated from a singe large modern wind turbine is shown in Figure 11. This example assumes hemispherical sound propagation and uses the formula presented above. In this case the wind turbine is assumed to be on a 50 m tower, the source sound power level is 102 dB(A), and the sound pressure levels are at estimated at ground level.

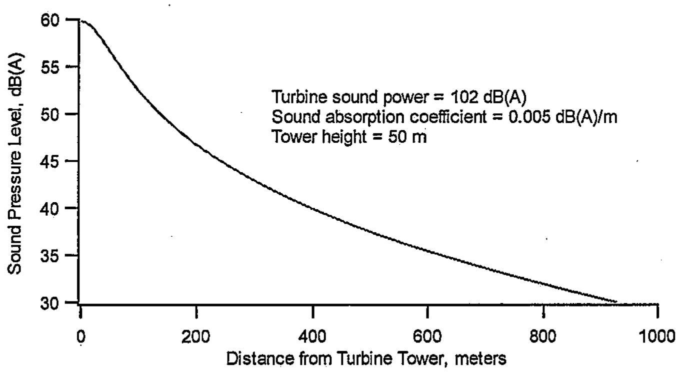

Figure 11: Example of propagation of sound from a large wind turbine

The location of the receptor is also significant. Upwind of a wind turbine there may be locations where no sound is heard. On the other hand sound may be propagated more easily downwind.

Ambient Sounds & Wind Speed

The ability to hear a wind turbine in a given installation also depends on the ambient sound level. When the background sounds and wind turbine sounds are of the same magnitude, the wind turbine sound gets lost in the background.

Ambient baseline sound levels will be a function of such things as local traffic, industrial sounds, farm machinery, barking dogs, lawnmowers, children playing and the interaction of the wind with ground cover, buildings, trees, power lines, etc. It will vary with time of day, wind speed and direction and the level of human activity. As one example, background sound levels measured in the neighborhood of the Hull High School in Hull Massachusetts on March 10, 1992 ranged from 42 to 48 dB(A) during conditions in which the wind speed varied from 5 to 9 mph (2-4 m/s).

Both the wind turbine sound power level and the ambient sound pressure level will be functions of wind speed. Thus whether a wind turbine exceeds the background sound level will depend on how each of these varies with wind speed.

The most likely sources of wind-generated sounds are interactions between wind and vegetation. A number of factors affect the sound generated by wind flowing over vegetation. For example, the total magnitude of wind-generated sound depends more on the size of the windward surface of the vegetation than the foliage density or volume. [Fégeant, 1999]. The sound level and frequency content of wind generated sound also depends on the type of vegetation. For example, sounds from deciduous trees tend to be slightly lower and more broadband than that from conifers, which generate more sounds at specific frequencies. The equivalent A-weighted broadband sound pressure generated by wind in foliage has been shown to be approximately proportional to the base 10 logarithm of wind speed [Fégeant, 1999]:

$$L_{A,eq} \propto \log_{10}(U)$$

The wind-generated contribution to background sound tends to increase fairly rapidly with wind speed. For example, during a sound assessment for the Madison (NY) Windpower Project, a project in a quiet rural setting, the background sound was found to be 25 dBA during calm wind conditions and 42 dBA when the wind was 12 mph (5.4 m/s). Background sound generated during sound measurements on a small wind turbine are shown in the Figure 12 [Huskey and Meadors, 2001]. The graph includes a logarithmic fit to that data based on the model mentioned above.

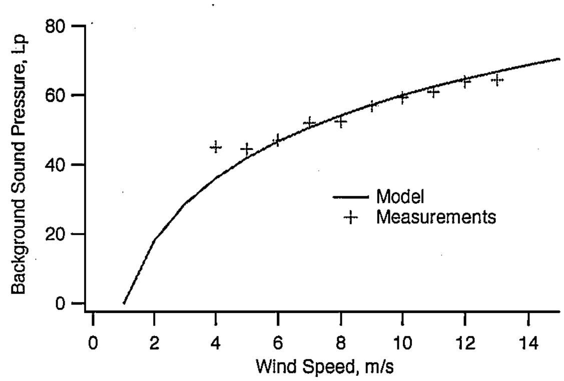

Figure 12: Sample background noise measurements as a function of wind speed

Sound levels from large modern wind turbines during constant speed operation tend to increase more slowly with increasing wind speed than ambient wind generated sound. As a result, wind turbine noise is more commonly a concern at lower wind speeds [Fégeant, 1999] and it is often difficult to measure sound from modern wind turbines above wind speeds of 8 m/s because the background wind-generated sound masks the wind turbine sound above 8 m/s [Danish Wind turbine Manufacturers Association, 2002].

It should be remembered that average sound pressure measurements might not indicate when a sound is detectable by a listener. Just as a dog's barking can be heard through other sounds, sounds with particular frequencies or an identifiable pattern may be heard through background sounds that is otherwise loud enough to mask those sounds. Sound emissions from wind turbines will also vary as the turbulence in the wind through the rotor changes. Turbulence in the ground level winds will also affect a listener's ability to hear other sounds. Because fluctuations in ground level wind speeds will not exactly correlate with those at the height of the turbine, a listener might find moments when the wind turbine could be heard over the ambient sound.

Noise Standards and Regulations

There are standards for measuring sound power levels from utility -scale wind turbines, as well as local or national standards for acceptable noise power levels. Each of these is reviewed here. As of this writing (February 2005), there are no sound measurement standards for small wind turbines, but both the American Wind Energy Association and the International Electrotechnical Commission (IEC) are working on future standards.

Turbine Sound Power Measurement Standards

The internationally accepted standard to ensure consistent and comparable measurements of utility-scale wind turbine sound power levels is the International Electrotechnical Commission IEC 61400-11 Standard: Wind turbine generator systems – Part 11: Acoustic noise measurement techniques [IEC, 2002]. All utility-scale wind turbines available today in the US comply with IEC 61400-11. It defines:

- The quality, type and calibration of instrumentation to be used for sound and wind speed measurements.
- Locations and types of measurements to be made.
- Data reduction and reporting requirements.

The standard requires measurements of broad-band sound, sound levels in one-third octave bands and tonality. These measurements are all used to determine the sound power level of the wind turbine at the nacelle, and the existence of any specific dominant sound frequencies. Measurements are to be made when the wind speeds at a height of 10 m (30 ft) are 6, 7, 8, 9 and 10 m/s (13-22 mph). Manufacturers of IEC-compliant wind turbines can provide sound power level measurements at these wind speeds as measured by certified testing agencies.

Measurements of noise directivity, infrasound (< 20 Hz), low-frequency noise (20-100 Hz) and impulsivity (a measure of the magnitude of thumping sounds) are optional.

Measured sound power levels for a sampling of wind turbines are presented in Figure 13 as a function of rated electrical power. The data illustrate that sound emissions from wind turbines generally increases with turbine size. The graph also shows that wind turbine designers' efforts to address noise issues in the 1990's and later have resulted in significantly quieter wind turbines than the initial designs of the 1980's.

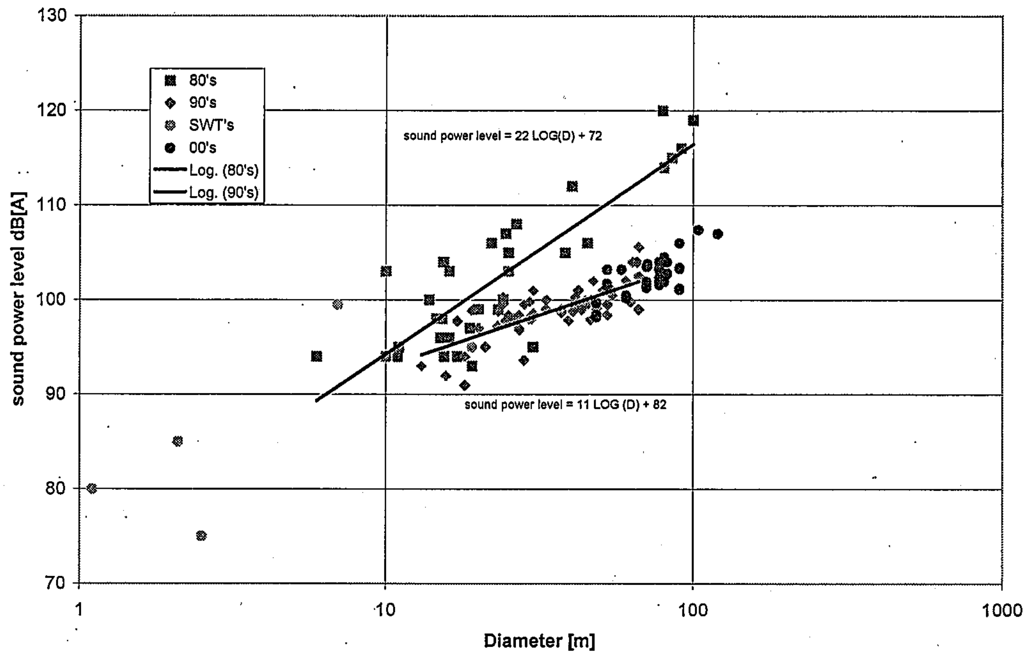

Figure 13: Sample wind turbine measured sound power levels

Community Standards for Determining Acceptable Sound Pressure Levels

At the present time, there are no common international noise standards or regulations for sound pressure levels. In most countries, however, noise regulations define upper bounds for the noise to which people may be exposed. These limits depend on the country and may be different for daytime and nighttime.

For example, in Europe, as shown in Table 2, fixed noise limits have been the standard [Gipe, 1995].

Country	Commercial	Mixed	Residential	Rural
Denmark			40	45
Germany				
(day)	65	60	55	50
(night)	50	45	40	35
Netherlands				
(day)		50	45	40
(night)		40	35	30

Table 2: Noise Limits of Sound Pressure Levels, L_{eq} (in dB(A)) in Various European Countries

In the U.S., although no federal noise regulations exist, the U.S. Environmental Protection Agency (EPA) has established noise guidelines. Most states do not have noise regulations, but many local governments have enacted noise ordinances to manage community noise levels. Examples of such ordinances for wind turbines are given in the latest Permitting of Wind Energy Facilities Handbook [NWCC, 2002].

The Massachusetts Department of Environmental Protection (DEP) regulates noise emissions as a form of air pollution under 310 CMR 7.00, "Air Pollution Control." These can be found at http://www.mass.gov/dep/air/laws/7a.htm. The application of these regulations to noise is detailed in the DEP's DAQC Policy Statement 90-001 (February 1, 1990). The regulation includes two requirements. First, any new broadband sound source is limited to raising noise levels no more than 10 dB(A) over the ambient baseline sound level. The ambient baseline is defined as the sound level that is exceeded 90% of the time, the L_{90} level. Second, "pure tones", defined here as an octave band, may be no greater than 3 dB(A) over the two adjacent octave bands. All these readings are measured at the property line or at any inhabited buildings located within the property.

It should be pointed out that imposing a fixed noise level standard may not prevent noise complaints. This is due to the changing of the relative level of broadband background turbine noise with changes in background noise levels [NWCC, 2002]. That is, if tonal noises are present, higher levels of broadband background noise are needed to effectively mask the tone(s). In this respect, it is common for community noise standards to incorporate a penalty for pure tones, typically 5 dB(A). Therefore, if a wind turbine meets a sound pressure level standard of 45 dB(A), but produces a strong whistling, 5 dB(A) are subtracted from the standard. This forces the wind turbine to meet a standard of 40 dB(A).

A discussion of noise measurement techniques that are specific to wind turbine standards or regulations is beyond the scope of this paper. A review of such techniques is given in Hubbard and Shepherd [1990], Germanisher Lloyd [1994], and Wagner, et al. [1996].

Sample Noise Assessment for a Wind Turbine Project

Much of the interest in wind turbine noise is focused on the noise anticipated from proposed wind turbine installations. When a wind turbine is proposed near a sensitive receptor, a noise assessment study is appropriate; these studies will typically contain the following four major parts of information:

1. An estimation or survey of the existing ambient background noise levels.
2. Prediction (or measurement) of noise levels from the turbine(s) at and near the site.
3. Identification of a model for sound propagation (sound modeling software will includes a propagation model.)
4. Comparing calculated sound pressure levels from the wind turbines with background sound pressure levels at the locations of concern.

An example of the steps in assessing the noise anticipated from the installation of a wind turbine according to the Massachusetts regulations follows.

Ambient Background Levels: Ambient sound levels vary widely and are important for understanding the noise as well as complying with ambient-based regulations. Background sound pressure levels should be measured for the specific wind conditions under which the wind turbine will be operating. In this example it will be assumed that measurements indicate that the L_{90} sound pressure levels are 45 dB(A) at 8 m/s wind speed.

Source Sound Levels: In order to calculate noise levels heard at different distances, the reference sound levels need to be determined. The reference sound level is the acoustic power being radiated at the source, and is not the actual sound pressure level as heard at ground level. Reference sound levels can be obtained from manufacturers and independent testing agencies. Measurements should be based on the standards mentioned above. In this example it will be assumed that the turbine will be on a 50 m tower and has a sound power level of 102 dB(A), as in the previous example of sound propagation from a wind turbine.

Sound Propagation Model: Sound propagation is a function of the source sound characteristics (directivity, height), distance, air absorption, reflection and absorption by the ground and nearby objects and weather effects such as changes of wind speed and temperature with height. One could assume a conservative hemispherical spreading model or spherical propagation in which any absorption and reflection are assumed to cancel each other out. More detailed models could be used that include the effects of wind speed and direction, since sound travels more easily in the downwind direction; however, a conservative model will assume that all directions are downwind at some time. If the hemispherical propagation model is used, then the data in Figure 11 shows the noise levels in the vicinity of the turbine.

Comparison of Calculated Sound Levels with Baseline Sound Levels: Calculated wind turbine sound levels do not include the additional background ambient sound levels. The mathematical relationship governing the addition of dB(A) levels require that if the turbine sound level is no more than 9.5 dB(A) above the ambient noise level, then the total noise levels will be within 10 dB(A) of the ambient sound level. If the ambient sound level is 45 dB(A), then, under Massachusetts regulations, the turbine can generate no more than 54.5 dB(A) at locations of concern. It can be seen from Figure 11 that the sound from the wind turbine would not exceed that limit at all locations more than 75 m (250 ft) from the wind turbine.

Conclusions and Recommendations

Modern, utility-scale wind turbines are relatively quiet; still, when sited within residential areas, noise is a primary siting constraint. The following are recommendations for standards, regulations and siting practices:

- Turbine Standards:
    - Utility-scale turbines: Any incentives to promote wind energy should be provided only to turbines for which the manufacturer can provide noise data based on IEC standards or for turbines which are to be located at sites where there will clearly be no problem.

- Small turbines: national standards for small wind turbine technology in general are needed. For noise in particular, sound levels should be measured at lower and higher wind speeds, in addition to those measured under the IEC standard. Any operation-mode-dependent, time-dependent and frequency-dependent components also need to be described. These standards need to provide sound measures that provide an accurate representation of issues of interest to potential listeners.

- Noise Regulations:
  - Community noise standards are important to ensure livable communities. Wind turbines must be held to comply with these regulations. Wind turbines need not be held to additional levels of regulations.
  - For small wind turbines: Because of the wide variety of sound levels from small wind turbines, blanket setback limits should not be set *a priori*. However, they should be examined carefully based on the technology proposed.

- Wind turbine siting practice:
  - In order to comply with state noise regulations and to fit within community land use, the siting of wind turbines must take sound levels into consideration.
  - If a wind turbine is proposed within a distance equivalent to three times the blade-tip height of residences or other noise-sensitive receptors, a noise study should be performed and publicized.

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Fundamental Research in Amplitude Modulation – a Project by RenewableUK

J Bass[1], D Bowdler[2], M McCaffery & G Grimes[3]

1. Renewable Energy Systems Ltd, Third Floor, STV, Pacific Quay, GLASGOW, G51 1PQ
2. The Haven, Low Causeway, Culross, Fife, KY12 8HN
3. RenewableUK, Greencoat House, Francis Street, London, SW1P 1DH

jeremy.bass@res-ltd.com
dick@dickbowdler.co.uk
m.mccaffery@renewable-uk.com
g.grimes@renewable-uk.com

Abstract

This paper outlines a research project designed to improve our understanding of the phenomenon known as 'amplitude modulation' (AM), and presents key results.

The frequency and severity of AM in the UK is such that there has been no need for a specific planning condition to control its emission. Regardless, there is increasing pressure from planning authorities and local residents for developers to accept such a condition for AM. The problem for the wind power industry is that there is currently insufficient knowledge on which to base a condition without potentially causing unnecessary difficulties in future.

The project aims to improve understanding of the AM phenomenon, so that a suitable condition can be developed, based on an objective method for quantifying levels of AM and a well-defined dose-response relationship for AM.

In parallel with this, fundamental research will be pursued so that the key drivers that cause AM in the first place can be identified. This knowledge will enable developers and manufacturers to predict when AM is likely to occur, and reduce or possibly even avoid entirely the potential for it.

The aim of this project, therefore, is to be highly targeted and to provide clear, definitive recommendations on AM for use by the industry, planners and the public, on a rapid timescale.

1 Introduction

This paper outlines a research project designed to improve our understanding of the phenomenon known as 'amplitude modulation' (AM). There is little peer-reviewed, published research into the causes of AM and, because there is an increasing pressure for controls on such noise in the planning system, it is essential that this lack of knowledge is rapidly remedied.

2 Background

RenewableUK are strongly of the view that the frequency and severity of AM are such that there is no need for a planning condition to control its emission – the University of Salford report 'Research into Aerodynamic Modulation of Wind Turbine Noise' makes precisely this point [1]. Despite this, there is increasing pressure from both local authorities and the public to accept a planning condition designed to control the emission of amplitude modulation. The problem for the industry is that there is currently insufficient knowledge to be able to draft such a condition or, at least, to draft one which does not cause difficulties for the industry in future. This lack of knowledge has not stopped opposition groups from drafting their own condition and, in the absence of an alternative from the industry, Planning Inspectors have, on several recent occasions, adopted an opposition condition. The concern is that this condition is completely untested and may pose a serious barrier to the continued development of onshore wind power in the UK whilst, at the same time, not giving proper protection to nearby residents. The best way to address this is to improve understanding of the phenomenon, so that a condition can be developed, based on an objective method for quantifying levels of AM and a well-defined dose-response relationship for AM.

In parallel with this, it is essential that the industry understands the key drivers that cause AM in the first place. Only with this knowledge will developers & manufacturers be able to predict when AM is likely to occur, and possibly even avoid or reduce the potential for this acoustic feature entirely.

3 Outcomes

Given this background to the situation, there is clearly little benefit in pursuing research which may deliver inconclusive results or simply highlight the need for further research. The aim of this project, therefore, is to be highly targeted and to provide clear, definitive recommendations for use by the industry, planners and the public, on a rapid timescale.

Specifically, the research will deliver the following hard outcomes:

- an improved understanding of the mechanisms causing the phenomenon, specifically an understanding of the key drivers that cause AM in the first place, so that developers & manufacturers are better able to predict when AM is likely to occur
- an objective measurement method for quantifying levels of AM and, associated with it, a well-defined dose-response relationship for AM.

In order to gain maximum credibility for this work, an essential element is widespread dissemination of the results, e.g. at this conference. In addition to ensuring that all individual work packages are publicised as widely as possible, both in the literature and at conferences, it is essential that a final report summarising all the findings of the work are published in a peer reviewed, internationally-respected acoustics journal. This will ensure maximum exposure of the work and should provide a definitive reference in future planning appeals, public inquiries and court cases.

It is anticipated that the project outcomes will allow the creation of model planning conditions for AM, which embody both the objective measurement methodology and the dose-response relationship.

4 Project Overview

The project commenced on 19 January 2011 and is due to report in July 2011. It comprises two phases, within which there are a number of separate work packages, as follows:

Phase 1 Research into Amplitude Modulation

Work Package A	Fundamental Research into the Causes of AM
Work Package B	Development of Objective Amplitude Modulation Measurement Method & Dose-Response Relationship
Work Package C	Collation and Analysis of Existing Acoustic Recordings
Work Package D	Measurement and Analysis of New Acoustic Recordings

Phase 2 Publication and Refinement of Results

Work Package E	Dissemination of Results

Details of each phase and each work plan are detailed below.

5 Project Phases

5.1 Phase 1: Research into Amplitude Modulation

Work Package A - Fundamental Research into the Causes of AM

Although there is little peer-reviewed, published research into the causes of amplitude modulation (AM), some of the work that has been published is convincing, e.g. that based on detailed aero-acoustic analysis which identifies possible mechanisms by which AM may be caused. Measurements using microphone arrays, for example, have shown that these predictions agree well with measured levels of AM [2,3].

To date this modelling has been developed assuming a wind turbine operating in rather unrealistic wind conditions, i.e. zero wind shear. It is intended to extend this work to consider the effects of other atmospheric conditions by explicitly including wind shear, since this may be an exacerbating factor to AM. The driver for this is anecdotal evidence which suggests that AM is particularly prevalent during stable atmospheric conditions – characterised by high shear, low turbulence and low levels of background noise – something that existing modelling does not yet include.

The goal of this work is to gain a more fundamental understanding of what causes AM at the source, i.e. at the wind turbine blades. This may give insight into what measures, if any, manufacturers may take to reduce or avoid such noise emission in future or, at the very least, may make AM a more 'predictable' phenomenon. Such measures may relate to the blade geometry and manufacture, the conditions in which the blade operates or some 'retrofit' option, e.g. serrated leading or trailing edges.

In addition to considering the source of this acoustic feature, guidance will also be provided to developers & manufacturers on other factors which may affect the levels of AM emitted, including, for example:

- 'stumpy' towers, i.e. towers which are relatively 'short' in relation to the rotor diameter
- high levels of turbulence
- yaw error
- closely spaced turbines, e.g. in a linear array.

Whilst there are relatively few researchers working in this field, there are several that are making important contributions. Efforts will be made to review the literature, locate those doing promising work and to identify the potential for this to make a significant contribution to understanding the underlying physics of AM in future.

The deliverables for this work package are as follows:

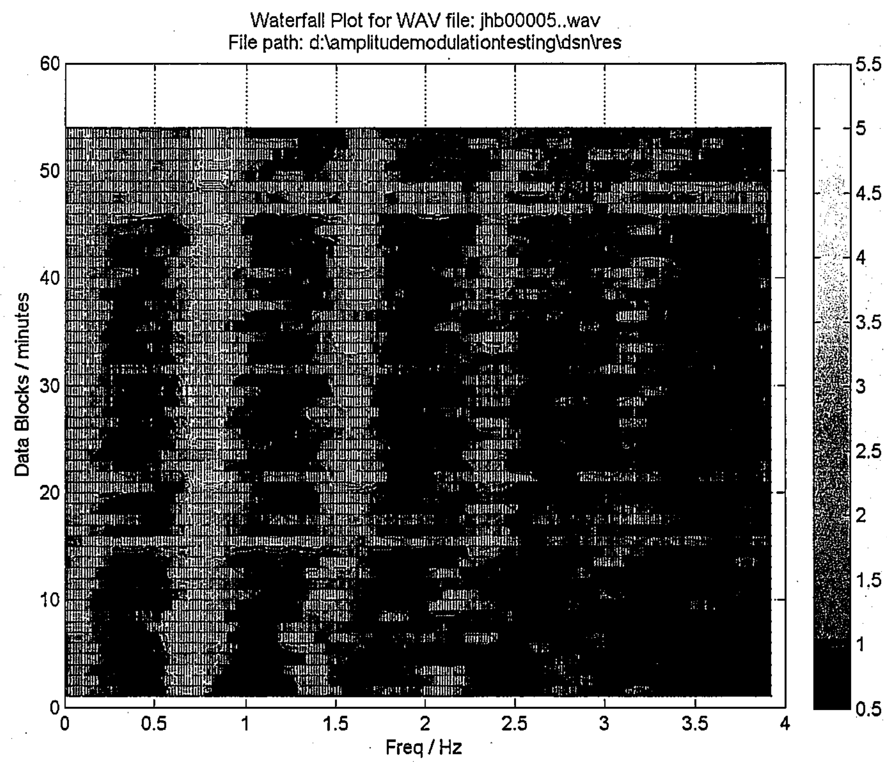
- an aero-acoustic model capable of predicting levels of AM in both 'near' and 'far' field from a modern wind turbine, to include a wide range of atmospheric conditions, e.g. wind shear, turbulence etc
- through analysis of this model and its results, a description of the fundamental causes of AM at the source, i.e. at the wind turbine blades
- identification of the key drivers of amplitude modulation, and hence guidance into measures manufacturers may take to reduce or avoid such noise emission at source. This may relate to blade geometries, construction, finish or retrofit options
- guidance into measures developers may take to reduce or avoid such noise emission. This may relate to turbine layout, hub height choice and the effects of a site's wind regime
- the identification of others working in the area who are pursuing promising lines of research and assessment of their potential for future contributions to the area.

Work Package B - Development of Objective Amplitude Modulation Measurement Methodology & Development of a Dose – Response Investigation

A fundamental requirement for understanding AM is having a methodology available able to provide an objective, repeatable measure of the level of AM present in a sample of acoustic data. If the wind industry is to understand the levels of AM residents are being exposed to, then such an objective method for measuring it absolutely essential.

Renewable Energy Systems Ltd (RES) has already developed a candidate methodology which serves as an objective measurement method for AM: this has been widely circulated among the acoustics section of the UK wind energy community. The methodology has been extensively tested on both artificially created test data and on around 60 hours of measured acoustics recordings from wind farms. As a result, the method should be regarded as a 'good, working model' that has received a reasonable degree of validation.

Figure 1: Typical Results from RES Analytical Software



However, this candidate methodology is clearly only a starting point and it will receive considerably more critical attention that it has done to date. This means detailed review by those experienced in the area of noise analysis and, particularly, frequency-based noise analysis. To achieve this, RES have provided the existing code base, and accompanying documentation, to this project for further development in this fashion.

In addition, the RES methodology needs to be tested on real-world data, hence Work Packages C & D, which will provide the raw material to allow this development.

The ability to quantify objectively the level of AM present in an acoustic recording is one thing, but for the number obtained to have any meaning it must be considered within a wider context, i.e. what is the psycho-acoustic (subjective) response of a typical listener to this level of AM?

To obtain this essential 'context' a series of detailed listening tests will be conducted in an audiometry chamber (or 'listening' room). A large number of listeners, drawn from as wide pool of the general public as possible, will be exposed to noises with varying degrees of amplitude modulation, of varying waveforms, and asked to rate them in terms of annoyance. Careful controls will be used to ensure that relative annoyance can be precisely determined using well-defined and accepted statistical methods.

As it is entirely possible that the results of such listening tests may highlight that the objective method, identified above, for quantifying AM does not provide a 'useful' measure, 'useful' in the sense that it does not correlate with the subjective responses, the listening tests will be conducted in two phases. The first phase will be a relatively quick, simple and cheap test to verify that the objective measurement methodology provides a useful index of subjective response. If it does, then a second phase of listening tests will be pursued, this similar to the first phase in content but considerably more detailed and lengthy, and aim to arriving at the best possible definition, in statistical terms, of the dose-response relationship. If it does not, then alternative objective metrics should be investigated, until some index can be isolated that correlates well with the subjective response. The second phase of listening tests will then be redesigned from the first phase, to take this new index into account, but be considerably more detailed and lengthy than the first phase. Again, the aim is to arrive at the best possible definition, in statistical terms, of the dose-response relationship.

To ensure the widest possible acceptance of the results of such tests, the following are essential:

- the experimental design will be peer-reviewed before commencement
- the tests will be conducted by an independent body whose reputation is impeccable and who have experience in the area of audiometry
- the statistical analysis of the results, leading to a dose-response relationship, will be peer-reviewed following analysis.

The outcome of this phase will be an objective measurement methodology for AM, a dose – response relationship for AM and, based on this, a meaningful noise penalty scheme for AM.

The deliverables for this work package are as follows:

- an objective, repeatable methodology for quantifying the level of amplitude modulation present in a sample of acoustic data
- a demonstration, by means of the real-world data obtained through Work Packages C & D, that this methodology can provide meaningful results

- the identity of a high-profile, independent body capable and willing to undertake AM listening tests who have experience in the area of audiometry.
- an initial experimental plan for deriving a dose - response relationship and details of a peer-review of this obtained prior to commencement
- a highly-credible listening test in an audiometry chamber, with a sample of listeners from the general population, and a rigorous statistical analysis of the results, this also to be peer-reviewed
- details of any refinement of the objective measure required depending on the results of the preliminary listening test
- developing a second, and final, experimental plan for deriving a dose - response relationship and details of a peer-review of this obtained prior to commencement
- a highly-credible listening test in an audiometry chamber, with a large sample of listeners from the general population, and a rigorous statistical analysis of the results, this also to be peer-reviewed
- a dose – response relationship for the amplitude modulation of wind turbine noise and, based on this, a penalty scheme for AM suitable for inclusion in noise planning conditions.

Work Package C - Collation and Analysis of Existing Acoustic Recordings

The most effective way to make rapid progress with the development of the objective AM assessment method, as described in Phase 1: Work Package B, is to test it on real-world data. This process can be greatly accelerated by making use of data that already exists within the wind energy community, i.e. acoustic data that has been collected for other purposes. Indeed, RES have already used 60 hours of such data in their development of the methodology.

To achieve this, developers, consultants and others with appropriate data will be approached with a view to compiling a database of wind farm acoustic recordings. It is likely that this database will feature data measured in both near and far fields, and from a wide variety of wind turbines. The benefits of doing this will be twofold:

- assuming the available data is representative of all UK wind farms, it will enable a 'broad' estimate of the frequency and severity of the AM problem to be determined
- it will enable the details of the analysis methodology (Phase 1: Work Package B) to be refined.

The acoustic data obtained should, as far as possible, consist of mono, or stereo, audio (WAV) recordings at high frequency (e.g. 48 kHz). Ideally this would be accompanied by information on:

- the site's topography/turbine model/hub height/rotor diameter/blade geometry etc...
- whether the site has any reported AM issues

- how the measurements were made, i.e. in free-field conditions, on a façade or by use of a parabolic microphone.
- meteorological data, such as wind speed, direction etc, up to tip height
- turbine operational data, if available from site operator.

If there are problems relating to commercial confidentiality, these could be addressed by either removing any meta-data enabling identification of the data source, or by asking the data owner to analyse the data themselves using a 'standard' version of the methodology.

The deliverables for this work package are as follows:

- a compilation of wind farm noise audio recordings suitable for testing using the AM assessment methodology, this to be accompanied by a description of the measurement circumstances, i.e. 'near' or 'far' field; turbine type & hub height, for each data file, as above
- an indication of the frequency and severity of the AM from UK wind farms, based on analysis of the above data, and those data directly assessed by the data owners
- identification of any common factors to low/high levels of AM etc, based on analysis of the above data, and those data directly assessed by the data owners
- insight into conditions where AM may be observed, and the effect of measurement conditions, i.e. free-field, façade or internal.

Work Package D - Measurement and Analysis of New Acoustic Recordings

Whilst existing data may prove useful to the understanding the frequency and severity of AM, as well as in the development of an objective AM assessment method, as described in Phase 1: Work Package B, the very fact that these data have been collected for other purposes may compromise its usefulness.

To gain real insight into these areas, and to optimise development of the methodology described in Phase 1: Work Package B, the ideal approach is to collect highly targeted acoustic data from the current fleet of UK wind farms. This would involve making acoustic measurements:

- at approximately 7 sites, and possibly more
- at least one measurement location per site, and possibly more
- as mono, or stereo, audio (WAV) recordings at high frequency (i.e. 48 kHz)
- at sites with varying topography/turbine models/hub heights/rotor diameters/blade geometries etc
- at sites both with, and without, reported AM issues

- in both free-field conditions, on a façade and possibly using a parabolic microphone.

It would also involve making non-acoustic measurements:

- of meteorological data such as wind speed; direction etc, up to tip height, possibly using remote sensing technology
- of turbine operational data, if available from site operator.

These data should enable the level of AM to be directly correlated with the operating conditions of the wind farms, e.g. wind direction; wind speed and atmospheric stability, to provide a greater understanding of the circumstances in which high levels of AM occur, and hence possible mitigation or prevention/minimisation of effects.

- assuming the available data is representative of all UK wind farms, it would enable a 'broad' estimate of the frequency and severity of the AM problem to be determined
- it would enable the details of the analysis methodology (Phase 1: Work Package B) to be refined.

The deliverables for this work package are as follows:

- a compilation of measured wind farm noise audio recordings suitable for testing using the AM assessment methodology, this to be accompanied by a description of the measurement circumstances, i.e. 'near' or 'far' field; turbine type & hub height, for each data file, as above
- based on analysis of the above data, an indication of the frequency and severity of the AM from UK wind farms
- based on analysis of the above data, identification of any common factors to low/high levels of AM etc
- insight into conditions where AM may be observed, and the effect of measurement conditions, i.e. free-field, façade or internal.

5.2 Phase 2: Publication & Refinement of Results

Work Package E – Dissemination of Results

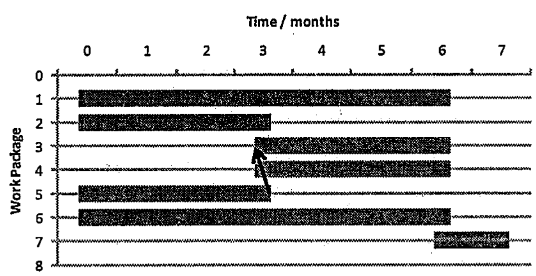
In order to gain maximum credibility for this work, an essential element is widespread dissemination of the results. In addition to ensuring that all individual work packages are publicised as widely as possible, both in the literature and at conferences, it is essential that a final report summarising all the findings of the work are published in a peer reviewed, internationally-respected acoustics journal. This will ensure maximum exposure of the work and should provide a definitive reference in future planning appeals, public inquiries and court cases.

The deliverables for this work package are as follows:

- the identity of an high-profile, international, independent, peer-reviewed journal best placed to receive the results of this work
- a published paper in this journal describing the results of all parts of this project, and publishing as much of the measured data as possible
- the identity of suitable workshops, conferences and seminars which are best placed to receive the results of this work
- a presentation at least 1 of the above events describing the results of this project
- a collation of feedback, comments, and other publications deriving from the above
- suggestions for modifications to the objective measure and AM penalty scheme developed in Work Package B above, based on feedback received following widespread dissemination
- an objective measurement methodology and dose-response relationship that can be used to used to write model planning conditions, in the form of a penalty scheme, capable of surviving inspection at Public Inquiry, and suitable for inclusion in UK noise planning conditions and standards
- a final report detailing the above deliverables.

6 Project Programme

Phase	Work Package	Duration
1	A-Fundamental Research	6 months
1	B-Development of AM Methodology-I	3 months
1	B-Development of AM Methodology-II	3 months
1	B-Dose-Response Investigation	3 months
1	C-Collate Existing Data	3 months
1	D-Obtain New Data	6 months
2	E-Dissemination	1 month



7 Conclusions

This paper outlines a research project designed to improve our understanding of the phenomenon known as AM so that a suitable planning condition can be developed, based on an objective method for quantifying levels of AM and a well-defined dose-response relationship for AM.

In parallel with this, fundamental research will be pursued so that the key drivers that cause AM in the first place can be identified. This knowledge will enable developers and manufacturers to predict when AM is likely to occur, and reduce or possibly even avoid entirely the potential for it.

The aim of this project is to be highly targeted and to provide clear, definitive recommendations on AM for use by the industry, planners and the public, on a rapid timescale.

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ACOUSTIC CONSULTING REPORT
Prepared for the Ontario Ministry of the Environment

WIND TURBINE FACILITIES NOISE ISSUES

Aiolos Report Number: 4071/2180/AR155Rev3
DECEMBER 2007

Author Ramani Ramakrishnan, Ph. D., P. Eng.
Lead Acoustician

Signature
Date: 28 December 2007

AIOLOS ENGINEERING CORPORATION

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EXECUTIVE SUMMARY

All proponents of a wind farm development need to apply for a Certificate of Approval from the Ministry of the Environment of Ontario. The noise assessment report required for the approval process uses the guideline Ministry document, "Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators" released in 2004. The above guidance document was to assist proponents of wind turbine installations in determining the list of necessary information to be submitted when applying for a Certificate of Approval (Air and Noise) under Section 9 of the *Environmental Protection Act*. The noise guidelines in MOE publications NPC-205/NPC-232 as well as the wind generated noise levels were applied to set the noise limits.

The Ministry has now initiated a review of the interpretation of the above policies, due to expanding body of knowledge of the noise impacts of wind turbines. The main aim of the proposed review is to assess the appropriateness of the Ministry's approach to regulating noise impacts of wind turbines.

The scope and requirements of the review can be summarized as: a) Review of the 2006 doctoral dissertation by van den Berg; b) Review of available noise policies and guidelines; review of relevant scientific literature; and review of MOE's current noise policies as applied to wind turbine noise and c) Provide expert opinion based on the above findings; and d) Prepare a report that provides advice on the state of the science regarding wind turbine noise, and on MOE policies and procedures that relate to wind turbine facilities. The results of the investigations are described below.

Van den Berg's research was initiated as a result of complaints, in Netherlands, against an existing wind farm in Germany very close to the Dutch border. The main hypotheses of the research are: a) atmospheric stability, particularly stable and very stable conditions happen mostly at night time and the hub-height wind speeds can be higher than those predicted from the 10 m high wind speeds using standard methods, such as the logarithmic profiles of the IEC standard. And hence, the wind turbine noise levels can be higher than expected. It was also conjectured that these discrepancies are prevalent during summer months; and b) beat-sounds can become very pronounced during stable and very stable conditions. Although, the data of van den Berg's research did not provide conclusive scientific evidence to support the above hypotheses, further review of the literature showed that some of the basic conjectures may well be true. Hence, the research of van den Berg must be considered as the catalyst that started serious discussion on many noise aspects of wind farm. Future research must therefore provide strong scientific data to validate these different noise concerns.

The noise policies from different Canadian provinces, USA states and a few other countries were reviewed. General comparison of the noise regulations was presented. The main differences between the different regulations seem to be: i) in the acceptable noise limits; and ii) in the evaluation of receptor noise levels from the cumulative operation of the turbines in the wind farm. Further, some jurisdictions have special legislation concerning wind turbines, while others apply general recommendations. The Ministry of the Environment assessment process in Ontario is similar to other jurisdictions.

A literature review, focussed mainly on a) Metrological effects on wind turbine noise generation; b) Assessment procedures of wind turbine noise levels and their impact; c) Particular characteristics of wind farm noise; and d) Human responses to wind farm noise levels, was conducted. It showed that - local terrain conditions can influence meteorological conditions and can affect the expected noise output of the wind turbines; assessment procedures of sound power levels and propagation models, applied in different jurisdictions are quite similar in their scope; wind farm noise do not have significant low-frequency (infrasound) components; and modulations effects can impact annoyance;

The Ministry of the Environment's procedures to assess wind farm noise levels follow a simple procedure that is sound for most situations. However, additional concerns still need to be addressed in the next round of revisions to their assessment process. These revisions may need to be addressed after the results from future research provide scientifically consistent data for effects such as meteorology, human response and turbine noise source character.

1.0 INTRODUCTION

1.1 BACKGROUND

The Ministry of the Environment released a guideline document, "Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators" in 2004. The above guidance document was to assist proponents of wind turbine installations in determining the list of necessary information to be submitted when applying for a Certificate of Approval (Air and Noise) under Section 9 of the *Environmental Protection Act*. The noise guidelines in MOE publications NPC-205/NPC-232 as well as the wind generated noise levels were applied to set the noise limits. The revisions to NPC-205/NPC-232 (in draft form) did not change the evaluation of noise limits and/or procedures applicable to wind turbines. The three Ministry documents are enclosed in Appendices A through C.

The Ministry has now decided to initiate a review of the interpretation of the above policies, due to expanding body of knowledge of the noise impacts of wind turbines. The main aim of the proposed review is to assess the appropriateness of the Ministry's approach to regulating noise impacts of wind turbines. And the Ministry, to support the proposed review, has retained Aiolos Engineering to provide acoustical technical expert advice on the recent findings about low frequency and wind profiles on wind turbine noise impacts.

The scope and requirements of the technical advice can be summarized as shown below:

(1) *Review of the 2006 doctoral dissertation by van den Berg*;
(2) *Review of*
    2.1 available noise policies and guidelines;
    2.2 Review of relevant scientific literature; and
    2.3 Review of MOE's current noise policies as applied to wind turbine and
(3) *Provide expert opinion based on the above findings;*
(4) *Participate in a focus group discussion;* and
(5) *Prepare a report that provides advice on the state of the science regarding wind turbine noise and on MOE policies and procedures that relate to wind turbine facilities.*

2.0 REVIEW OF G. P. VAN DEN BERG'S DISSERTATION

2.1 BACKGROUND

Dr. G. P. van den Berg of the University of Groningen conducted research on the noise characteristics of wind turbines, the impact of wind profiles on its propagation as well as the subjective response of sensitive receptors. The results of the above research are summarized in the 2004 Journal of Sound and Vibration article (Reference 2) with the details given in his 2006 doctoral dissertation (Reference 1).

A list of documents used for this assessment is enclosed in the reference list. *NOTE:* References 2, 3 and 4 by van den Berg presents only summary results of his research and the complete details are included in his dissertation (Reference 1). Hence, references 2, 3 and 4 will not be commented upon in this review.

The main aims of van den Berg's dissertation can be summarized as follows:

i) A group of residents complained against the perceived noise effects from a wind farm located along the border between Germany and Netherlands and were unable to obtain satisfactory resolution from the authorities and hence the university's Science Shop for Physics was retained to investigate the validity of the residents' claims;

ii) The main complaints seem to centre around perception during evening and night hours, and hence the dissertation focussed on atmospheric stability and the resulting noise effects;

iii) The main hypotheses are: a) atmospheric stability, particularly stable and very stable conditions happen mostly at night time and the hub-height wind speeds can be higher than those predicted from the 10 m high wind speeds using standard methods, such as the logarithmic profiles of the IEC standard. And hence, the wind turbine noise levels can be higher than expected. It was also conjectured that these discrepancies are prevalent during summer months; and b) beat-sounds can become very pronounced during stable and very stable conditions.

The research uses a set of measurements near one wind farm as well as wind data from locations between 10 km and 40 km from the wind farm area. The whole thrust of the dissertation is to prove the hypotheses listed above.

The dissertation is broken into ten chapters, four general sections and four appendices. The chapter titles are: I) Wind power, society and this book: an introduction; II) Acoustical practice and sound research; III) Basic Facts; IV) Loud sound in weak winds; V) The beat is getting stronger; VI) Strong winds blow upon all turbines; VII) Thinking of solutions; VIII) Rumbling sound; IX) General conclusions and X) Epilogue.

Chapter I is basically an introduction and a justification for conducting the doctoral research by van den Berg. The reasons are seen to be based on anecdotal responses rather than from a truly scientific and statistical analysis of response surveys. Chapter II is a strong criticism of acoustic consultants and their inadequate effort in finding the true wind turbine noise levels and their potential impacts.

Chapters III, IV, V and VI are the relevant chapters for this review and assessment. The assessment will be presented in subsequent sections. Chapters VII through X are not critical for the current assessment and will not be commented upon. The assessments are presented next.

2.2 CHAPTER III – BASIC FACTS

Chapter 3 contains four sections and Sections 2 and 4 provide relevant background materials. Section 2 discusses wind profiles and Section 4 presents the many sources of wind turbine sound.

2.2.1 Wind Profiles and Atmospheric Stability

The main contention of this dissertation is that the hub-height velocity can be much higher than predicted with simple formula used currently in standards and other literature. This section presents two simple velocity profile equations to obtain wind velocities at different heights (Equations III.1 and III.3). Eq. III.3 is the standard logarithmic profile used in current literature.

This equation is being questioned as to its validity by this dissertation. Equation III.1 is a simple power law relationship with a shear coefficient as the exponent. Even though the dissertation states that Eq. III.1 has no physical basis, the dissertation applies this equation with 'suitably chosen' shear coefficient 'm' throughout the dissertation. Equation III.1 has been applied in many areas of engineering application and it is based both on dimensional analysis and empirical relationship obtained from field measurements. These two equations from Reference 1 are presented here for completeness sake.

$$V_{h2} / V_{h1} = (h_2/h_1)^m \qquad \text{III.1}$$

where 'm' is the shear coefficient, h_1 and h_2 are the two heights and V are the wind velocities at heights h_1 and h_2.

$$V_{h2\,log} / V_{h1} = \log(h_2/z_0) / \log(h_1/z_0) \qquad \text{III.3}$$

where z_0 is a roughness length of the surrounding terrain.

2.2.2 Main Sources of Wind Turbine Sound

A brief summary is presented of the different mechanism of noise generation including the interaction between the mast and the blade. Considerable amount of literature is available that outlines the noise from rotating aerofoil from early 1900s onwards. Hence, the information presented is a summary of earlier research.

However, it must be pointed that the dissertation mentions and/or presents information throughout the dissertation either heuristically or by presenting only scant data. One such case can be seen in Chapter III where it is stated, "An overview of stability classes with the appropriate value of m is given in Table III.1." No documentary evidence is given for the chosen values of 'm' or how the appropriateness of 'm' was determined. The reason this point is made here is the 'stability class' designation can change drastically depending on the value of 'm'. Table III.1 of Reference 1 is reproduced below.

Table III.1: stability classes and shear exponent m

Pasquill class	name	comparable stability class [TA-Luft 1986]	m
A	very unstable	V	0.09
B	moderately unstable	IV	0.20
C	neutral	IV2	0.22
D	slightly stable	IV1	0.28
E	moderately stable	II	0.37
F	(very) stable	I	0.41

2.3 Chapter IV: Loud Sounds in Weak Winds – Effect of the Wind-Profile on Turbine Sound Level

This is one of the most important chapters in the dissertation. The main hypothesis of the chapter is to show that the hub-height velocity can be higher than predicted from the 10 m high wind speeds using standard methods during stable and very stable atmospheric conditions and hence the wind turbine noise levels can be higher than expected even though the ground level velocities can be small at 2 m and 10 m heights. Such a wind-profile is possible when the atmospheric stability class is a combination of Pasquill Classes E and F with quiet winds and no cloud cover.

Chapter IV is supposed to prove the above hypothesis with scientific support.

2.3.1 Basic Assessment

The first three sections of the chapter provide background information on the Rhede wind farm in northwest Germany that abuts Netherlands. Even though, the noise assessment showed that the wind farm complies with both German and Dutch guidelines, nearby Dutch residents complained about the noise levels. The Science Shop for Physics of the University of Groningen (van den Berg's faculty) was retained to assist the residents to resolve their concerns. Section 3 presents anecdotal responses of two residents and their perception of wind turbine noise – 'pile driving sound', 'thumping sound', 'endless train sound' and such. There is no subjective polling under a blind survey to accompany the technical data presented.

2.3.2 Sound Emission and Sound Immission Levels

Long-term noise measurements were conducted at two receptor locations near the Rhede Wind Farm at two different time periods. Location A is 400 m west of the wind farm and Location B is 1500 m west of the wind farm. Wind velocities at 2 m and 10 m heights were measured only at Location A. ***NOTE:*** *It must be pointed out that wind speeds at hub-height were not measured.* The area around Location B has both low and tall trees in its vicinity. The following explanation and we quote, "As, because of the trees, the correct (potential) wind velocity and direction could not be measured on location B, wind measurements data provided by the KNMI were used from their Nieuw Beerta site 10 km to the north. These data fitted well with the measurements on location A" was offered to justify the use of data from a far-off wind-measuring location. The above statement is heuristic at best since no data (figures and/or tables) were provided to back the above claim. Hence, it was very difficult to make sense of the data presented in the dissertation document. Similarly, meteorological data from Elde site (40 km to the west) was used to establish neutral and stable atmospheric classes for the above two sites. Even though the section states that not all Elde observations would be valid for Locations A and B, the report still used the Elde information without qualifying its validity.

The main aim of the fourth chapter was to show that the atmospheric class during night is 'stable' or 'very stable'. The stable classes, supposedly, produce hub-height wind speeds that are higher than day time values, even though the 10 m high wind speeds could be low at night and the standard wind profiles are not able to predict the high hub-wind speeds at night. The outcome of the above hypothesis is that the night time noise levels, therefore, are higher than expected. However, as shown above, the establishment of atmospheric classes itself becomes suspect. Hence, the subjective perception that the noise levels were high may be due to low ambient sound levels during the late evening and night time hours, thereby making the wind farm noise audible.

2.3.2.1 Sound Emission Levels

Sound emission levels are the sound levels generated by the wind turbines and it is crucial to extract the levels from field measurements of overall levels. The noise levels from nine turbines were measured (Section 6) and an empirical relationship between the sound power and turbine rpm was established. The resulting sound power levels were used to calculate the noise levels at receiver locations and compare them with local measurements.

2.3.2.2 Sound Immission Levels

Sound immission, a phrase used in Europe, refers to the sound levels at receptor locations. Sound immission levels at Locations A and B were discussed in Section 7 of Chapter IV of Reference 1. The data provided is very difficult to analyse and at times very confusing. 371 hours of data for Location A and 1064 hours of data for Location B were collected. Since the monitors were un-manned, the differences in A-weighted sound levels between the 5th and 95th percentiles over 5-minute intervals were used to determine the dominance of turbine sound. The report uses a value, $L_5 - L_{95} \leq 4$ dBA, to deduce (Figure IV.4 of Reference 1) the duration of high sound levels at night time and at day time. There was no reason given as to the selection of the 4 dBA number. One would have expected a lower value, if the wind turbines were the main dominant noise sources. Actually, the value was close to 3 dB as described in Chapter V of Reference 1 (page 71 – $R_{bb,90}$ at Location P was around 3 dB). Figure IV.4 is reproduced below.

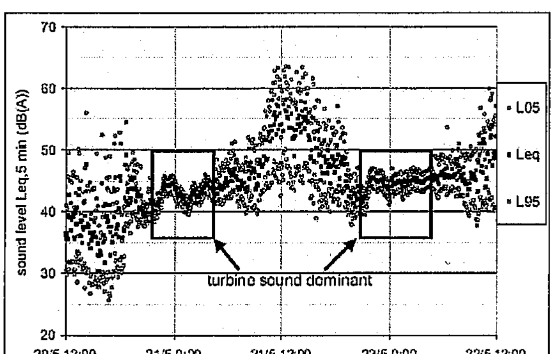


Figure IV.4: 48 hour registration of immission level (L_5, L_{eq} and L_{95}) per 5 minutes at location A; turbines are considered the dominant sound source if L_5-$L_{95} \leq 4$ dB

The criterion of $L_5 - L_{95} \leq 4$ dBA to determine the dominance of wind turbine noise is critical to the assessment. If the sound was steady during the 5-minute period, the above difference would be zero. Since outdoor sound levels are never steady, one would expect some variability. However, it is our belief that 4 dBA range is too high. If one were to reduce the difference to 2 dBA or 3 dBA, the night time duration for dominant sound levels would reduce substantially compared to the results presented in Table IV.3 of Reference 1. Table IV.3 is reproduced below.

Table IV.3: total measurement time in hours and selected time with dominant wind turbine sound

Location	total time (hours and % of total measurement time at location)	Night 23:00-6:00	Evening 19:00-23:00	Day 6:00-19:00
A: total	371 h	105	75	191
A: selected	92 h 25%	76 72%	9 12%	7 4%
B: total	1064 h	312	183	569
B: selected	136 h 13%	119 38%	13 7%	4 0,7%

The sound immission levels from all the measurements (the entire 1435 hours of data) were organized into the dominant turbine noise levels based on the 4 dBA difference and presented in Figure IV.5 of Reference 1, which is reproduced below. This figure with four sub-plots, is the most difficult figure to decipher. This is one of the most important figures used to conclusively provide evidence for the main argument of the dissertation. If one does not accept the 4dBA argument, the whole data structure of Figure IV.5 of Reference 1 is suspect. Further to cloud the issue, stable and neutral atmospheric classes, gleaned from Elde data (located 40 kms away) was superimposed. [Reference 1 on Page 47 does state that not all Elde data would be valid for Locations A and B, but continues, anyway, to use the invalid data to determine stability classes]. One must also infer that 'stable' classes occur only at night time and 'neutral' classes occur during the day time, even though the above was not stated explicitly in the report. No proper explanation was given for applying the above inference.

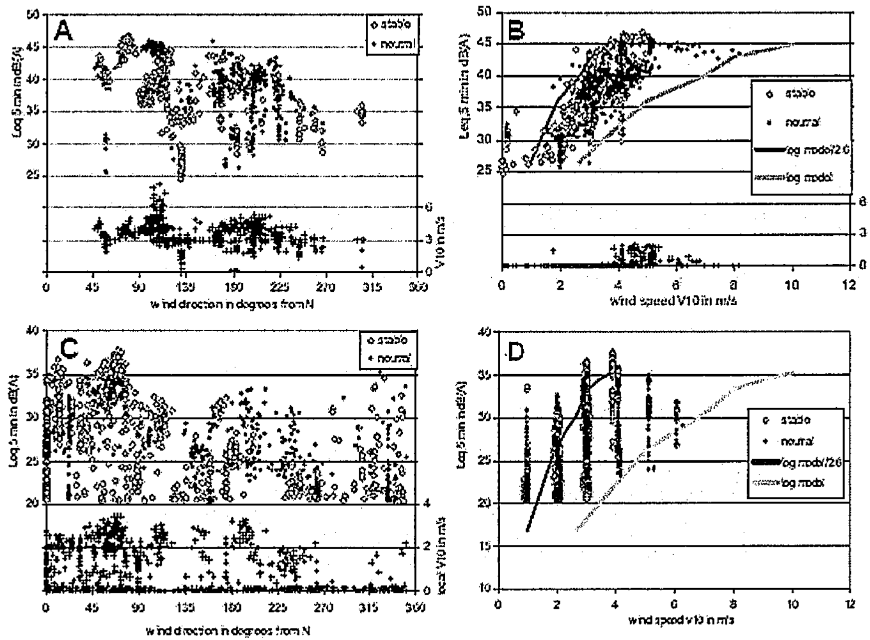


Figure IV. 5: measured sound levels $L_{eq,5\,min}$ at locations A (above) and B (below) as a function of median wind direction (left) and average wind speed (right) at reference height (10 m), separated in classes where the atmosphere at Eelde was observed as stable (open diamonds) or neutral (black dots). Also plotted are expected sound levels according to logarithmic wind profile and wind speed at reference height (grey lines in B and D), and at a 2.6 times higher wind speed (black lines in B and D). Figures A, B and C also contain the wind speed v_{10}(A), v_2 (B), and the local v_{10} (C) disturbed by trees, respectively.

Figures IV.5 B and IV.5D Reference 1 present the variation of 'dominant' turbine noise levels as a function of wind speed measured at a height of 10 m. **NOTE:** It must be pointed out that no wind speeds were measured for Location B. The data points ($L_{eq,\ 5\ min}$ in dBA) were also separated into 'stable' and 'neutral' atmospheric classes. In addition, the calculated sound levels from the sound power data from Section IV.6 were also plotted in these two figures. The wind speed at 10 m height for the calculated plot was evaluated using the logarithmic wind profile of Equation III.3 shown in Section 3 of the current assessment report. Since the logarithmic wind profile was supposed to be incorrect, a corrected noise level plot, by applying a factor of 2.6, was also included in Figures IV.5B and IV.5D of Reference 1. These two figures were used to make two strong statements against the procedures used to assess wind-turbine and wind farm noise impacts.

<u>Statement I:</u> 'Stable' atmospheric conditions occur at night time and wind turbine noise levels are higher than expected due to high wind-velocities at hub-height.

<u>Statement II:</u> Logarithmic wind profile, generally used in standard procedures, is incapable of predicting current wind speeds at various heights for 'Stable' atmospheric classes, occurring at night time. And hence, these higher than expected noise levels occur at night time with low ground wind speeds, thereby, increasing the impact on residents.

However, the two figures do not provide conclusive evidence to support the above two statements for the following reasons. Contrary evidence to Statement I will be further discussed in the next section with field data from New Zealand and Australia.

a) The 'stable' and 'neutral' class designations used in the two figures are applied from a location 40 kms away and hence not valid for Locations A and B;
b) Both classes seem to produce high as well as low sound levels as clearly seen for Location B (Figure IV.5D Reference 1);
c) The light grey sound level line supposed to represent the 'neutral' class quite accurately (as stated in Chapter III of the dissertation). If that were to be true, all of the 'neutral' class data points would have collapsed near that line. However, that was not the case, as the data points are scattered all over the figures;
d) Even at a distance of 400 m from the wind farm (Location A), only a small percentage of the 'neutral' class noise levels is near the neutral line;
e) Finally, if the $L_5 - L_{95}$ value is close to 2 or 3 dBA, the entire dominant sound levels at night time could occur well below the 25% to 35% time presented in this dissertation.

As part of the current investigation Aiolos Engineering undertook a brief review of summer weather data near a wind farm located adjacent to Lake Huron in Southern Ontario. Summer data was reviewed as the main hypothesis of van den Berg is that the wind speed discrepancies due to stability classes are severe during the evening and night hours of summer months. The objective of this review was to test the rigour of the two "van den Berg" Statements I and II. Since this review was conducted in the context of the current investigation and this report, the scope of the review was limited both in its duration and site selection. The review of this data will show that limited data of the type that van den Berg relied on cannot be used to draw strong conclusions.

Aiolos Engineering compiled wind speed data from one weather station in Ontario for a period of three summer months (June, July and August 2006). The Environment Canada's weather station at Goderich, Ontario is situated within a few kms of a wind farm with 21 wind turbines. The Kingsbridge wind farm has the capacity to generate 40 MW of power. The data for the three month period was compiled in different formats and the results are presented in Appendix D. The atmospheric stability classes were approximated using the information from the AIR-EIA website (Reference 19). Even a cursory perusal of the Appendix D data would show that the correlation between stability classes and power generation is quite inconsistent. The power generated by the wind farm was obtained from the Independent Electricity System Operator's data base for Ontario (Reference 34). Unless a detailed study of the wind power generation and wind speed behaviour at the wind farm location is conducted, one cannot make strong conclusions as presented by van den Berg's work. Another salient observation from Appendix D data is that the wind farm power generation and wind speed behaviour is highly localised, controlled by the local conditions

One must point out at this juncture, that the conjectures presented in van den Berg's Statements I and II may well be true. However, the research presented in van den Berg's dissertation has not provided strong scientific evidence for the same. In addition, the data of figures IV.5 clearly shows that the sound levels at Location A, 400 m west of the wind farm is less than 40 dBA and the noise levels at Location B, 1500 m west of the wind farm, is less than 35 dBA for a substantial portion of the measurement period.

2.4 CHAPTER V: THE BEAT IS GETTING STRONGER – LOW FREQUENCY MODULATED WIND TURBINE SOUND.

Chapter V deals with the effect of frequency modulation of the wind turbine noise levels. This chapter is an important chapter since it is supposed to provide evidence that the beating phenomena gets stronger with worst results during the 'stable' atmospheric classes. The 'stable' atmospheric classes are supposed to occur only during late evening and night time hours and the turbine is supposed to generate higher than expected noise levels with the ambient sound levels at the receivers being low due to lower than expected ground speeds. The inference here, therefore, is that any modulation of higher noise levels would cause additional hardships on the receiver. This chapter aims to show that the above is true.

Chapter V is broken into 3 main sections. Section V.1 discusses the effects of atmospheric stability on wind turbine noise generation. It discusses, three possible effects, purely as theoretical conjunctures that beating (or modulation) can be due to - a) the increase in the angle of attack changes between the blade at its highest location and at its lowest location during stable conditions; or b) increase in the wind direction gradient between the blade at its highest location and at its lowest location during stable conditions; or c) reduced wind turbulence during stable conditions. No supporting experimental evidence was forthcoming. We agree that purely from theoretical consideration that the three possible mechanisms can produce amplitude modulation phenomena. But, does this happen only for 'stable' and 'very stable' atmospheric conditions and only at night time?

The other major misconception arising out of this chapter is the terms used to describe the said phenomenon – 'swishing', 'thumping', and 'beating'. The beating phenomenon in acoustics called *beat* is a special event when two sounds occur with their dominant frequencies very close to each other. A general description of *beating* is presented in Appendix E. The amplitude modulation phenomenon is different from *beating*. The acoustical principles that describe the amplitude modulation phenomenon are generally considered to be related to the movement of the turbine blades through air and the interaction of the blades with the stationary mast. In addition, the amplitude modulation could be caused by the nature of wind itself – random both in speed and direction. Irrespective of the underlying principles, the amplitude modulation produced by wind turbines is a different phenomenon from acoustical *beating*.

The UK working group on Wind Farm noise (Reference 30) studied the phenomenon of amplitude modulation and found the levels inside residential bedrooms to be below the sleep disturbance level. Importantly, the UK report recommended that further studies be conducted to understand the amplitude modulation better. [Further descriptions of the aerodynamic modulation will be presented in Section 4].

Section V.2 presents measurement at three locations; two near the Rhede wind farm and the third location (Location Z) is near a single small wind turbine. Between 10 and 15 minutes of data were collected. The measurement results are presented in terms of spectral variations. The wind velocity was measured only near one location and the wind speed data for Location Z was obtained from a number of nearby weather stations. Two conclusions were obvious from the results:

a) the infra-sound, when measured as dBG with the G-weighting scale, was found to be not audible, approximately between 15 – 20 dB below the threshold of perception, indicating that modern wind farms do not generate infrasound levels that are perceptible. For information on G-weighting network, please see Reference 31;
b) the A-weighted sound levels correlated with spectra around 400 Hz which indicates the major source is the trailing edge noise.

The main thrust of this chapter was to discuss the amplitude modulation phenomena. The modulation at Location P was audible during the measurements period, but very small at Locations R and Z. The main effect of the modulation is not to produce low frequency sounds, but change the amplitudes which are discernable by the receivers. The results showed amplitude modulation at Location P with a variation of about 5 dBA between maximum and minimum. Even though the measurements were conducted for a long duration, only 180 second of measured data was shown to prove the existence of the modulation (beating) in Figure V.4 of

Reference 1. The modulation was seen to be strong only for 30 seconds. Even though the variation was 1 dB more at Location R, no modulation was discernable. No explanation was given for these discrepancies. Even though the level variation did not indicate beating at Location R, the level variations for Locations A and B from Chapter IV were shown in Figure V.7 of Reference 1 to conjecture that modulation would happen at these locations, 28% of the time and 18% of the time respectively. Since the measurements at Locations R, P and Z were conducted at early morning hours (midnight), it was assumed to be stable weather conditions. No data was provided to substantiate the absence of modulation during other weather conditions, such as 'neutral' and/or 'unstable' atmospheric classes. Hence, one cannot immediately conclude that modulation occurs only during the 'stable' and 'very stable' atmospheric class. Figures V.4 and V.7 of Reference 1 are reproduced below,

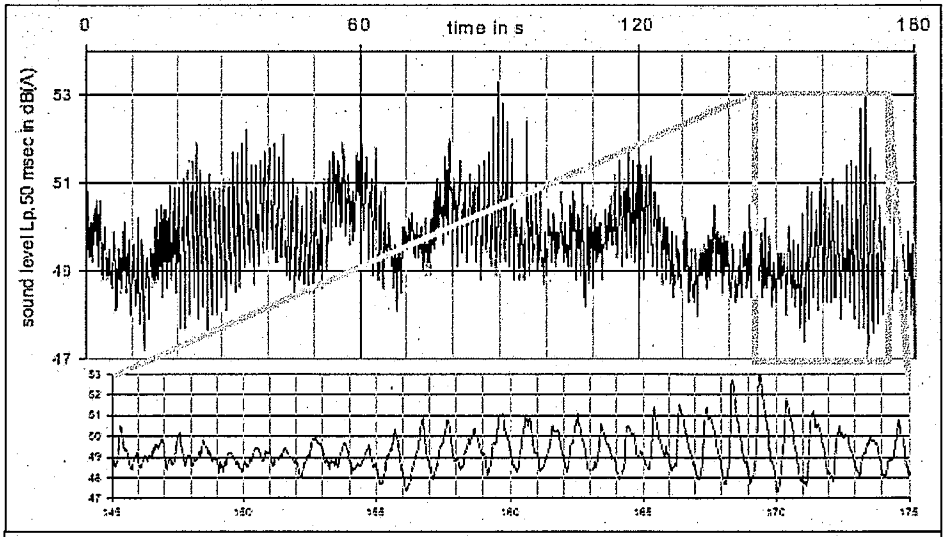


Figure V.4: fluctuations in broad band A-weighted sound immission level at façade of dwelling P; the lower panel is an expansion of the part within the grey rectangle

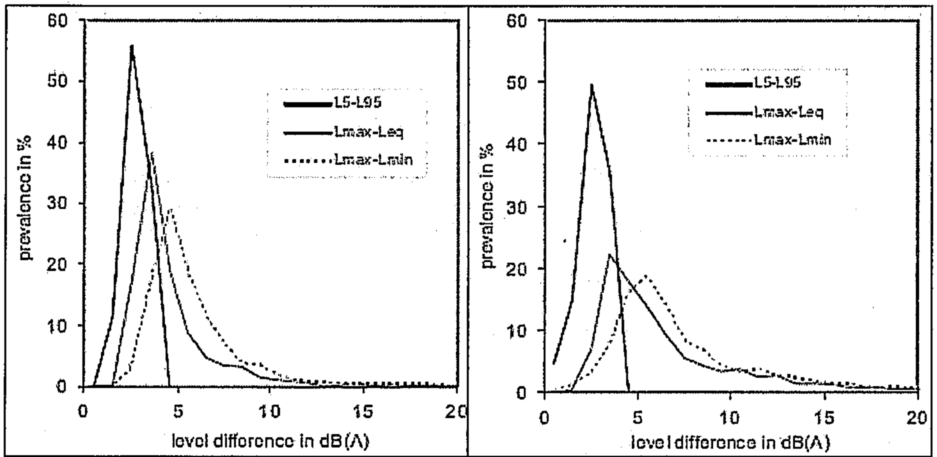


Figure V.7: statistical distribution of level differences (in 1 dB-classes) between high and low sound levels within 5 minute periods at 400 m (left) and 1500 m (right) from the nearest wind turbine

Finally, Section V.3 discusses the perception of the modulated sound. It begins by quoting the subjective response work of Pedersen and Waye (Reference 5) that about 20% of residents would be annoyed with noise levels in the range of 37.5 dBA to 40 dBA. It then jumps to anecdotal responses of two residents near the Rhede farm. There are no studies cited in van den Berg's work that show a correlation between modulated sound and annoyance and hence van den Berg conjectures the annoyance would be worse since the expected amplitude variations make the perception of the sound strong. However, no evidence other than anecdotal responses was forthcoming.

2.5 CHAPTER VI: STRONG WINDS BLOW UPON TALL TURBINES – WIND STATISTICS BELOW 200 M ALTITUDE

This chapter deals with actual wind speed data from one site in western part of the Netherlands. The wind velocities at different heights, 10 m, 20 m, 40 m, 80 m, 140 m and 200 m were measured at half-hour intervals. The results, averaged for the entire year showed that higher wind velocities compared to the predicted wind speeds from the 10 m high wind velocity, indicating a stable atmosphere. Even the daily variations over seven days in summer months are small during the night time hours (Figure VI.3 of Reference 1, reproduced below).

The data described in Section 2.3.2.2 and presented in Appendix D was further analysed to look at the daily variations in wind speeds. In addition to Goderich weather station, the data from a few more weather stations located within 30 km radius of existing wind farms were compiled by Aiolos Engineering. Figures 2.1 thru' 2.6 show results of one-hour averaged wind speeds from three weather stations near three wind farm sites in southern Ontario. The weather data was collected at a height of 10 m above ground. The daily variations for a few summer days shown in Figures 2.1, through 2.6 seen to indicate substantial variations in wind speeds from day to day. As was explained in Section 2.3, summer data was reviewed as the main hypothesis of van den Berg is that the wind speed discrepancies due to stability classes are severe during the evening and night hours of summer months.

The measurement results of Botha [Reference 22] for four sites in New Zealand and Australia showed contradictory results of wind speed gradient. They will be discussed in Section 4. Hence, the main conclusion here is that the data presented in Chapter VI of Reference 1 is valid only for that one site in Netherlands.

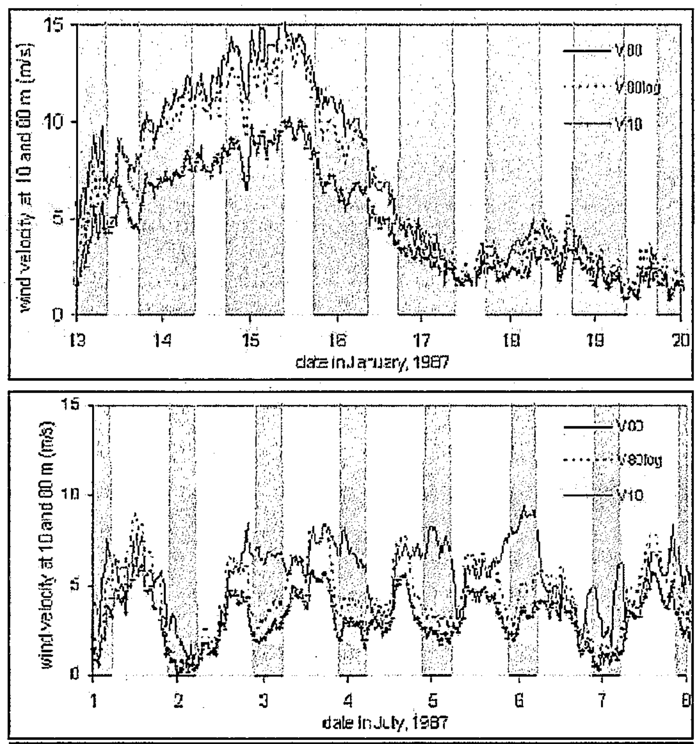


Figure VI.3: wind velocity at 10 and 80 m (solid lines), and logarithmically extrapolated V_{80log} (dotted line) over 7 days in January (top) and July (bottom); grey background: time when sun is down

The chapter then calculates expected power production at these velocities as well as calculates noise levels from the wind farm. The results show that the discrepancy for the Cabauw site between stable noise and standard logarithmic wind profiles is of the order of 2 dB. These differences are averaged from one site. The main drawback of the results of this chapter is that they are not transferable to every wind farm site in the world.

One must point out that it may be possible that during summer months stable and very stable conditions may exist at night time producing higher than expected noise levels and hence increasing the impact. However, the data presented so far does not lead one directly to that conjecture.

Figure 2.1 Elora Wind speeds

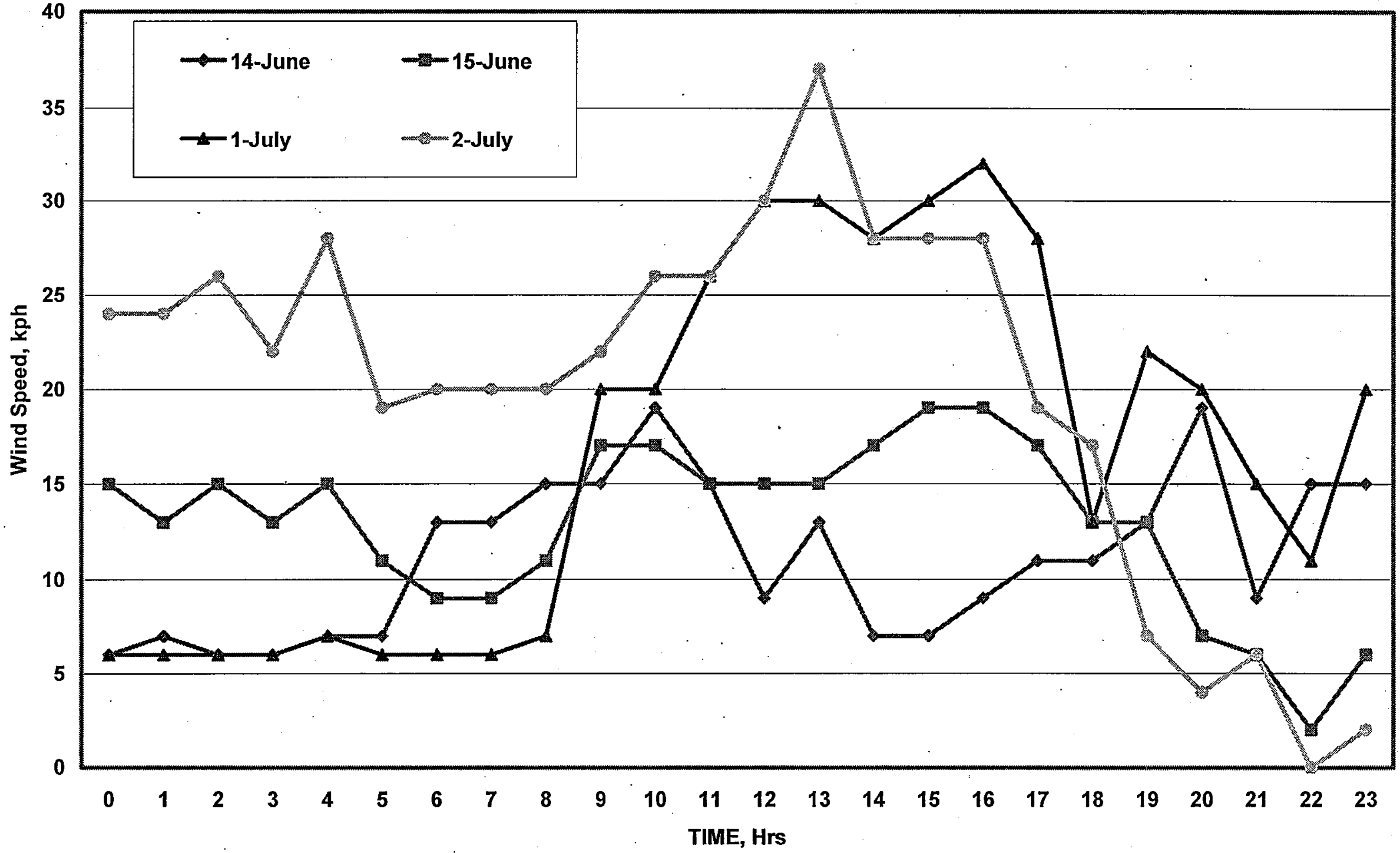


Figure 2.2 Elora Wind speeds - 2.

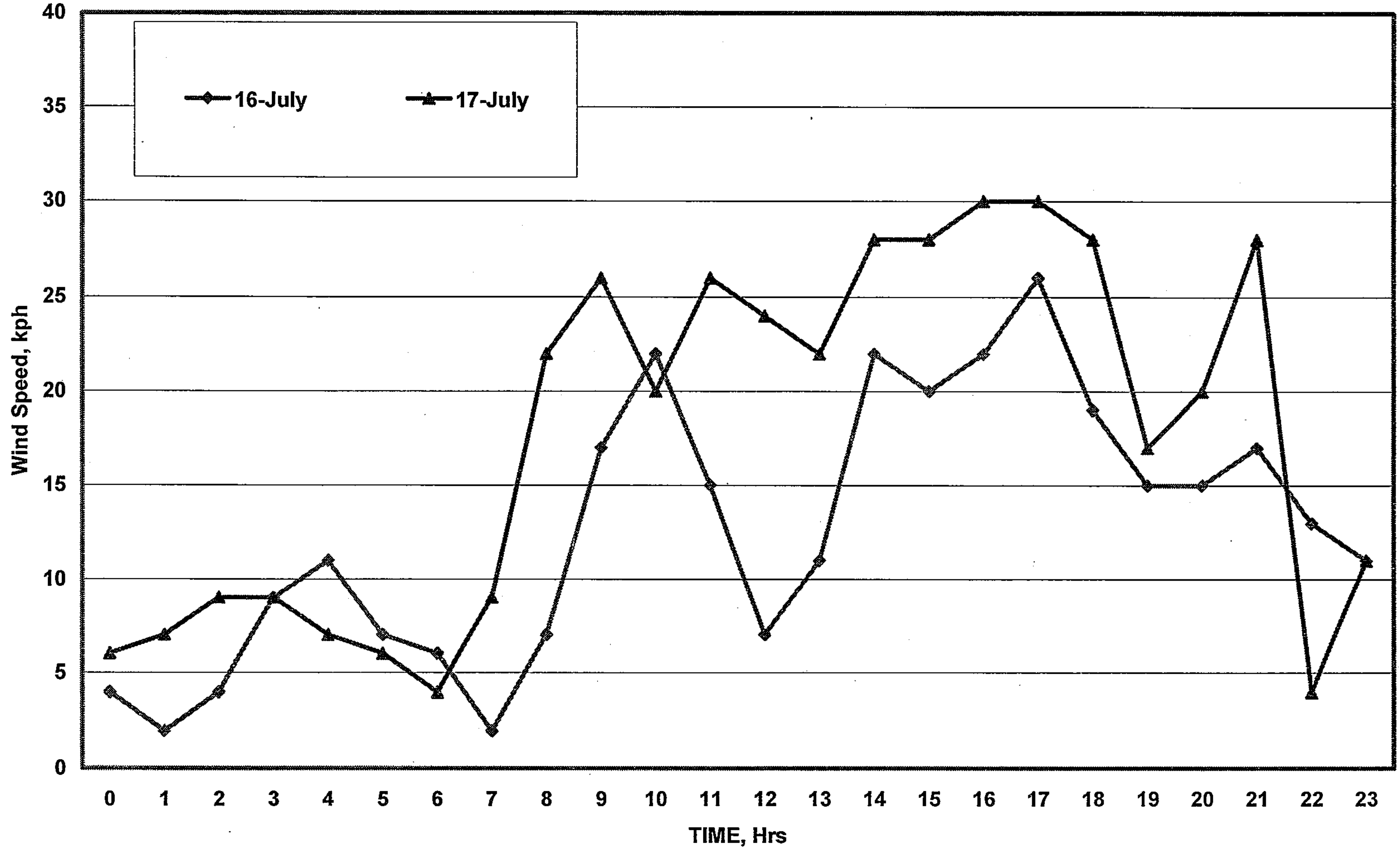


Figure 2.3 Goderich Wind speeds

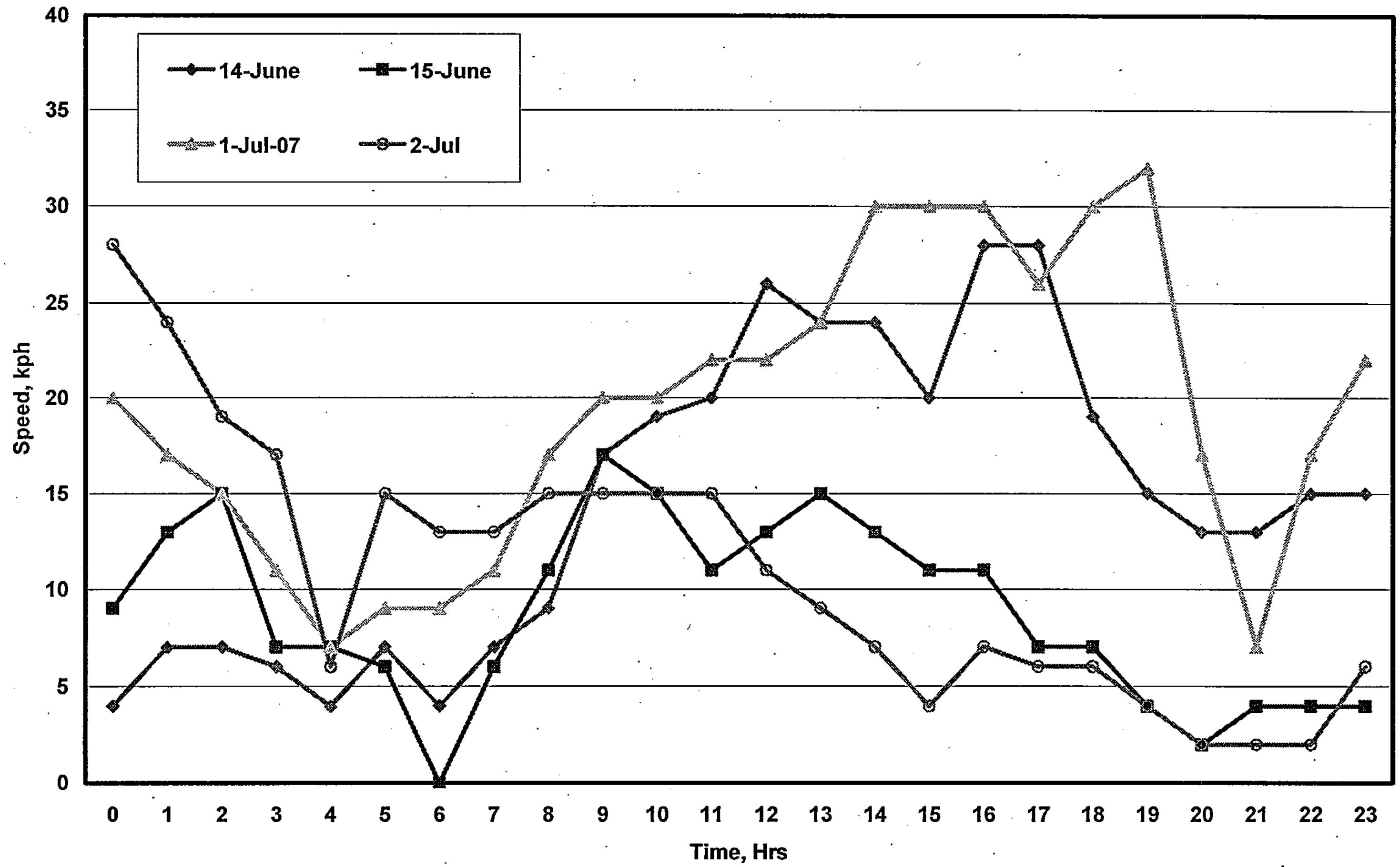


Figure 2.4 Goderich Wind speeds - 2

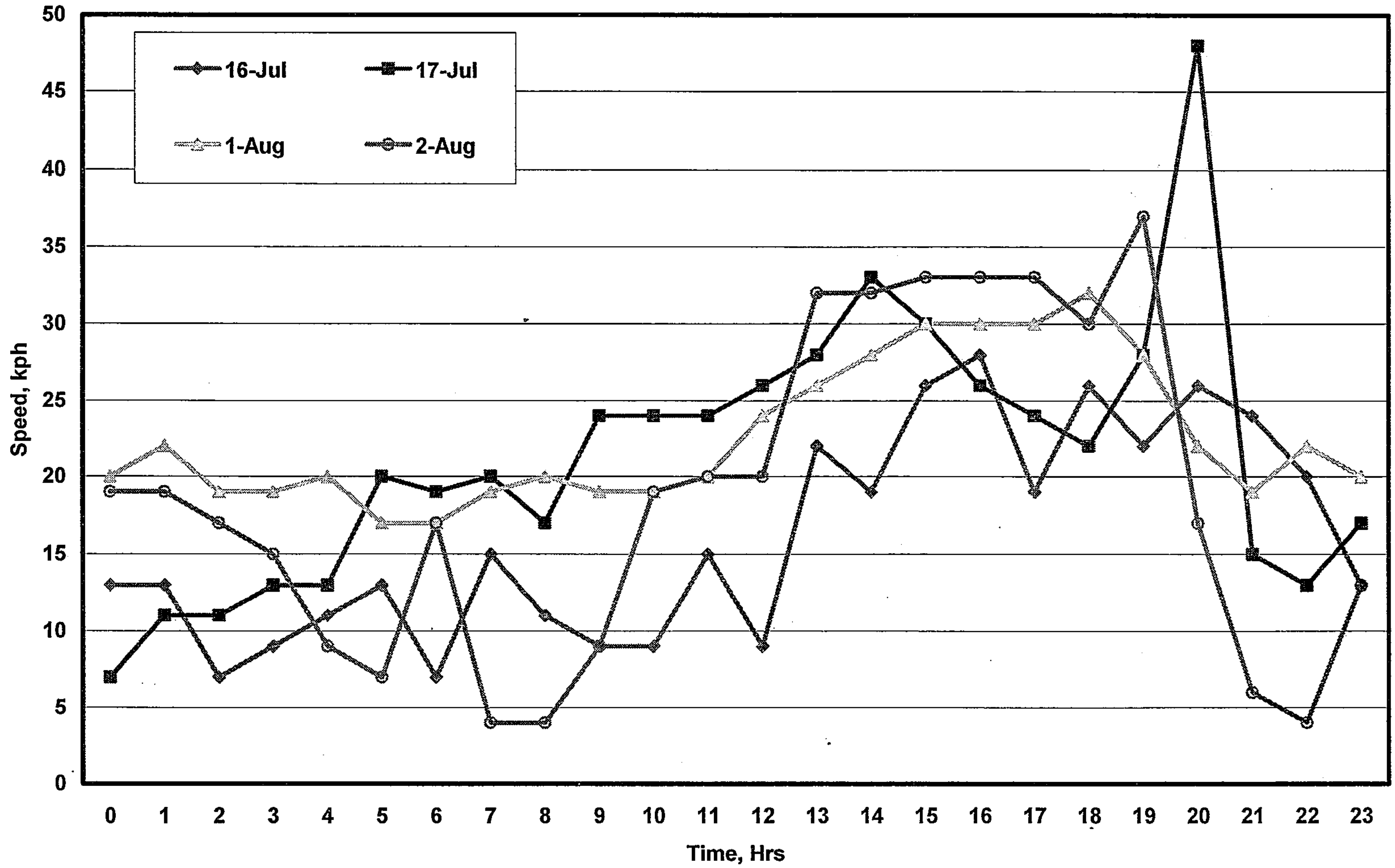


Figure 2.5 Elora and Goderich Wind speeds.

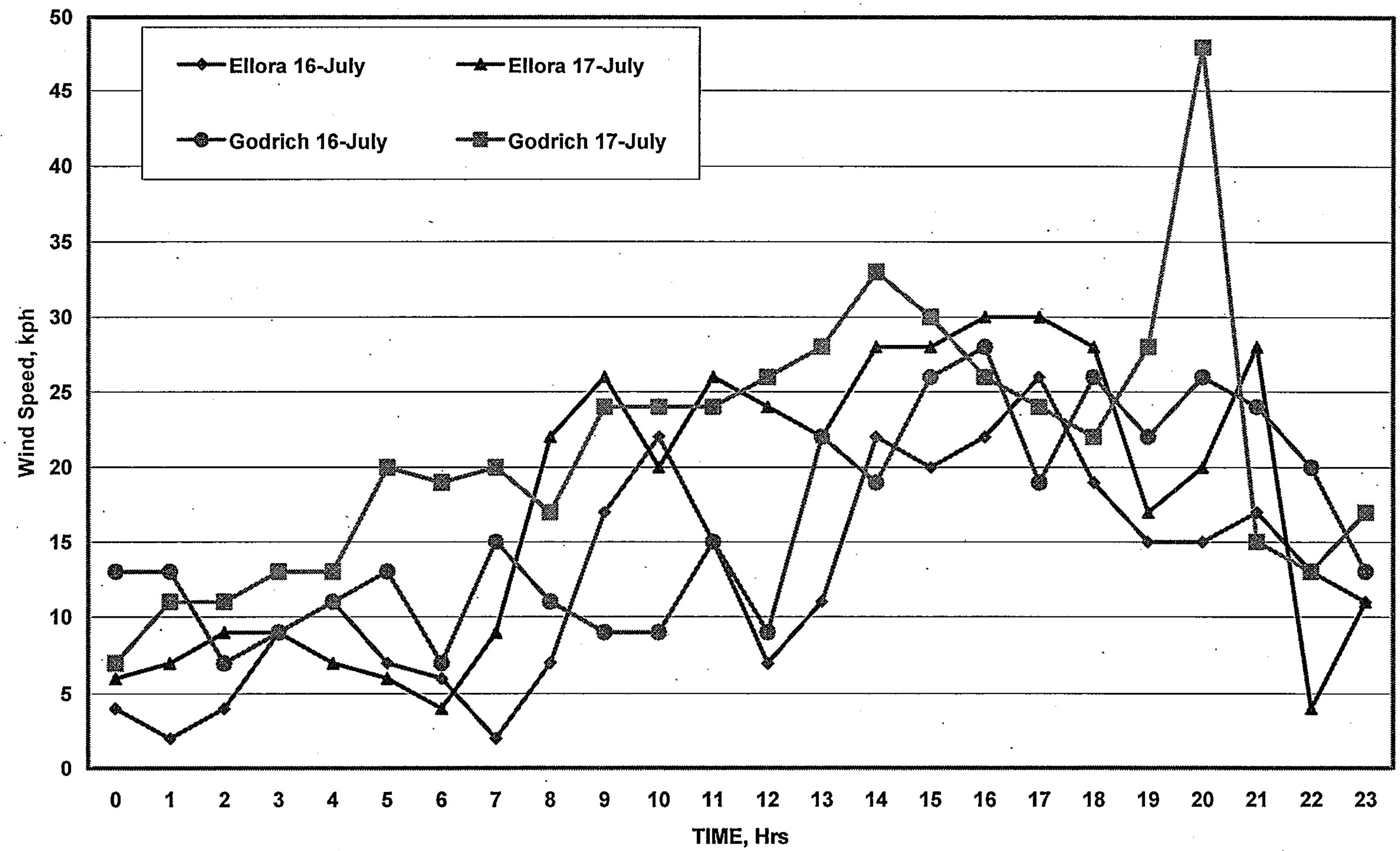
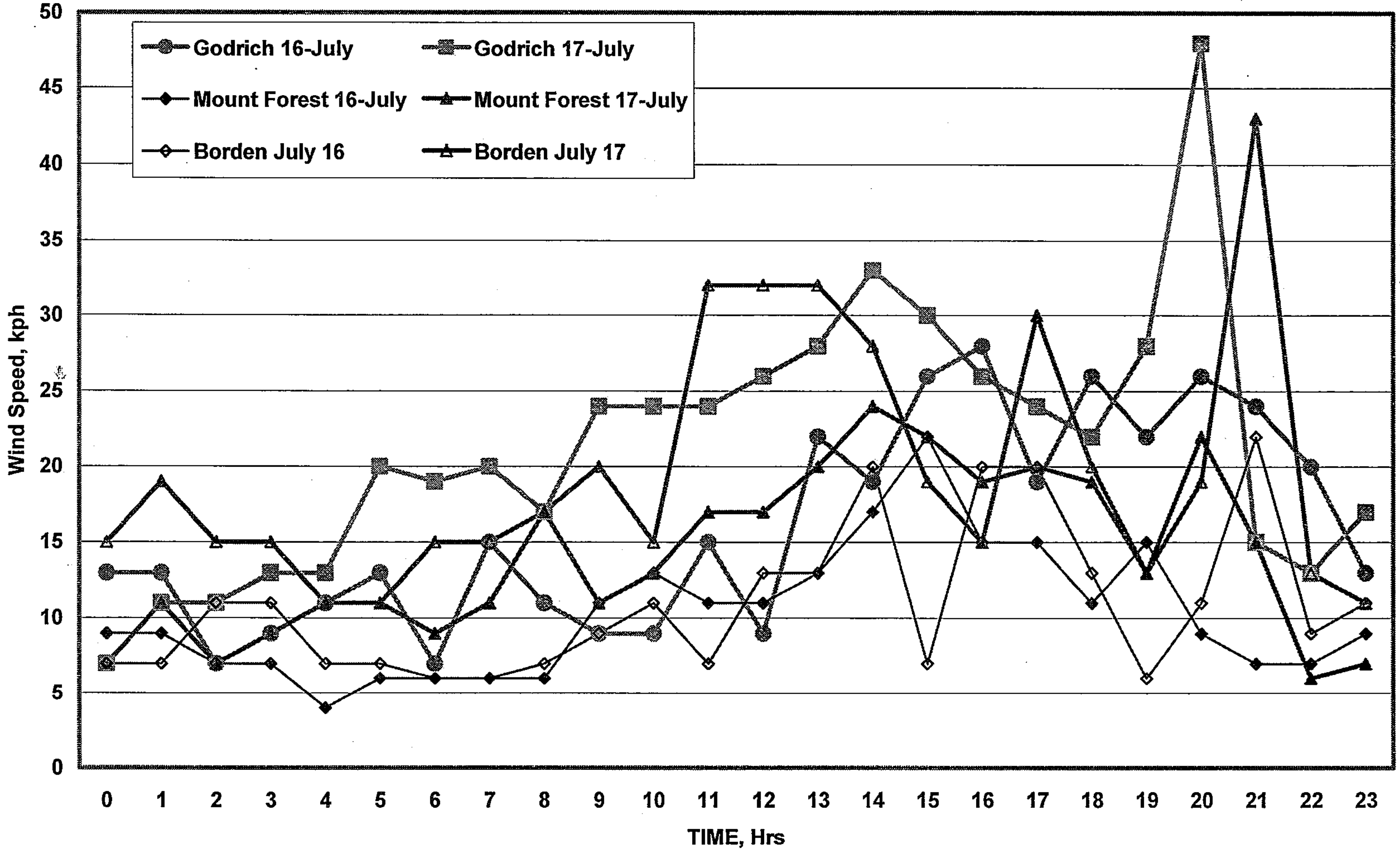


Figure 2.6 Borden, Mount Forest and Goderich Wind speeds.



2.6 SUMMARY

The doctoral dissertation of G. P. van den Berg was reviewed and comments were provided in this section. The dissertation was to provide scientific evidence for increased annoyance from wind farm during evening and night time hours. The review showed the above was not the case and the review comments are summarized below.

One of the main criticisms of the doctoral dissertation of van den Berg is that the conjectures of his research have not been supported by solid scientific data.

The major deficiencies of the doctoral dissertation are highlighted below:

A) Simultaneous noise measurements and subjective response from a random sample of the residents were not performed other than a few anecdotal responses;

B) The wind velocities at various heights were not conducted either at the turbines or near them to evaluate the atmospheric classes, but applied weather data from a location 40 kms away;

C) The wind farm noise levels at receptors were unmanned and the procedure to evaluate the dominance of turbine noise may not be correct.

D) The immission levels measured at 400 m and 1500 m distances had a large scatter to provide strong conclusions. **NOTE:** It must be pointed out that the receptor noise levels, for a substantial portion of the measurement period, were less than 40 dBA at a location 400 m away and less than 35 dBA at a location 1500 m away.

E) The *beat* of acoustics is being identified, wrongfully, with amplitude modulations and no strong evidence was provided to show the modulation gets worse at night compared to day time in the summer.

Despite the rather strong conclusions of Reference 1 some of the basic conjectures in the dissertation merit further examination. Hence, the research of van den Berg may be considered as the catalyst that started serious discussion on many aspects of wind farm noise. Future research must therefore provide stronger scientific data to validate these different noise concerns.

3.0 REVIEW OF AVAILABLE NOISE POLICIES AND GUIDELINES

The second task for the current project was to provide an evaluation of the noise policies on Wind Turbine noise applied in jurisdictions other than the Province of Ontario.

The noise policies from different Canadian provinces, USA states and a few other countries were reviewed. The regulations from Germany and the Netherlands were gathered from other review papers. [See for example Reference 18].

General comparison of the noise regulations is presented in Table 3.1.

3.1 WHO GUIDELINES FOR COMMUNITY NOISE
(Reference R1)

The community noise guidelines are the result of significant amounts of research in the relationship between noise and health. There is an understanding that noise pollution can be the cause of serious health effects through short term and long term, or cumulative, exposure. The guidelines include the values of what the World Health Organization feels to be the thresholds to health effects in various situations. The limit that has been listed in an outdoor living area, such as around a dwelling, is 50 dBA for moderate annoyance. Once the sound level has increased to 55 dBA, it is considered to be a serious annoyance. For indoors, the World Health Organization recommends the noise level to stay below 35 dBA before moderate annoyance occurs, and below 30dBA to avoid sleep disturbance at nighttime. For conditions at nighttime with an open window, the suggested limit is 45 dBA to avoid sleep disturbance. Many of the documents below reference these guidelines in the justification of selecting certain noise limits, although the Ontario Ministry of the Environment publication does not. They are also widely referred to in other literature relating to noise level limits.

Table 3.1 Comparison of Noise Regulations.

Jurisdiction	Daytime Limit	Nighttime Limit	Background SPL Establishment	Wind Turbine SPL Establishment	Minimum Setback	How Impact is Assessed
ONTARIO	Whichever is greatest: - Urban Areas, wind speeds below 8m/s: 45 dBA or hourly background level - Rural Areas, wind speeds below 6m/s: 40 dBA or hourly background level - Wind speeds above 8 and 6 m/s each type: wind induced background level LA_{90} plus 7dBA or hourly background level		NPC-205 or NPC-232 whichever is higher	IEC 61400-11, to be provided by manufacturer	N/A	Impact Assessment to ISO 9613 method to be submitted prior to approval for critical points of reception up to 1000 m.
Alberta	Nighttime + 10 dBA	40 dBA – 56 dBA minimum	Pre-assumed based on proximity to transportation and number of dwellings OR 24 hours, 10 min. intervals in special cases	Modeling at wind speeds of 6 to 9 m/s to achieve worst-case scenario	N/A	Noise Impact Assessment Required to be submitted for application – form given in document Noise measurements, including CSLs *recommended* for speeds 4 to 6 m/s between 1.2 and 10 m above grade
British Columbia	40 dBA at residential property		N/A	Modeling of 8-10m/s wind speeds at 10m height to be provided by manufacturer	Siting to conform to ISO 9613-2	Risk assessment required if the difference between modeled SPL and acceptable limit is close -Measurements made if complaint is filed

Jurisdiction	Daytime Limit	Nighttime Limit	Background SPL Establishment	Wind Turbine SPL Establishment	Minimum Setback	How Impact is Assessed
Quebec	Sensitive Land: Type I = 45 dBA Type II = 50 dBA Type III = 55 dBA Non Sensitive Land: Type IV = 70 dBA Dwelling on Industrial Land: 55 dBA	Sensitive Land: Type I = 40 dBA Type II = 45 dBA Type III = 50 dBA Non Sensitive Land: Type IV = 70 dBA Dwelling on Industrial Land: 50 dBA	Length of time to current practiced standards – not specified. Measurements to fully cover reference intervals favoured	N/A	N/A	Measurements taken post-construction to ensure conformity, assess impact
New York (Town of Clinton)	50 dBA or Ambient + 5 dBA		Highest whole number in dBA exceeded for more than 5min per hour (requires independent certification)	IEC 61400-11 or other accepted procedures	- 500 ft from property line or road - 1200 ft from nearest off-site residence - 2500 ft from a school, hospital or nursing facility	Independent certification required before and after construction that noise limits are met.
Maine	Residential: 60dBA Comm/Ind.: 70 dBA Rural: 55 dBA	Residential: 50dBA Comm/Ind.: 60 dBA Rural: 45 dBA	Estimation based on population within 3000m radius or measurements during all hours the development will operate	N/A	N/A	Post-development one-hour equivalent measurements to be made
Pennsylvania	Fifty (55) dBA (note: this is what is in the document, not a typo here)		N/A	AWEA Standard 2.1 - 1989	1.1 x turbine height (consenting) or 5 x hub height (non-consenting)	N/A
Washington	Residential: 60 dBA Commercial: 65 dBA Industrial: 70 dBA	Residential: 50 dBA Commercial: 55 dBA Industrial: 60 dBA	N/A (Environmental noise measurement procedure is reserved)	N/A	N/A	Noise measurement only made if a complaint is filed

Jurisdiction	Daytime Limit	Nighttime Limit	Background SPL Establishment	Wind Turbine SPL Establishment	Minimum Setback	How Impact is Assessed
Oregon	Ambient + 10 dBA		26 dBA assumed	IEC 61400-11	350m minimum, or 1000m non-consenting	
Michigan	55 dBA or L_{90} + 5 dBA		55 dBA assumed, not indicated for higher levels	IEC 61400, ISO 9613 (modeling)	1.5 x height of tower including blade in top position	ANSI S12.18 (post construction), ISO 9613 model
Australia	35 dBA or $L_{A90,10}$ + 5 dBA		Minimum of 2000 data points of background noise and wind speed pairs with a best fit curve	IEC 61400-11, must be overlaid on graph of background sound levels	N/A	Demonstration of compliance at all relevant receivers, if compliance is not demonstrated, operation will be restricted
New Zealand	40 dBA or L_{95} + 5 dBA		NZS 6801 (10-14 days of continuous monitoring)	Obtained from Manufacturer	N/A	Measurements taken if necessary, to follow same procedure as background levels
UK (Britain)	$L_{90,\ 10min}$ + 5 dBA OR 45dBA OR 35-40 dBA	43 dBA or 45 dBA	Minimum 7 days continuous 10 min interval monitoring	IEA Recommended Practice – using 8m/s at 10m height	N/A	Measurements made if complaint filed; no formal impact assessment required
Ireland	45 dBA or L_{90} + 5 dBA OR 35-40 dBA if L_{90}<35 dBA,	43 dBA	10 minute intervals	N/A	N/A	N/A

Jurisdiction	Daytime Limit	Nighttime Limit	Background SPL Establishment	Wind Turbine SPL Establishment	Minimum Setback	How Impact is Assessed
Denmark	45 dBA in open areas 40 dBA near residential		Annex 1 of the document; requires regression analysis of min. of 10 L_{Aeq} values measured for at least one minute each over different wind speeds	EN 45000 standards or min. of 10 L_{Aeq} values measured for at least one minute each over different wind speeds – see Annex 1 of document for full procedure	N/A	- Calculations of noise level at nearest property - Measurements after operation has begun or when deemed necessary, but not more than once per year
Germany	55 dBA/50 dBA in residential areas and 45 dBA in areas with hospitals, health resorts etc.	40 dBA/35 dBA in residential areas and 35 dBA in areas with hospitals, health resorts etc.	N/A	Recommended Practice – using 10 m/s at 10m height	-	- Calculations of noise level at nearest property, using DIN ISO 9613-2.
Netherlands	50 dBA	40 dBA (night) 45 dBA (evening)	N/A	-	-	-

3.2 NORTH AMERICAN NOISE LEVEL LIMITS AS APPLIED TO WIND TURBINES

The situation in North America in terms of noise level limits for wind turbines is currently under development. Many jurisdictions are only beginning to draft standards specifically for wind turbines, and few have gone beyond the draft stage. This is true for both the United States and Canada, where wind is still a relatively under-utilized energy source. There are a number of examples of noise level limits below from the Northern U.S. States, and some Canadian provinces, and they represent the variability from one jurisdiction to the next.

3.2.1 Ontario - Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators
(Reference R2)

The Ontario Ministry of the Environment has produced a document listing noise requirements for wind turbines. The document segregates development into three separate classes, the first two referring to urban environments, and the third referring to a rural environment. The sound level limits are dependent not only on their classification, but on the wind speed also. Where wind speeds are lower than 8 m/s in an urban environment, the hourly equivalent sound level from the wind turbine facility must not exceed 45 dBA or the hourly background sound level, whichever is greater. Similarly, in a rural environment where wind speed is less than 6 m/s, the hourly equivalent sound level must not exceed the greater of 40 dBA or the hourly background sound level. In the cases where the wind speeds exceed these levels, rather than a fixed limit, the sound level is permitted to be the wind induced background sound level, L_{A90}, plus 7 dBA. This is demonstrated in the Table 3.2 below.

Table 3.2. Ontario Noise Assessment Limits

Wind Speed (m/s)	4	5	6	7	8	9	10	11
Wind Turbine Noise Criterion NPC-232 (dBA) (Rural)	40	40	40	43	45	49	51	53
Wind Turbine Noise Criterion NPC-205 (dBA) - (Urban)	45	45	45	45	45	49	51	53

The noise limits apply to both daytime and nighttime periods, with the level being measured at the nearest point of reception: a location within 30 m of an existing or zoned for future dwelling. After a distance of 1000 m between the wind turbine facility and the point of reception, a detailed noise assessment is not required.

3.2.2 Alberta - EUB Directive 038 Noise Control
(Reference R3)

Of all the documents reviewed, the sound level limits for wind farms are perhaps the most complicated to determine in the province of Alberta, Canada. Primarily, the permissible sound level, PSL, depends on the location of the nearest residences. If there are no dwellings within 1.5 km, the limit is a fixed 40 dBA (this corresponds to an increase over the assumed ambient sound level of 35 dBA in rural areas). However, if there are places of residence, the PSL must be determined by the flowing equation:

$$\text{PSL} = \begin{matrix}\text{Basic Sound}\\\text{Level}\end{matrix} + \begin{matrix}\text{Daytime}\\\text{Adjustment}\end{matrix} + \begin{matrix}\text{Class A}\\\text{Adjustment}\end{matrix} + \begin{matrix}\text{Class B}\\\text{Adjustment}\end{matrix}$$

The Basic sound level is the main component of the sound level limit and ranges from 40 dBA to 56 dBA, depending on the receiving property, and is selected from a table. The daytime adjustment allows the addition of 10 dBA to the PSL during the time period of 7 a.m. – 10 p.m. The other adjustments, Class A and Class B, require technical verification to be applied, and are only done so in specific circumstances. In order to properly determine the ambient noise level and the wind farm development's noise emissions, certain procedures must be followed which are documented in the directive. For example, the ambient sound level measurement requires continuous monitoring over a 24-hour period, 15m away from the nearest dwelling. The environmental conditions at the time of the measurements are also strictly detailed. Although their sound level limits are higher than the MOE limits, similar documentation is required, such as a noise impact assessment.

3.2.3 British Columbia - Land Use Operational Policy: Wind Power Projects (Reference R4)

The British Columbia policy regulating noise from wind turbines enforces a fixed limit of 40 dBA during all hours of the day. This limit is more restrictive than in Ontario, where allowances for higher sound levels are made when the wind speed increases. This limit is to be measured at the exterior of the nearest permanently occupied residence and/or the property line of undeveloped land zoned for future residential use. The siting must conform to ISO 9613-2, which is referenced by other jurisdictions, including Ontario, for use in impact assessment. The modeling is also similar to other jurisdictions, requiring the sound power level (PWL) to be estimated for 8-10 m/s wind speeds at a 10 m height. Should the modeling demonstrate that the estimated level is close to the acceptable limit, the policy requires that a risk assessment be conducted prior to approval. Testing of the sound levels of the facility post-construction is performed if a complaint is filed.

3.2.4 Québec - Instruction Memo 98-01 on Noise (Note: revised as of June 9, 2006) (Reference R5)

Quebec does not have a specific document relating only to wind turbines; the applicable paper discusses noise from all fixed sources. Different limits have been assigned based on the land use of the receiving property and the residual level of noise in the area. The location of measurement is at a distance 3 m or more from reflective structures, and 0.5 m from an open window. All sound levels averaged during a period of one hour must comply with these limits. There are two main categories of land use: sensitive zones (i.e. residential, hospitals, schools) and non-sensitive (agriculture and industrial use) zones. See table below for limits. In the case of a dwelling on agricultural land, the limits for a sensitive zone apply. For dwellings on industrial land, a 50 dBA nighttime limit and a 55 dBA daytime limit will apply. In terms of sensitive areas, the noise limits are comparable to those in Ontario, although there are different levels for day and night. However, an exception is given in the case of industrial and agricultural land, unless a dwelling exists, for the sound level limits to be much higher. The sound that is measured at the receiving property is based on an equation given in the document, accounting for the equivalent sound level of the source, and corrective factors to account for impact noise, tonal noise and special situations. However, the length of time that applies is up to the discretion of the person performing the evaluation, and should correspond to the current practice methods. Similarly, when measuring background noise, measurements taken that cover the full reference range are favoured, but not required. Post construction, measurements must be taken to ensure the compliance of the facility with the appropriate limits.

Table 3.3 Noise Regulations in Quebec

Zone	Night	Day
I – Sensitive – Single family dwellings, schools, hospitals	40dBA	45dBA
II – Sensitive – Multi-residential and camping areas	45dBA	50dBA
III – Sensitive – Commercial use and park land	50dBA	55dBA
IV – Non-sensitive – Industrial or Agricultural	70dBA	70dBA

3.2.5 Oregon - Revising Oregon's Noise Regulations for Wind Turbines (Reference R6)

Oregon has recently undergone a revision to its existing noise standards, which were last updated in the 1970s. There are two tests, or limits, that apply in the case of wind turbine developments, the Table 8 test (refers to Table 8 in the regulation) and the ambient degradation test. The authors of the revision have taken steps to coordinate their standard with that of the British and Australian guidelines on wind turbine noise. They have assumed a standard ambient background L_{50} of 26 dBA, although extensive documentation can be submitted for background noise greater than this level. The noise level limit is not allowed to increase the ambient noise levels by 10 dBA in any one hour, thus having an assumed limit of 36 dBA, which is lower than the MOE limits. It is also low enough to respect the WHO guidelines for indoor levels without accounting for sound reduction through walls. This limit applies to both daytime and nighttime, just like the MOE limits. However, unlike the Ontario requirements, there are also setbacks that must be adhered to; a minimum of 350 m for a consenting owner, and 1000 m between the nearest wind turbine and the property of a non-consenting owner. The methods of evaluating the sound created by the wind turbine development use the same methods that the majority of manufacturers provide to make things easier. The project must be evaluated under the maximum sound power level conditions according to IEC 61400-11 (8 m/s at 10 m height), but no correlation between 10 m and hub height is assumed.

Table 3.4 Oregon's Table 8 Limits, dBA

Statistical Descriptor	Daytime (7 a.m. – 10 p.m.)	Nighttime (10 p.m. – 7 a.m.)
L_{50}	55	50
L_{10}	60	55
L_{1}	75	60

NOTE: Maximum Permissible levels for New Industrial and Commercial Noise Sources, dBA - As in Bastasch, Noise-Con 2004, originally from OAR 340-35-035.

3.2.6 Pennsylvania - Wind Farm Model Ordinance Draft 12-08-06 (Reference R7)

The draft document developed in Pennsylvania is a model document prepared for the use by different local municipalities. It is not the regulation for the entire state. Local municipalities can use the draft document to prepare their own policies and guidelines. There is only one limit in the Pennsylvania draft, which applies to both daytime and nighttime. The sound level limit is slightly unclear however, because it states that the audible sound "shall not exceed fifty (55) dBA" (note that this has been correctly recorded here, the discrepancy between the written word and the numerical value given in parentheses). This value is much higher than the value given in the MOE regulation, and also equals the WHO recommendation for serious annoyance in an outdoor setting. [See Reference R1]. There is no mention or consideration of ambient sound levels, but waivers to this sound level may be considered. It also does not mention whether this is an hourly limit or not. The point of receiving is considered to be the "exterior of any occupied building on a non-participating Landowner's property." There are also associated setbacks that must be followed. The distance between a wind turbine and the nearest building on the same property must be a minimum of 1.1 times the turbine height. The distance between a turbine and the nearest occupied building on a non-participating property must be at least 5 times the hub height of the turbine. These setbacks exist in response to both safety and noise related issues.

Table 3.5. Pennsylvania Draft Ordinance

	Receiving Property Designation					
Source	**Residential (Class A)**		**Commercial (Class B)**		**Industrial (Class C)**	
	Daytime	Nighttime	Daytime	Nighttime	Daytime	Nighttime
Class C	60 dBA	50 dBA	65 dBA	55 dBA	70 dBA	60 dBA

Note: Daytime is considered to be 7am – 10pm
Nighttime is considered to be 10pm – 7am

3.2.7 Washington - Chapter 173-60 WAC Maximum Environmental Noise Levels (Reference R8)

In Washington State, there is no specific regulation for wind turbine noise, so sound levels must comply with the limits in the environmental noise legislation. This results in noise limits that are the highest among those reviewed here (along with Maine), much higher than the MOE limits. Noise level limits are dependant upon the designation, or class, of both the source property and the receiving property. Wind turbines, as a source, would fall under neither Class A, residential, nor Class B, commercial; therefore they would be considered Class C. The hourly sound levels must not exceed the listed measures anywhere within the property line of the neighbouring property. However, it is also mentioned that local governments should adopt their own noise policies. Chapter 173-58 WAC details the proper sound level measurement procedures to follow.

3.2.8 Michigan - Michigan Wind Energy System Siting Guidelines Draft #8 (Reference R9)

The Michigan wind energy draft is meant to apply to smaller local governments and non-urban areas that do not have other existing guidelines in place. There are different guidelines for small, on-site use wind turbines, and larger developments meant for grid energy use.

The Michigan guideline considers the measure of the ambient sound level to be L_{90} and it is assumed to be less than 55 dBA in most cases. The guidelines state that the sound level generated by the turbines should not exceed 55dBA at any property line, unless with written consent. This level is similar to the one developed by the State of Pennsylvania (see above). During any one hour, this is not to be exceeded for more than three (3) minutes. Should the ambient sound level be greater than 55dBA, then the sound level limit is L_{90} + 5dBA, L_{90} as the measured ambient sound level. For demonstration of the compliance to these limits, a submission following IEC 61400 and ISO 9613 methods must be completed for project approval, and within 60 days of the project's completion, the levels must be verified to ANSI S12.18 by a professional third party. The State of Michigan is the only other jurisdiction among those reviewed that requires submission of noise impact according to ISO 9613 like the Ontario MOE requirements. However, the noise level limits are much higher than the MOE limits.

3.2.9 Maine - Chapter 375 No Adverse Environmental Effect Standard of the Site Location Law
(Reference R10)

This is another example of a state that has written a standard for use where local governments have not written their own. Local standards take precedence over the state limits unless they contain values over 5 dBA higher for the same situation. As with the Washington sound level limits, the noise limits within this document apply to all environmental noise, including wind turbines, resulting in much higher values. The noise limits apply to new and expanding developments and are measured at the property line, but no specific information is provided on how the sound levels from wind farms are to be modeled. The limits vary based on the zoning of the receiving property or the ambient sound level, and are different for day and night. The noise limits are summarized in the Table 3.6.

Table 3.6 Regulations in Maine

Receiving Property	Daytime Sound Level Limit (7am – 7pm)	Nighttime Sound Level Limit (7pm – 7am)
Any location that is not zoned for commercial, transportation or industrial	60 dBA	50 dBA
Any location that is zoned for commercial, transportation or industrial	70 dBA	60 dBA

These limits apply unless the ambient sound level prior to development is equal to or less than 45 dBA during the daytime hours and 35 dBA during the nighttime hours, such as in a rural environment. Should this be the case, the limits are required to be 55 dBA during the day and 45 dBA during the night; a 10dBA increase, regardless of the zoning of the receiving property. There are two methods allowed to demonstrate the level of the ambient sound, by performing measurements, or, if the population within a 3000 m radius of the property is greater than 300 people, the state allows the assumption that the ambient level exceeds 45 dBA during the day and 35 dBA at night. Additionally, if it can be proven that the development will not emit sound levels greater than 50 dBA during the day and 40 dBA during the night, there is no requirement to estimate or measure the sound levels.

There are further requirements for short duration repetitive sounds and tonal sounds. There are also regulations on the personnel carrying out the measurements, the instrumentation and calibration necessary, and the location, configuration and environment conditions for the microphones, but not necessarily in the specific case of applying the measurements to wind farms.

3.2.10 New York - Power Naturally: Examples of NY Local Government Laws/ Zoning Provisions on Wind
(Reference R11)

The state of New York does not have a standard for wind turbine noise, but relies on local governments to develop their own, which many have. The town of Clinton, NY, is one such municipality, and is a good indication of what the standards in New York State are like. The limit, which applies at any time of the day, is $L_{10} \leq 50$dBA, meaning that in any one hour, 50 dBA can be equaled or exceed only ten percent of the time. The sound level is measured at the nearest residence, located off-site, which may or may not include more than one property. If the owner consents to a higher threshold of noise, a waiver can be granted allowing an increase to the noise level limit. If the ambient sound, which is defined as the highest whole number in dBA exceeded for more than 5 minutes per hour, is greater than 50 dBA, then the sound level limit is the ambient sound level plus 5dBA. These levels are higher than the MOE limits, but remain just below the level of moderate annoyance for outdoor noise of 50dBA listed in the WHO Community Noise document.

3.3 NOISE LIMITS FROM EUROPE

Europe has long been at the forefront of developing and utilizing wind energy as an energy source. It is not surprising that they have been able to develop noise limit standards to a higher degree than North America. It does not mean that they are more complicated; in fact, they are often simpler than North American noise limits. The following are some examples of noise level limits of wind farms from European countries.

3.3.1 UK - ETSU-R-97: The Assessment and Rating of Noise from Wind Farms (Reference R12)

The document produced by the Working Group on Noise from Wind Farms is perhaps the most comprehensive document of all the ones reviewed here. It covers the history and philosophy of developing noise limits, as well as a thorough explanation of the current limits. The document regulates a separate limit for daytime and nighttime noise levels. These are in part based on the background noise level, $L_{A90,\ 10min}$, which is determined by continuous monitoring of ten minute intervals over a period of time, correlated with different average wind speeds measured over the same period. There is no distinction between zoning or the use of the receiving property as in the Ontario MOE limits.

The principle of the limits is that the wind farm noise is limited to 5 dBA above the wind dependent background noise level, subject to a minimum value at low wind speeds. During the daytime, this minimum value in low noise environments is not to be lower than a range between 35 dBA and 40 dBA, depending on the number of dwellings and the effect on the amount of energy produced. At night, this minimum value is 43dBA. Both of these limits are recommended to be increased to 45 dBA in cases where there is financial benefit to those involved. As with other standards, a 5 dB penalty is incurred if tonal characteristics occur. Should this appear to be the case, a tonal assessment must be performed, consisting of 2 minute measurements. The document does not require an impact assessment of the development to be submitted.

3.3.2 Ireland - Wind Energy Development Guidelines
(Reference R13)

Ireland has adopted noise limits that are similar to the UK limits for wind turbines. The daytime limit is allowed to be the maximum of 45 dBA or 5 dBA above the background level, L_{90}. However, if the current level of background noise is very low, below 30dBA, the noise level limit will fall in the range of 35 dBA to 40 dBA. The standard does not state how this limit will be determined. The nighttime limit is fixed at 43dBA. These noise levels are comparable to the Ontario MOE limits. The Irish Guidelines have no set-back limits. Instead it states and we quote, "In general noise is unlikely to be a significant problem where the distance from the nearest turbine to any noise sensitive property is more than 500 m." [Reference R13). The document has stated that in order to determine the ambient sound level, measurements should be taken at ten minute intervals, however, it has not dictated how the wind farm noise level should be predicted or what steps to determine the impact of the wind farm should be taken.

3.3.3 Denmark - Document: Statutory Order From the Ministry of the Environment No. 304 of May 14, 1991, On Noise From Windmills
(Reference R14)

Denmark's noise limits are fixed, ambient conditions having no effect, and apply to both daytime and nighttime with no distinction. This is in contrast to the MOE limits, which may depend on both the wind speed and the hourly background level; however, the actual sound level limits have a direct comparison to Ontario's. When the wind farm is located in the open country, the outdoor sound level limit is 45 dBA at the nearest neighbouring property, considered to be any residential building other than the "private house of the windmill owner". For wind farms closer to residential areas, the fixed limit is 40 dBA.

3.3.4 Germany - Document: Lärm (Techniche Anleitung Lärm, Germany), 1998
(Reference R15)

The German noise limits are defined in the above document and are outlined in Table 3.7 below.

Table 3.7. German Noise Regulations.

Area	Day Time	Night Time
Industrial Area	70 dBA / 65 dBA	70 dBA / 50 dBA
Mixed residential area and industry or Residential areas mixed with industry	60 dBA	45 dBA
Purely residential areas with no commercial developments	55 dBA / 50 dBA	40 dBA / 35 dBA
Areas with hospitals, health resorts etc.	45 dBA	35 dBA

Calculation of sound propagation is done according to ISO 9613-2. All calculations have to be done with a reference speed of 10 m/s at 10 m heights.

3.3.5 *Netherlands: Bseluit van 18 oktober 2001, houdende regels voor voorziengen en installaties; Besluit voorziengen en installaties milieubeheer; Staatsblad van het Koninkrijk der Nederlanden 487*
(Reference R16)

Noise regulations specific to wind turbines in the Netherlands were issued in 2001, but are currently under review by the Dutch authorities. The 2001 wind farm noise limits followed a wind speed dependent curve and are shown in Table 3.3.2 for night time noise limits. The limit for day time started at 50 dBA and for evening hours, the limit started at 45 dBA and increased to 50 dBA for a speed of 12 m/s.

Table 3.8. 2001 Netherlands Noise Assessment Limits – Night time.

Wind Speed at 10 m height (m/s)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Wind Turbine Noise Criterion, dBA	40	40	41	41	42	42	43	44	46	47	48	50

As noted above, the 2001 assessment process is currently under review. In the interim, the Dutch authorities use their established general limits, not specific to wind turbines, of 40 dBA (night), 45 dBA (evening) and 50 dBA (day).

3.4 WIND FARM NOISE LIMITS FROM AUSTRALIA AND NEW ZEALAND

The wind farm noise limits of these two countries relate more to those of the European countries rather than North America. They require extensive data collection for the determination of ambient sound levels, and the sound level limits themselves are among the lowest, being developed in accordance with the World Health Organization document Guidelines for Community Noise. The standards as written are much more detailed in their requirements, and thus are of great value when reviewing noise standards for wind farms.

3.4.1 Australia - Planning Bulletin 67: Guidelines for Wind Farm Development and Environmental Noise Guidelines: Wind Farms
(References R17 and R18)

There are documents from both Western and Southern Australia; however, there is only one set of noise limits since the Western Australia guidelines reference the South Australian noise limits. The South Australian guidelines have elected to define fixed limits that must be followed, and are among the strictest that are reviewed here. The limit during the daytime is 35 dBA or the background noise plus 5 dBA, $L_{A90,\,10}$ + 5 dBA. The other jurisdiction that has a comparable noise level limit is the American state of Oregon. Both Australia and Oregon have limits that are more strict than Ontario. In order to determine the ambient levels, extensive data collection of noise levels over continuous 10-minute intervals must be examined according to a regression analysis. Wind speeds must be measured at 10m above the ground and also analyzed over the same periods. In order to determine the sound level limit compliance, the sound is measured not at the property line, but at a distance of up to 20 m away from the nearest house. In addition, demonstration is required that shows the operational sound levels do not exceed the predetermined limits or else restrictive measures may be taken to limit the operation of the wind farm.

3.4.2 New Zealand - NZS 6808: 1998: Acoustics – The Assessment and Measurement of Sound From Wind Turbine Generators
(Reference R19)

New Zealand also has a fixed sound level limit, as with other countries. At any residential home, the sound level limit outside of the house must not exceed 40 dBA. This limit has been selected to achieve an indoor sound level that corresponds to the values recommended in the WHO Guidelines for Community noise. If the background noise, L_{95}, exceeds 35 dBA, then the sound level limit is permitted to be L_{95} + 5 dBA. These levels are higher than the strict limits of Australia and Oregon, and are comparable to the Ontario and Danish sound level limits. This limit is to apply at the property line of the nearest residential property, or the "notional boundary" if the dwelling is located on a large rural property. The standard allows the sound levels from the wind farm development to be estimated using the sound power levels supplied by the manufacturer, but for determination of the ambient sound levels, extensive data collection over a period of ten to fourteen days is required. Post-installation verification is not always required by the standard.

3.5 DISCUSSION

The assessment of wind farm noise and their impact on sensitive receptor locations as applied in different jurisdictions were described above. The main differences between the different regulations and guidelines are twofold:

a) The acceptable noise limits; and
b) The evaluation of receptor noise levels from the cumulative operation of the turbines in the wind farm.

The commonality among the regulations and guidelines is quite striking. All of them accept the IEC Standard 61400-11 (Reference 26) procedures to establish the sound power levels of wind turbines as well as the determination of the hub-height and/or the 10 m high wind speeds within the operating range of the wind turbines. In addition, none of them consider the effect of atmospheric classes on night time operational character of the wind farm such as higher-than-expected wind speeds at hub-height compared to the conventional wind-shear prediction methodologies.

It is seen therefore, that the main difference between the regulations and guidelines is the noise limits and hence a comparison table is given below in Table 3.8 below. Table 3.8 summarizes only the night time noise limits. Note that direct comparisons of limits may not be appropriate as different jurisdictions have different legal, procedural and assessment frameworks.

Table 3.8. Approximate Ranking of Noise Regulations (Night time limit, dBA).

Jurisdiction	Noise Limit, dBA
Australia	35 and adjusted higher with wind speeds
Germany and Oregon, USA	35 to 36
Alberta, British Columbia, Quebec, Denmark, and Netherlands (Interim)	40
United Kingdom, Ireland, Ontario and New Zealand	40 and adjusted higher with wind speeds
New York, Maine, Pennsylvania and Washington, USA	50 and higher

3.6 SUMMARY

Regulations and guidelines from different jurisdictions in North America, Europe and Australasia were highlighted in this section. These are some of the examples of different assessments of noise impact from wind turbines and wind farms. It was shown that some jurisdictions have special legislation concerning wind turbines, while others apply general recommendations. Different descriptors such as L_{Aeq} or $L_{A90,\ 10\ min.}$ were used to quantify wind turbine noise levels. The noise levels could be either absolute values or related to the background noise level. The background noise levels could be standardised, measured or related to ambient wind speeds. The review of the regulations and guidelines of the jurisdictions investigated showed that the Ontario, Canada assessment process is similar to other jurisdictions.

4.0 REVIEW OF AVAILABLE LITERATURE

A substantial portion of information, both scientific and non-scientific is available in the open literature. The literature review focussed mainly on the following:

I) Metrological effects on wind turbine noise generation;
II) Assessment procedures of wind turbine noise levels and their impact;
III) Particular characteristics of wind farm noise; and
IV) Human responses to wind farm noise levels.

NOTE: The literature review did not consider material that was available after June 2007.

The exact noise generation mechanisms of wind turbines and control techniques of wind farm and turbine noise were not reviewed by the current investigations. Relevant databases such as journals through ScholarsPortal, internet and conference proceedings were searched for the literature. Proceedings from a few conferences were searched also. It must be pointed out that conference papers are usually accepted without proper peer-reviews. Only a few articles were available and are listed in the main reference list. The results of the review are summarized below.

4.1 METEOROLOGICAL EFFECTS

The paper by P. Botha of New Zealand has shown the effects of weather conditions on wind speed profiles with height (Reference 22). This is the only paper, to our knowledge, that has scientifically shown variation of wind speeds with heights from measurements conducted at four sites – two (2) in New Zealand and two (2) in Australia. The measurements were conducted for a period of one year. The two Australian sites (Sites 1 and 2) were flat terrain and the two New Zealand sites (Sites 3 and 4) were complex terrain. Wind speeds were collected in 10 minutes intervals and the composite results from Reference 22 are reproduced below as Figure 6.1.

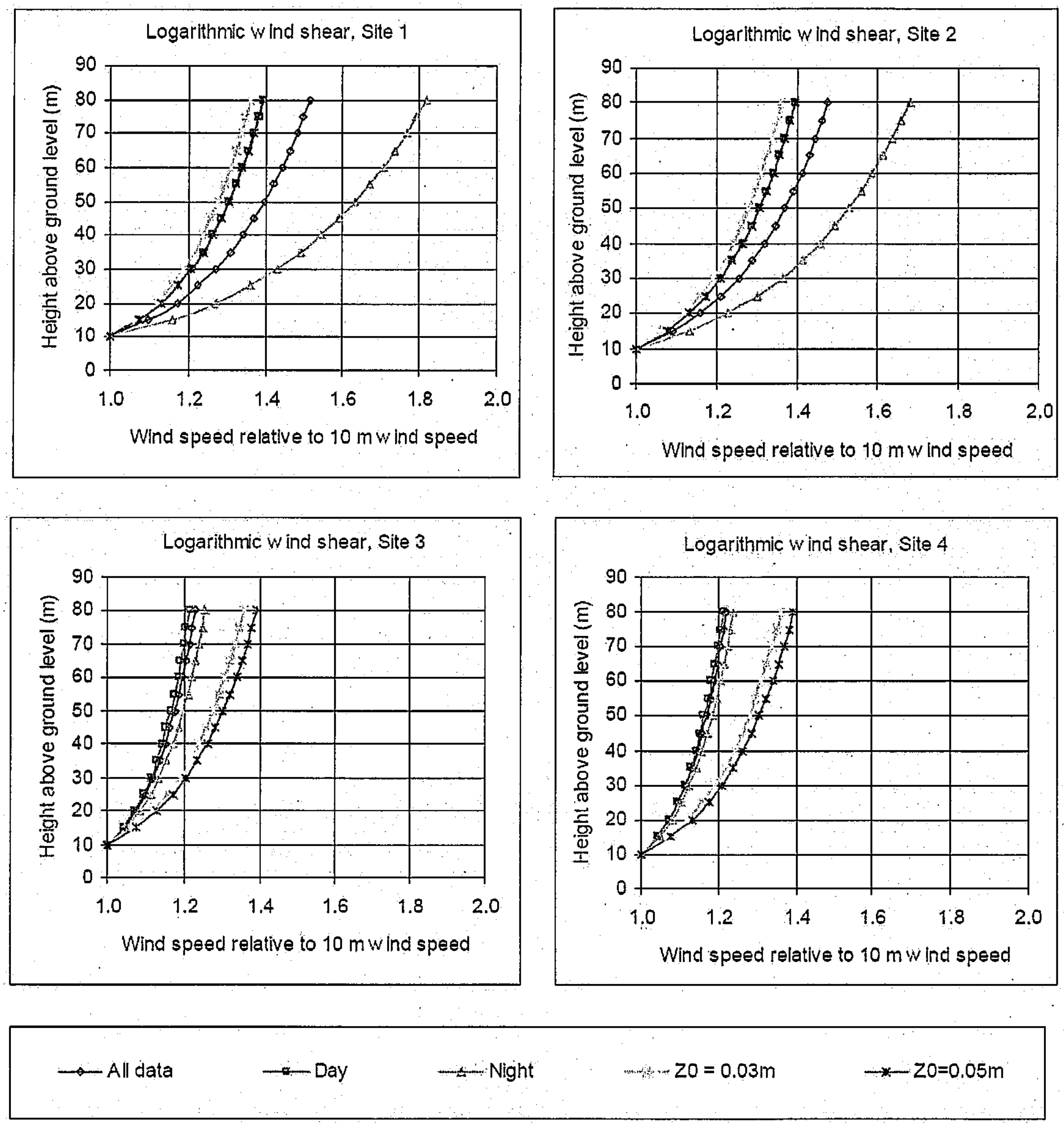


Figure 4.1. Wind speed profiles at 4 different sites

(From Reference 22 – Figure 1)

Five graphs were plotted for each site: Composite profile for all day data, profile for day data, profile for night data, IEC standard logarithmic profile with the shear coefficient from observed site conditions (Z_0 = 0.03) as well as the standard shear coefficient, Z_0, of 0.05. The results do indicate that for some terrains, the hub-height wind speeds can be more at night time than during day time when compared to the 10 m height wind speeds. However, the local conditions determine the meteorology and one cannot, as analysed by van den Berg, apply information from far-off sites to local conditions. Further, for the terrains in Australia, the Sound Power Levels at night time would be around 2 dBA more than predicted from standard procedures from day time profiles. It must also be highlighted that the measurements of Reference 22 clearly showed the wind profiles were nearly identical between day and night time for the complex terrains of New Zealand.

The main conclusions of this section are: a) wind shear is an important parameter that must be accounted for appropriately in any assessment; and b) the effect of meteorology is highly localized and strong conclusions cannot be easily transferred from site to site.

4.2 ASSESSMENT PROCEDURES OF WIND TURBINE NOISE LEVELS

Papers by Botha (Reference 22), Sloth (Reference 23) and Sondergaard (Reference 24) are examples of work undertaken to look into the assessment procedures currently applied in many jurisdictions. These three papers evaluate the application of sound power levels of wind turbines standardized to a 10 m height wind speed. The main conclusion of these papers is that the normal procedure of basing the analysis and assessment on the standardized sound power levels is not sufficient. Sloth shows a method to incorporate the relevant sound immission data with appropriate uncertainties accounted for so as to minimize noise annoyance. One such method is suggested in Appendix F. Sonderggard has also pointed out that additional research is required to account for many of these deficiencies. References 27 and 28 showed that many of the propagation models have uncertainties associated with them and can produce "less than accurate" results if local weather conditions are not properly modelled.

One of the main criticisms about noise assessment process of wind farm application is that the sound power levels of wind turbines are measured and reported following the procedures of the IEC-Standard [Reference 26]. It must be noted that the IEC 61400-11 standard for wind turbine noise is a measurement standard and is primarily intended to define how manufacturers obtain and report the sound power from wind turbines under standardized wind shear conditions. It does not prevent one from adjusting the sound power to reflect the actual site specific wind shears obtained from testing.

4.3 PARTICULAR CHARACTERISTICS OF WIND FARM NOISE

Two main issues are usually discussed regarding the source characteristics of noise generated by wind turbines – low frequency or infra sound and the swishing (thumping) sound normally termed as the amplitude modulation phenomenon.

The measurement results from wind turbines, such as the data reported by van den Berg (Reference 1) and Howe and McCabe (Reference 28) show the absence of significant low frequency components and the same conclusion is highlighted by Regan and Casey ((Reference 25) in their primer on wind turbine noise aspects. The results of Reference 1 (van den Berg's dissertation) show that the infra-sound levels, even if present, are well below the threshold of perception.

The nature of the amplitude modulation phenomenon and its relationship to the acoustical *beating* phenomenon was already discussed in Section 2.4. The different principles of these phenomena will not be discussed further. Due to the nature of the amplitude modulation phenomenon, the swishing or thumping exists all the time. Only van den Berg has attempted to show that the modulation gets stronger at night time. Our review of van den Berg's work was presented in Section 2. We were unable to find other works in the literature that provide evidence for increased modulation at night time. The only effect, discussed in the next section, of the phenomenon is the modulated sound becomes audible at night time. This could be due to quieter ambient sound at night time. As Reference 18 states, "In summary, the modulation in the noise from wind turbines is not yet fully explained and will not be reduced in the near future and is therefore a factor of importance when discussing noise annoyance from wind turbines."

Reference 30 has addressed the issues connected with modulation. One of its principal findings is and we quote, "the common cause of complaint was not associated with low-frequency noise, but the occasional audible modulation of aerodynamic noise, especially at night. Data collected showed that the internal noise levels were insufficient to wake up residents at these three sites. However, once awoken, this noise can result in difficulties in returning to sleep." Reference 30 does not use the term "beating" to describe the amplitude modulation that has been observed as well as measured. It has been referred to simply as "aerodynamic modulation." Reference 30 also points out that the many mechanisms hypothesized by van den Berg (Reference 1) for the modulation behaviour are debatable. It was shown in Section 2 during the current investigation that the data provided by Reference 1 do not support its findings. Further, no support was seen for the modulation behaviour to get stronger under stable atmospheric classes at night time as postulated by van den Berg. The same points were presented in Section 2 of this report. Finally, Reference 30 discussed the many possible mechanisms that can cause the amplitude modulation as well as provided measurement results to show that modulation can produce changes in noise levels of the order of 10 dB. It concluded that detailed research is required to settle many of the unknowns that can cause the amplitude modulation.

4.4 Human Responses to Wind Farm Noise Levels

A considerable body of literature is available on this subject, both scientific and anecdotal. Only a few of the scientific and review articles, References 5, 12, 18, 20, and 25, are highlighted in the current study.

According to Reference 25, the only health effect of wind turbine noise is annoyance. Sheppard et al. (Reference 12) conducted a laboratory study with unbiased subjects and played different sounds including wind turbine noise at various levels. Since the study was conducted in early 80s, the old type wind turbines were included in their investigations. Their study developed a human response criterion for wind turbine generators based on receptor received noise levels and termed it 'Perception Detection Threshold.' The study showed that the thresholds for wind turbine noise were below the thresholds of general tones. After validating the usefulness of the response function, the following annoyance table, based on an old ISO standard, now defunct, was recommended to evaluate the community response. The annoyance table is presented in Table 4.1 below.

Table 4.1 Estimated Community Response to Wind Turbine Generator Noise

(From Reference 12 –Figure 12 of Reference 12, based on an ISO standard)

Amount in dB by which the rated noise exceeds Threshold Level	Estimated Community Response	
	Category	Description
0	None	No Observed Reaction
5	Little	Sporadic Complaints
10	Medium	Widespread Complaints
15	Strong	Threats of Community Action
20	Very Strong	Vigorous Community Action

NOTE: **Rated Noise Level** – The actual noise level that would be measured at the receptor locations;
Threshold Level – The average ambient sound level that would exist in areas around the wind farm site.

A study, similar to that of Sheppard (Reference 12) is required to evaluate the detection threshold for modern wind turbines.

The annoyance study of Pedersen and Waye concluded that annoyance increases with sound levels. However, these annoyance studies have very small sample sizes and focussed on subjects living close to wind farms. No blind survey was conducted. Only 65 of the 356 respondents were exposed to noise levels of 37.5 dBA and above. The following categories – perception, dose-annoyance, sensitivity, attitude to source, visual exposure and rural setting – were included in the survey. The correlation between most of the categories and noise levels were small. The noise level and annoyance response was proportional to the exposure level. However, the sample size was too small. The subjects had prior exposure to wind turbines, making the sample biased. It must be acknowledged that the research of Pedersen and Waye has provided important insights into the human response of wind turbine noise and has considered important parameters.

However, the work of Pedersen and Waye need to be expanded to include large enough samples with unbiased subjects.

Finally, one of the arguments presented by anti-wind farm proponents is that 'beating' increases human annoyance. The only result that can be culled from the literature, Reference 18, is that the modulation frequencies, 0.5 to 1 Hz for wind turbines, are such that the wind turbine noise can be detected. Since major studies on wind turbine beating and human annoyance have not been conducted, major conclusions are not possible at this stage.

4.5 SUMMARY

Available literature on wind turbine noise was reviewed and the review focussed on four categories, considered important to the Ministry's stated goals. The results of the review were presented in this section. The main findings of this section are:

A) The local terrain conditions can influence meteorological conditions and can affect the expected noise output of the wind turbines;

B) Assessment procedures applied in different jurisdictions are quite similar in their scope;

C) Wind farm noise do not have significant low-frequency (infrasound) components;

D) Further study needed in order to determine effect of modulation on human annoyance.

5.0 REVIEW OF MOE'S NOISE POLICIES AS APPLIED TO WIND FARM NOISE

The Ministry of the Environment released a guideline document, "Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators" in 2004. The above guidance document was to assist proponents of wind turbine installations in determining the list of necessary information to be submitted when applying for a Certificate of Approval (Air and Noise) under Section 9 of the *Environmental Protection Act*. A summary of these interpretations by John Kowalewski was also published in the Canadian Acoustics Journal (Reference 33). The noise guidelines in MOE publications NPC-205/NPC-232 as well as the wind generated noise levels were applied to set the noise limits. These three documents are enclosed in Appendices A, B and C.

5.1 MOE'S ASSESSMENT PROCESS

The assessment procedures of MOE are summarized below for completeness sake:

I) All wind farm applications must obtain a Certificate of Approval from MOE. If individual wind turbines have a capacity of 2 MW or more, the project must undergo an Environmental assessment review;

II) If there are no receptors within 1000 m of the wind farm boundary, no detailed noise assessment is necessary;

III) The noise limits are established based on the location of the receptors in Class 1 & 2 areas and Class 3 areas.

IV) The sound power levels of the wind turbines are to be obtained from the standard procedures contained in IEC Standard 61400-11, by applying the wind speeds at 10 m height above ground. [Reference 26].

V) The sound pressure levels at each receptor location are to be evaluated applying the procedures of ISO 9613.

VI) The noise impact is assessed by comparing the predicted noise levels at individual receptor location with the noise limits established in Step III. The noise impact is evaluated at each wind speed over the operating range of the wind turbine specifications.

The noise limits are wind speed dependent and are summarized in Table 5.1 below.

Table 5.1 Ontario Noise Assessment Limits

Wind Speed (m/s) @ 10 m height	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Wind Turbine Noise Criterion NPC-232 (dBA) (Rural) – Class 3 Areas	40	40	40	43	45	49	51	53
Wind Turbine Noise Criterion NPC-205 (dBA) (Urban) – Class 1 & 2 Areas	45	45	45	45	45	49	51	53

The MOE procedures outlined in Appendix A do not explicitly discuss the application of penalties for source character or apply particular meteorological conditions.

The MOE's assessment process is very similar to the procedures applied in the New Zealand (Reference R19), as it recognizes the usefulness of masking effects of ambient wind. The implicit assumption is that it is the ambient wind that generates the noise of wind turbines as well as background noise levels at receptor locations.

The Ministry's noise assessment guidelines for stationary sources of sound are based on the premise that noise from the stationary sources may be annoying when it is audible over and above the level of the so-called "ambient" or surrounding environmental "noise climate" at a particular location. However, audibility does not necessarily mean annoyance. Furthermore, annoyance is not the same for the entire population; people at the extreme of the statistical distribution may be annoyed at different noise levels. Such an approach was considered a 'sound' policy from the inception of the Model Municipal Noise Control by-Law issued by MOE in August 1978. The policies provide adequate protection from adverse noise pollution impacts as well as not imposing restrictive conditions on industrial noise sources. However, the MOE's assessment, even though has provided a very simple procedure, has been very general in its overall scope. Two issues need to be resolved and are highlighted below.

5.2 PENALTY FOR SOURCE CHARACTER

The guideline document that deals with noise assessment of wind turbines, enclosed in Appendix A, does not explicitly discuss penalties for characters such as tonal components of the wind turbine noise levels, even though reference to NPC-104 is included in the interpretation document. Further, the Ministry document, NPC-205 (enclosed in Appendix C) contains guidelines for penalties, which must be used if a particular wind turbine was found to contain tonal components. The implicit assumption is that the modern up-wind wind turbines have no dominant tones in their spectrum. It must be pointed out that most of the measurement results do show that the turbine noise spectrum is devoid of dominant tones. However, MOE needs to clarify and include source character adjustments in the main body of the interpretation document and even make references to the procedures contained in the IEC Standard (Reference 26) that are used to determine the presence of tones in the noise spectrum.

5.3 METEOROLOGICAL CONDITIONS

One of the main arguments posed by van den Berg (Section 2) is that meteorological condition affect wind speed profiles with height and that the hub-height wind speed may be higher than predicted with the 10 m high wind speed being low. It was made clear in the review presented in Section 2 that the evidence presented to support these arguments were tenuous at best. However, the works of Botha (Reference 22) and Sondergaard (Reference 24) showed that local terrain conditions can dictate the wind profiles and the measurements of Reference 22 has shown that in flat terrains, the wind speed profile with height cannot be predicted accurately by standard methods such as the logarithmic shear function applied in Reference 26.

It is therefore, possible that, for a 'worst-case scenario', the hub-height velocities can be higher than expected thereby resulting in higher-than-expected noise levels with lower masking effect of the ambient wind at receptor locations. Some preliminary evaluations presented in Reference

32 showed that discrepancies of the order of 3 dBA are possible. Such a scenario needs to be accounted for in the Ministry's future updates of the assessment procedures. One example of a possible assessment procedure is described in Appendix F.

5.4 SUMMARY

The assessment procedures, currently, applied in the Province of Ontario by the Ministry of the Environment to evaluate wind farm noise levels were reviewed. The results showed that the procedures may have to be revised to incorporate additional factors. One possible assessment process is suggested Appendix F.

6.0 CONCLUSIONS

As part of the review process of their assessment procedures, the Ministry of the Environment for the Province of Ontario has instituted a work project with different tasks. Four individual tasks were part of the review process.

The results of each of the tasks were presented in the previous sections. The conclusions for each of the tasks were included at the end of the relevant sections. The basic conclusions are summarized below:

A) The research work undertaken by G. P. van den Berg didn't provide scientific evidence to support the few major hypotheses postulated concerning the wind turbine noise characteristics. However, the work of other researchers showed that local terrain conditions can impact the local meteorology and thereby the resulting noise levels;

B) Assessment procedures applied in different jurisdictions showed the current Ministry of the Environment process is similar to other jurisdiction. Further, the MOE process has provided a balanced approach between noise impact and the need for wind farms, based on currently available scientific data.

C) Literature review showed that additional research is still required to make definitive conclusions about wind turbine noise impacts as well as human response to wind farms. In addition, detailed research on meteorological conditions, and their impact on sound generation needs to be undertaken to realise definitive conclusions;

D) The Ministry of the Environment's procedures to assess wind farm noise levels follow a simple procedure that is sound for most situations. However, additional concerns still need to be addressed in the next round of revisions to their assessment process. These revisions may need to be addressed after the results from future research provide scientifically consistent data for effects such as meteorology, human response and turbine noise source character.

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APPENDIX A

INTERPRETATION FOR APPLYING MOE NPC TECHNICAL PUBLICATIONS TO WIND TURBINE GENERATORS

INTERPRETATION FOR APPLYING MOE NPC TECHNICAL PUBLICATIONS TO WIND TURBINE GENERATORS

Noise impacts of proposed wind turbine generators, i.e. wind turbines, are considered in the course of assessing an application for a Certificate of Approval (Air), in accordance with Section 9 of the Environmental Protection Act. The purpose of this guidance document is to assist proponents of wind turbine installations in determining what information should be submitted when applying for a Certificate of Approval (Air). It has been developed in order to provide consistency in the submissions and to streamline the review and approval process.

As a minimum, the information package must include details of the wind turbine design and operation, location of the wind turbine within the specific site and surrounding area as well as summary of compliance applicable to noise. The following defines a template for reports to be submitted to the MOE. This information is supplementary to the information in MOE Publication NPC-233, Information to be Submitted for Approval of Stationary Sources of Sound.

REFERENCES

[1] NPC-102 - Instrumentation
[2] NPC-103 - Procedures
[3] NPC-104 - Sound Level Adjustments
[4] NPC-205 - Sound Level Limits for Stationary Sources in Class 1 & 2 Areas (Urban)
[5] NPC-206 - Sound Levels due to Road Traffic
[6] NPC-232 - Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)
[7] NPC-233 - Information to be Submitted for Approval of Stationary Sources of Sound
[8] IEC 61400-11 - "Wind turbine generator systems - Part 11: Acoustic noise measurement techniques - International Restrictions", Dec. 2002
[9] ISO 9613-2 - "Acoustics-Attenuation of sound during propagation outdoors - Part 2: General method of calculation", Dec. 1996
[10] ETSU-R-97 - "The Assessment and Rating of Noise from Wind Farms", Final Report, September 1996

TECHNICAL DEFINITIONS

"Class 1 Area"
: means an area with an acoustical environment typical of a major population centre, where the background noise is dominated by the urban hum.

"Class 2 Area"
: means an area with an acoustical environment that has qualities representative of both Class 1 and Class 3 Areas, and in which a low ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realized as early as 19:00 hours.

Other characteristics which may indicate the presence of a Class 2 Area include:

i. absence of urban hum between 19:00 and 23:00 hours;
ii. evening background sound level defined by natural environment and infrequent human activity; and
iii. no clearly audible sound from stationary sources other than from those under consideration.

"Class 3 Area"
means a rural area with an acoustical environment that is dominated by natural sounds having little or no road traffic, such as the following:

i. a small community with less than 1000 population;
ii. agricultural area;
iii. a rural recreational area such as a cottage or a resort area; or a wilderness area.

Point of Reception

"Point of Reception" means any point on the premises of a person within 30 m of a dwelling or a camping area, where sound or vibration originating from other than those premises is received.

For the purpose of approval of new sources, including verifying compliance with Section 9 of the Act, the Point of Reception may be located on any of the following existing or zoned for future use premises: permanent or seasonal residences, hotels/motels, nursing/retirement homes, rental residences, hospitals, camp grounds, and noise sensitive buildings such as schools and places of worship.

For equipment/facilities proposed on premises such as nursing/retirement homes, rental residences, hospitals, and schools, the Point of Reception may be located on the same premises.

NOISE LIMITS

The noise limits for a wind turbine or an array of such units (referred to as a "wind farm") are set relative to the existing MOE Noise Guidelines in NPC-205/NPC-232 as well as to the wind generated background noise. The proponents are required to demonstrate compliance with the following sound level limits:

Wind turbine installations in Class 1 & 2 Areas (Urban)
Wind speeds below 8 m/s

The lowest sound level limit at a Point of Reception in Class 1 & 2 Areas (Urban), under conditions of average wind speed up to 8 m/s (29 km/h), expressed in terms of the hourly equivalent sound level (Leq) is 45 dBA or the minimum hourly background sound level established in accordance with requirements in Publications NPC-205/NPC-233, whichever is higher.

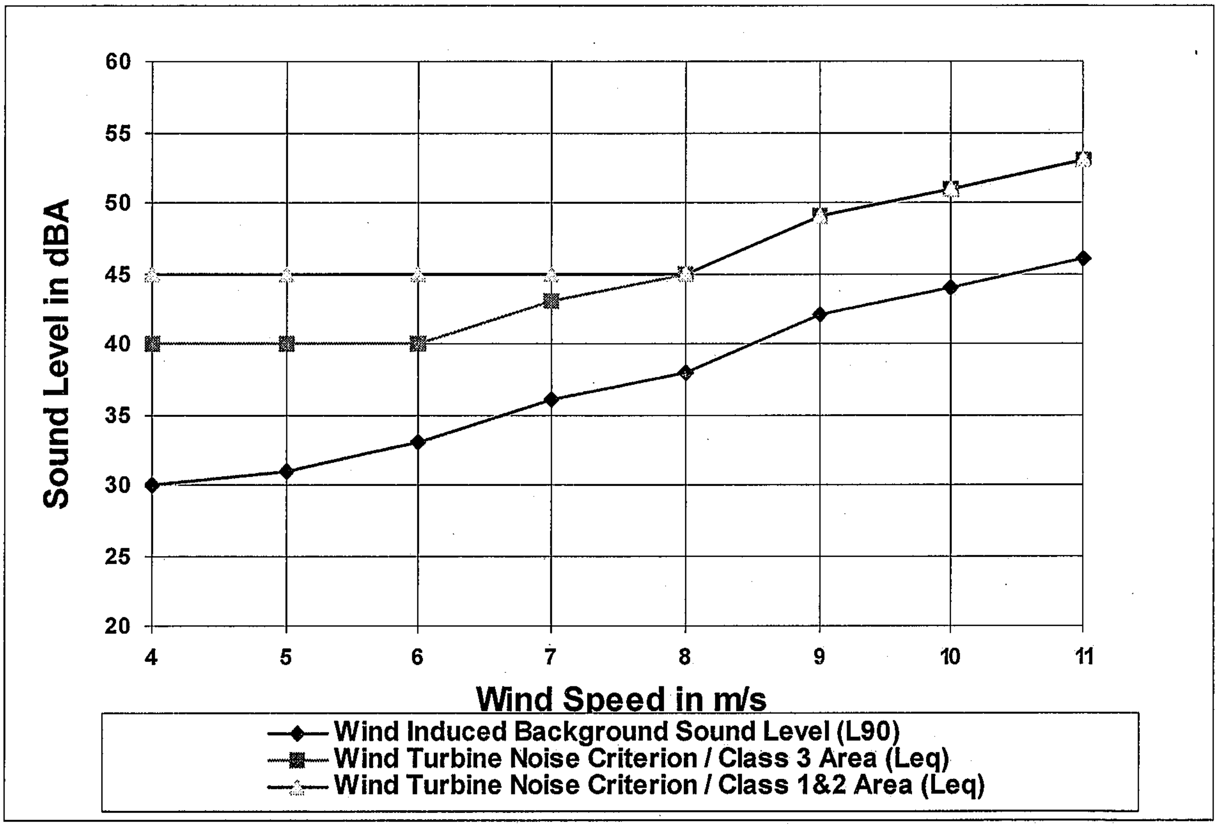
Wind Turbine Installations in Class 3 Areas (Rural)
Wind speeds below 6 m/s

The lowest sound level limit at a Point of Reception in Class 3 Areas (Rural), under conditions of average wind speed up to 6 m/s (22 km/h), expressed in terms of the hourly equivalent energy sound level (Leq) is 40 dBA or the minimum hourly background sound level established in accordance with requirements in Publications NPC-232/NPC-233, whichever is higher.

Wind Turbine Installations in Class 1& 2 and Class 3 Areas
Wind speeds above 8 and 6 m/s respectively

The sound level limit at a Point of Reception in Class Areas 1 & 2 (Urban) or in Class 3 Areas (Rural), under conditions of average wind speed above 8 m/s and 6 m/s respectively, expressed in terms of the hourly equivalent energy sound level (Leq), is the wind induced background sound level, expressed in terms of ninetieth percentile sound level (L_{A90}) plus 7 dB, or the minimum hourly background sound level established in accordance with requirements in Publications NPC-205/NPC-232/NPC-233, whichever is higher.

A summary of the above limits is shown in figure and table below.



Wind Speed (m/s)	4	5	6	7	8	9	10	11
Wind Turbine Noise Criterion NPC-232 (dBA)	40	40	40	43	45	49	51	53
Wind Turbine Noise Criterion NPC-205 (dBA)	45	45	45	45	45	49	51	53

NOTE:

1. The measurement of wind induced background sound level is not required to establish the applicable criterion. The wind induced background sound level reference curve in the figure above was determined by correlating the ninetieth percentile sound level (L_{A90}) with the average wind speed measured at a particularly quiet site.

2. If the existing minimum hourly background sound level, established in accordance with requirements in Publications NPC-205/NPC-232/NPC-233, is selected as the sound level limit, the measurement of wind speed (for the purpose of determination of wind induced background sound level) is not required. The selected limit applies in the entire range of wind speed under consideration from 4 m/s to 11 m/s with exception of the wind turbine noise criterion values higher than the existing minimum hourly background sound level.

3. Wind Turbine Noise Criterion at wind speeds expressed as fractional values of m/s should be interpolated from the above graph.

REPORT CONTENTS AND FORMAT

The noise report must contain the required information, organized in a clear and concise manner. The report should include the following sections in the given sequence:

1. **Introduction**
   Objectives of report
2. **General Description of Wind Turbine Installation Site and Surrounds**
   Description of the site general environment, including: adjacent zoning, sensitive receiver locations (Points of Reception); suitable mapping of the site and surrounding area, providing elevations of source receivers and intervening structures or topography where applicable to the assessment;
3. **Description of Receptors**
   Detailed acoustical description of the area surrounding the facility including: Identification of the closest and/or the critical Points of Reception, identifying noise sensitive residential or institutional uses - (industrial, commercial uses are also desirable information); Determination of the applicable minimum hourly background sound level limit at the critical Points of Reception, in accordance with NPC 205/232 and NPC-233;
4. **Description of Sources**
   Description of the wind turbine (wind farm) including: manufacturer & model number; Design principle & geometric configuration (horizontal, vertical, upwind, downwind, rotor diameter and centre height, blade type, number of blades, tower height); Power train (direct from rotor to generator, indirect through gearbox); Operating details (single, twin or variable speed, power curve, generator rated power output and rotational speed); Park lay-out (for a wind farm);
5. **Wind Turbine Noise Emission Rating**
   Noise emission levels in terms of sound power level of the wind turbine as a function of wind speed (determined in accordance with IEC 61400-11 method), provided by the wind turbine manufacturer;

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6. **Impact Assessment**
Calculation of the sound pressure level at each critical Point of Reception for each wind turbine or an aggregate of units (wind farm) using ISO 9613 method.
Noise impact assessment under a "worst case scenario" at the critical Points of Reception, up to a distance of 1000 m from the wind turbine (or closest unit in a wind farm); Impact assessment is not required for Points of Reception farther than 1000 m from the wind turbine (or closest unit in a wind farm);
Comparison with the applicable noise limit;
7. **Wind Turbine Summary Tables**
Wind Turbine Source Summary Table and Wind Turbine Assessment Summary Table; (samples attached);
8. **Conclusions and Recommendations**
Summary of impacts and verification of compliance with the noise limits;
9. **Appendices, etc.**
Details of measurements and calculations, specifications, plans, eng. dwgs, etc.

WIND TURBINE SUMMARY TABLES

The noise report must contain Wind Turbine Summary Tables, summarising the results of the Acoustical Report and demonstrating compliance. The Wind Turbine Summary Tables must address pertinent source(s) and receptors (Points of Reception).
The information in the Wind Turbine Summary Tables must be presented in two tables:

1. Wind Turbine Source Summary Table
2. Wind Turbine Assessment Summary Table

The following examples of summary tables must be incorporated into the report:

Wind Turbine Noise Emission Summary Table
(add rows for additional sources)

	Wind Turbine ID	Max PWL at wind speed <6 m/s	PWL at selected wind speed in m/s				
			7	8	9	10	11
1	WT6000	93	97	99	100	104	106
2							
3							

Note:
1. PWL denotes Sound Power Level in dB re 10^{-12} Watt
2. Noise emissions of a wind farm are represented by a sum of PWL values for individual wind turbine units.

Wind Turbine Noise Impact Assessment Summary Table

Identify all receptors (add rows for additional Points of Reception)

Point of Reception ID	Receptor Description	Distance to closest Wind Turbine (m)	Calculated Sound Pressure Level at Receptor (dBA) at selected Wind Speed in m/s						Sound Level Limit (dBA) at selected Wind Speed in m/s						Applicable Background Sound Level		Compliance with Limit (Yes/No)
			6 or <	7	8	9	10	11	6 or <	7	8	9	10	11	NPC 205	NPC 232	
R1	Residence to East	100	43	44	**<u>48</u>**	**<u>50</u>**	**<u>54</u>**	**<u>56</u>**	45	45	45	49	51	53	46		No
R2	Apt. Bldg. to South	150	40	42	45	47	51	**<u>53</u>**	45	45	45	49	51	53	51		No
R3	Nursing Home to West	200	37	39	42	44	48	50	45	45	45	49	51	53	47		Yes
R4	Residence to North	260	35	38	40	42	46	48	40	43	45	49	51	53		44	Yes

Note: Values in the table which are **<u>underlined/bold</u>** denote an excess over the applicable limit.

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APPENDIX B

NPC - 232 - SOUND LEVEL LIMITS FOR STATIONARY SOURCES IN CLASS 3 AREAS (RURAL)

SOUND LEVEL LIMITS FOR STATIONARY SOURCES IN CLASS 3 AREAS (RURAL)

PUBLICATION NPC-232

OCTOBER 1995

Ontario

Ministry
of the
Environment

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Ontario

MINISTRY OF THE ENVIRONMENT

Sound Level Limits for Stationary Sources in Class 3 Areas (Rural) Publication NPC-232

October 1995

This Publication establishes sound level limits for stationary sources such as industrial and commercial establishments or ancillary transportation facilities, affecting points of reception in Class 3 Areas (Rural). It replaces Publication NPC-132 "Guidelines for Noise Control in Rural Areas" of the "Model Municipal Noise Control By-Law, Final Report, August 1978".

TABLE OF CONTENTS

1. SCOPE

This Publication establishes sound level limits for stationary sources of sound such as industrial and commercial establishments or ancillary transportation facilities, affecting points of reception in Class 3 Areas (Rural). The limits apply to noise complaint investigations carried out in order to determine potential violation of Section 14 of the Environmental Protection Act. The limits also apply to the assessment of planned stationary sources of sound in compliance with Section 9 of the Environmental Protection Act, and under the provisions of the Aggregate Resources Act and the Environmental Assessment Act.

This Publication does not address sound and vibration produced by blasting; blasting in quarries and surface mines is considered in Reference [7].

The Publication includes an Annex, which provides additional details, definitions and rationale for the sound level limits.

2. REFERENCES

Reference is made to the following publications:

[1] NPC-101 - Technical Definitions

[2] NPC-102 - Instrumentation

[3] NPC-103 - Procedures

[4] NPC-104 - Sound Level Adjustments

[5] NPC-205 - Sound Level Limits for Stationary Sources in Class 1 & 2 Areas (Urban)

[6] NPC-206 - Sound Levels due to Road Traffic

[7] NPC-119 - Blasting

[8] NPC-216 - Residential Air Conditioning Devices

[10] NPC-233 - Information to be Submitted for Approval of Stationary Sources of Sound

[12] ORNAMENT, Ontario Road Noise Analysis Method for Environment and Transportation, Technical Document, Ontario Ministry of the Environment, ISBN 0-7729-6376, 1989

References [1] to [4] and [7] can be found in the
Model Municipal Noise Control By-Law, Ontario Ministry of the Environment, Final Report, August 1978.

2. DEFINITIONS

"Ambient sound level"
means Background sound level.

"Background sound level"
is the sound level that is present in the environment, produced by noise sources other than the source under impact assessment. Highly intrusive short duration noise caused by a source such as an aircraft fly-over or a train pass-by is excluded from the determination of the background sound level.

"Class 1 Area"
means an area with an acoustical environment typical of a major population centre, where the background noise is dominated by the urban hum.

"Class 2 Area"

means an area with an acoustical environment that has qualities representative of both Class 1 and Class 3 Areas, and in which a low ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realized as early as 19:00 hours.

Other characteristics which may indicate the presence of a Class 2 Area include:

- absence of urban hum between 19:00 and 23:00 hours;
- evening background sound level defined by natural environment and infrequent human activity; and
- no clearly audible sound from stationary sources other than from those under impact assessment.

"Class 3 Area"

means a rural area with an acoustical environment that is dominated by natural sounds having little or no road traffic, such as the following:

- a small community with less than 1000 population;
- agricultural area;
- a rural recreational area such as a cottage or a resort area; or
- a wilderness area.

Other technical terms are defined in Reference [1] and in the Annex to Publication NPC-232.

3. ESTABLISHMENT OF LIMITS - OBJECTIVE

The sound level limit at a point of reception must be established based on the principle of "predictable worst case" noise impact. In general, the limit is given by the background sound level at the point of reception. The sound level limit must represent the minimum background sound level that occurs or is likely to occur during the operation of the stationary source under impact assessment.

4. BACKGROUND SOUND LEVELS OF THE NATURAL ENVIRONMENT

The One Hour Equivalent Sound Level (L_{eq}) and/or the One Hour Ninetieth Percentile Sound Level (L_{90}) of the natural environment shall be obtained by measurement performed in accordance with Section 7. The results of the measurements must not be affected by the sound of the stationary source under impact assessment.

The time interval between the background sound level measurement and the measurement of the sound level produced by the stationary source under impact assessment should be minimized as much as possible. Preferably, the two measurements should be carried out within one hour of each other.

5. SOUND LEVELS DUE TO STATIONARY SOURCES

(1) Complaint Investigation of Stationary Sources

The One Hour Equivalent Sound Level (L_{eq}) and/or the Logarithmic Mean Impulse Sound Level (L_{LM}) produced by the stationary sources shall be obtained by measurement performed in accordance with Section 7.

(2) **Approval of Stationary Sources**
The One Hour Equivalent Sound Level (L_{eq}) and/or the Logarithmic Mean Impulse Sound Level (L_{LM}) produced by the stationary sources shall be obtained by measurement or prediction. The estimation of the L_{eq} and/or L_{LM} of the stationary source under impact assessment shall reflect the principle of "predictable worst case" noise impact. The "predictable worst case" noise impact occurs during the hour when the difference between the predicted sound level produced by the stationary source and the background sound level of the natural environment is at a maximum.

6. PROCEDURES

All sound level measurements of the One Hour Equivalent Sound Level (L_{eq}) and the Logarithmic Mean Impulse Sound Level (L_{LM}) shall be made in accordance with Reference [3].

All sound level measurements of the One Hour Ninetieth Percentile Sound Level (L_{90}) shall be made using a Sound Level Meter capable of measuring percentile sound levels. The meter shall meet the applicable requirements for an Integrating Sound Level Meter of Reference [2]. The measurements shall be carried out following procedures for the measurement of varying sound described in Reference [3].

Sound from existing adjacent stationary sources may be included in the determination of the background hourly sound levels L_{eq} and L_{90}, if such stationary sources are not under consideration for noise abatement by the Municipality or the Ministry of Environment and Energy.

7. SOUND LEVEL LIMITS - GENERAL

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source, the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}), is the lower of:

- the background One Hour Equivalent Sound Level (L_{eq}) obtained pursuant to Section 5; and
- the background One Hour Ninetieth Percentile Sound Level (L_{90}) plus 15 dB, i.e. L_{90} + 15 dB, obtained pursuant to Section 5.

(2) For sound from a stationary source, including Quasi-Steady Impulsive Sound but not including other impulsive sound, the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the One Hour Equivalent Sound Level (L_{eq}), is the lower of:

- the background One Hour Equivalent Sound Level (L_{eq}) obtained pursuant to Section 5; and
- the background One Hour Ninetieth Percentile Sound Level (L_{90}) plus 10 dB, i.e. L_{90} + 10 dB, obtained pursuant to Section 5.

8. SOUND LEVEL LIMITS - SPECIFIC IMPULSIVE SOUNDS

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is an industrial metal working operation (including but not limited to forging, hammering, punching, stamping, cutting, forming and moulding), the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}), is 60 dBAI, if the stationary source were operating before January 1, 1980, and otherwise is 50 dBAI.

(2) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is the discharge of firearms on the premises of a licensed gun club, the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}), is:

- 70 dBAI if the gun club were operating before January 1, 1980; or
- 50 dBAI if the gun club began to operate after January 1, 1980; or
- the L_{LM} prior to expansion, alteration or conversion.

(3) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is not a blasting operation in a surface mine or quarry, characterized by impulses which are so infrequent that they cannot normally be measured using the procedure for frequent impulses of Reference [3], the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the impulse sound level, is 100 dBAI.

9. SOUND LEVEL LIMITS - PEST CONTROL DEVICES

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a pest control device employed solely to protect growing crops, the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}), is 70 dBAI.

(2) For sound, including Quasi-Steady Impulsive Sound but not including other impulsive sound, from a pest control device employed solely to protect growing crops, the sound level limit at a point of reception within 30 m of a dwelling or a camping area, expressed in terms of the One Hour Equivalent Sound Level (L_{eq}), is 60 dBA.

10. PROHIBITION - PEST CONTROL DEVICES

The operation of a pest control device employed solely to protect growing crops is prohibited during the hours of darkness, sunset to sunrise.

11. PRE-EMPTION

The least restrictive sound level limit of Sections 8, 9 and 10 applies.

12. EXCLUSION

No restrictions apply to any stationary source resulting in a One Hour Equivalent Sound Level (L_{eq}) or a Logarithmic Mean Impulse Sound Level (L_{LM}), at a point of reception within 30 m of a dwelling or a camping area, lower than the minimum values for that time period, as specified in Table 232-1.

TABLE 232-1
Minimum Values of One Hour L_{eq} or L_{LM} by Time of Day

Time of Day	One Hour L_{eq} (dBA) or L_{LM} (dBAI)
0700 - 1900	45
1900 - 2300	40
2300 - 0700	40

May 21, 1999

00003285

Annex to Publication NPC-232
Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)
October 1995

A.1. GENERAL

The definitions in Publication NPC-232 of a Class 3 Area (Rural), as well as Class 1 and 2 Areas (Urban), provide a broad characterization of the areas including a range of localities. In formulating the definitions, consideration was given to the fact that the terms "rural" and "urban" embody a conception of distinct types of dwelling habitat.

On one hand, the term "urban" traditionally conveys a distinct image of a concentration of people and activities in a predominantly man-made environment dominated by road traffic noise, making intensive use of the space available. On the other hand, the term "rural" brings to mind a sparse distribution of people and activities in a predominantly natural environment using land extensively (farming) or not at all (wilderness areas). In between these two categories fall areas that exhibit characteristics of both "urban" and "rural" areas, particularly at different times of the day.

It is, however, evident that not all of the environment will fit neatly into one of these categories. The predominance of road traffic in the area is a significant factor in determining rurality. For example, a residential property in an isolated recreational area, but close to a major roadway, would not be considered to be located in a Class 3 Area.

While examples of a rural setting, described in Publication NPC-232 provide some general guidelines, any classification of a point of reception as being in a Class 1, 2 or 3 Area should be made on an individual basis. The classification can, and should, utilize normally available information on zoning by-laws, official plans, and other policy statements, as well as the future character of the particular piece of land in question and the land in its vicinity.

The standard of environmental noise acceptability for a stationary source is, in general, expressed as the difference between the noise from the source and the background noise. In rural areas, this background noise is formed by natural sounds rather than man-made sounds.

The background noise may also include contributions from existing stationary sources adjacent to the stationary source under impact assessment. Contributions of these secondary stationary noise sources are considered to be a part of the existing noise environment, and may be included in the measurement of the background sound levels, provided that they are not under consideration for noise abatement by the Municipality or the Ministry of Environment and Energy.

In Class 1 and 2 Areas where the acoustical environment is governed primarily by road traffic, the background noise is best described by the energy equivalent sound level (L_{eq}). However, the background noise in Class 3 Areas is often better described in terms of the ninetieth percentile sound level (L_{90}). Therefore, Publication NPC-232 has established both the L_{90} as well as the L_{eq} of the background as the limits against which the intrusion of the source, measured in terms of the L_{eq}, is assessed.

A.2. APPLICATION

Sound level limits contained in this Publication do not apply to non-stationary noise sources nor to any equipment, apparatus or device used in agriculture for food crop seeding, chemical spraying or harvesting. In addition, several specific noise sources have been addressed in separate Publications. Limits for residential air conditioners are contained in Publication NPC-216 - Residential Air Conditioning Devices, Reference [8], and the limits for blasting operations in quarries and surface mines are contained in Publication NPC-119 - Blasting, Reference [7].

A.3. STATIONARY SOURCES

The objective of the definition of a stationary source of sound is to address sources such as industrial and commercial establishments or ancillary transportation facilities. In order to further clarify the scope of the definition, the following list identifies examples of installations, equipment, activities or facilities that are included and those that are excluded as stationary sources.

(1) Included Sources

Individual stationary sources such as:

- Heating, ventilating and air conditioning (HVAC) equipment;
- Rotating machinery;
- Impacting mechanical sources;
- Generators;
- Burners;
- Grain dryers.

Facilities, usually comprising many sources of sound. In this case, the stationary source is understood to encompass all the activities taking place within the property boundary of the facility. The following are examples of such facilities:

- Industrial facilities;
- Commercial facilities;
- Ancillary transportation facilities;
- Aggregate extraction facilities;
- Warehousing facilities;
- Maintenance and repair facilities;
- Snow disposal sites;
- Routine loading and unloading facilities (supermarkets, assembly plants, etc.).

Other sources such as:

- Car washes;
- Race tracks;
- Firearm Ranges.

(2) Excluded Sources

Specific sources or facilities:

- Construction activities;
- Transportation corridors, i.e. roadways and railways;
- Residential air conditioning devices including air conditioners and heat pumps;
- Gas stations;
- Auditory warning devices required or authorized by law or in accordance with good safety practices;
- Occasional movement of vehicles on the property such as infrequent delivery of goods to convenience stores, fast food restaurants, etc.

Other noise sources, normally addressed in a qualitative manner in municipal noise by-laws:

- The operation of auditory signalling devices, including but not limited to the ringing of bells or gongs and the blowing of horns or sirens or whistles, or the production, reproduction or amplification of any similar sounds by electronic means;
- Noise produced by animals kept as domestic pets such as dogs barking;
- Tools and devices used by occupants for domestic purposes such as domestic power tools, radios and televisions, etc., or activities associated with domestic situations such as domestic quarrels, noisy parties, etc;

Noise resulting from gathering of people at facilities such as restaurants and parks.

Activities related to essential service and maintenance of public facilities such as but not limited to roadways, parks and sewers, including snow removal, road cleaning, road repair and maintenance, lawn mowing and maintenance, sewage removal, garbage collection, etc.

A.4. PREDICTABLE WORST CASE IMPACT

The assessment of noise impact requires the determination of the "predictable worst case" impact. The "predictable worst case" impact assessment should establish the largest noise excess produced by the source over the applicable limit. The assessment should reflect a planned and predictable mode of operation of the stationary source.

It is important to emphasize that the "predictable worst case" impact does not necessarily mean that the sound level of the source is highest; it means that the excess over the limit is largest. For example, the excess over the applicable limit at night may be larger even if the day-time sound level produced by the source is higher.

A.5. DEFINITIONS

In the interpretation of Publication NPC-232, the following definitions are of particular relevance:

- Ancillary Transportation Facilities
  "Ancillary transportation facilities" mean subsidiary locations where operations and activities associated with the housing of transportation equipment (or personnel) take place. Examples of ancillary transportation facilities include, but are not limited to, substations, vehicle storage and maintenance facilities, fans, fan and vent shafts, mechanical equipment plants, emergency services buildings, etc;

- Construction
  "Construction" includes erection, alteration, repair, dismantling, demolition, structural maintenance, painting, moving, land clearing, earth moving, grading, excavating, the laying of pipe and conduit whether above or below ground level, street and highway building, concreting, equipment installation and alteration and the structural installation of construction components and materials in any form or for any purpose, and includes any work in connection therewith; "construction" excludes activities associated with the operation at waste and snow disposal sites;

- Construction Equipment
  "Construction equipment" means any equipment or device designed and intended for use in construction, or material handling including but not limited to, air compressors, pile drivers, pneumatic or hydraulic tools, bulldozers, tractors, excavators, trenchers, cranes, derricks, loaders, scrapers, pavers, generators, off-highway haulers or trucks, ditchers, compactors and rollers, pumps, concrete mixers, graders, or other material handling equipment;

- Conveyance
  "Conveyance" includes a vehicle and any other device employed to transport a person or persons or goods from place to place but does not include any such device or vehicle if operated only within the premises of a person;

- Highway
  "Highway" includes a common and public highway, street, avenue, parkway, driveway, square, place, bridge, viaduct or trestle designed and intended for, or used by, the general public for the passage of vehicles;

- Motor Vehicle
  "Motor vehicle" includes an automobile, motorcycle,and any other vehicle propelled or driven otherwise than by muscular power, but does not include the cars of diesel, electric or steam railways, or other motor vehicles running only upon rails, or a motorized snow vehicle, traction engine, farm tractor, self-propelled implement of husbandry or road-building machine within the meaning of the Highway Traffic Act;

- Motorized Conveyance
  "Motorized conveyance" means a conveyance propelled or driven otherwise than by muscular, gravitational or wind power;

- Noise
  "Noise" means unwanted sound;

- Point of Reception - Class 3 Area
  "Point of reception - Class 3 Area" means a point on the premises of a person within 30 m of a dwelling or a camping area, where sound or vibration originating from other than those premises is received.

  For the purpose of approval of new sources, including verifying compliance with Section 9 of the Environmental Protection Act, the point of reception may be located on any of the following existing or zoned for future use premises: permanent or seasonal residences, hotels/motels, nursing/retirement homes, rental residences, hospitals, camp grounds, and noise sensitive buildings such as schools and places of worship.

  For equipment/facilities proposed on premises such as nursing/retirement homes, rental residences, hospitals, and schools, the point of reception may be located on the same premises;

- Stationary Source
  "Stationary source" means a source of sound which does not normally move from place to place and includes the premises of a person as one stationary source, unless the dominant source of sound on those premises is construction or a conveyance;

- Urban Hum
  means aggregate sound of many unidentifiable, mostly road traffic related noise sources.

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APPENDIX C

NPC - 205 - SOUND LEVEL LIMITS FOR STATIONARY SOURCES IN CLASS 1 & 2 AREAS (URBAN)

SOUND LEVEL LIMITS FOR STATIONARY SOURCES IN CLASS 1 & 2 AREAS (URBAN)

PUBLICATION NPC-205

OCTOBER 1995

Ontario

Ministry
of the
Environment

Cette publication technique
n`est disponible qu`en anglais.

ISBN 0-7778-4922-4
PIBS 3406E

Ontario

MINISTRY OF THE ENVIRONMENT

Sound Level Limits for Stationary Sources in Class 1 & 2 Areas (Urban) Publication NPC-205

October 1995

This Publication establishes sound level limits for stationary sources such as industrial and commercial establishments or ancillary transportation facilities, affecting points of reception in Class 1 and 2 Areas (Urban). It replaces Publication NPC-105 "Stationary Sources" of the "Model Municipal Noise Control By-Law, Final Report, August 1978".

TABLE OF CONTENTS

1. SCOPE

This Publication establishes sound level limits for stationary sources such as industrial and commercial establishments or ancillary transportation facilities, affecting points of reception in Class 1 and 2 Areas (Urban). The limits apply to noise complaint investigations carried out in order to determine potential violation of Section 14 of the Environmental Protection Act. The limits also apply to the assessment of planned stationary sources of sound in compliance with Section 9 of the Environmental Protection Act, and under the provisions of the Aggregate Resources Act and the Environmental Assessment Act.

This Publication does not address sound and vibration produced by blasting; blasting in quarries and surface mines is considered in Reference [7].

The Publication includes an Annex, which provides additional details, definitions and rationale for the sound level limits.

2. REFERENCES

Reference is made to the following publications:

[1] NPC-101 - Technical Definitions

[2] NPC-102 - Instrumentation

[3] NPC-103 - Procedures

[4] NPC-104 - Sound Level Adjustments

[6] NPC-206 - Sound Levels due to Road Traffic

[7] NPC-119 - Blasting

[8] NPC-216 - Residential Air Conditioning Devices

[9] NPC-232 - Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)

[10] NPC-233 - Information to be Submitted for Approval of Stationary Sources of Sound

[12] ORNAMENT, Ontario Road Noise Analysis Method for Environment and Transportation, Technical Document, Ontario Ministry of the Environment, ISBN 0-7729-6376, 1989

References [1] to [4] and [7] can be found in the
Model Municipal Noise Control By-Law, Ontario Ministry of the Environment, Final Report, August 1978.

3. TECHNICAL DEFINITIONS

"Ambient sound level"
means Background sound level.

"Background sound level"
is the sound level that is present in the environment, produced by noise sources other than the source under impact assessment. Highly intrusive short duration noise caused by a source such as an aircraft fly-over or a train pass-by is excluded from the determination of the background sound level.

"Class 1 Area"
means an area with an acoustical environment typical of a major population centre, where the background noise is dominated by the urban hum.

"Class 2 Area"

means an area with an acoustical environment that has qualities representative of both Class 1 and Class 3 Areas, and in which a low ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realized as early as 19:00 hours.

Other characteristics which may indicate the presence of a Class 2 Area include:

- absence of urban hum between 19:00 and 23:00 hours;
- evening background sound level defined by natural environment and infrequent human activity; and
- no clearly audible sound from stationary sources other than from those under impact assessment.

"Class 3 Area"

means a rural area with an acoustical environment that is dominated by natural sounds having little or no road traffic, such as the following:

- a small community with less than 1000 population;
- agricultural area;
- a rural recreational area such as a cottage or a resort area; or
- a wilderness area.

Other technical terms are defined in Reference [1] and in the Annex to Publication NPC-205.

4. ESTABLISHMENT OF LIMITS - OBJECTIVE

The sound level limit at a point of reception must be established based on the principle of "predictable worst case" noise impact. In general, the limit is given by the background sound level at the point of reception. The sound level limit must represent the minimum background sound level that occurs or is likely to occur during the operation of the stationary source under impact assessment.

5. BACKGROUND SOUND LEVELS

The time interval between the background sound level measurement and the measurement of the sound level produced by the stationary source under impact assessment should be minimized as much as possible. Preferably, the two measurements should be carried out within one hour of each other.

6. SOUND LEVELS DUE TO STATIONARY SOURCES

(1) Complaint Investigation of Stationary Sources

The One Hour Equivalent Sound Level (L_{eq}) and/or the Logarithmic Mean Impulse Sound Level (L_{LM}) produced by the stationary sources shall be obtained by measurement performed in accordance with Section 7.

(2) Approval of Stationary Sources

The One Hour Equivalent Sound Level (L_{eq}) and/or the Logarithmic Mean Impulse Sound Level (L_{LM}) produced by the stationary sources shall be obtained by measurement or prediction. The estimation of the L_{eq} and/or L_{LM} of the stationary source under impact assessment shall reflect the principle of "predictable worst case" noise impact. The "predictable worst case" noise impact occurs during the hour when the difference between the predicted sound level produced by the stationary source and the background sound level of the natural environment is at a maximum.

7. PROCEDURES

All sound level measurements and calculations shall be made in accordance with References [3], [6]and [12].

Sound from existing adjacent stationary sources may be included in the determination of the background One Hour Equivalent Sound Level (L_{eq}) if such stationary sources of sound are not under consideration for noise abatement by the Municipality or the Ministry of Environment and Energy.

8. SOUND LEVEL LIMITS - GENERAL

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source, the sound level limit expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}) is the background One Hour Equivalent Sound Level (L_{eq}) typically caused by road traffic as obtained pursuant to Section 6 for that point of reception.

(2) For sound from a stationary source, including Quasi-Steady Impulsive Sound but not including other impulsive sound, the sound level limit expressed in terms of the One Hour Equivalent Sound Level (L_{eq}) is the background One Hour Equivalent Sound Level (L_{eq}) typically caused by road traffic as obtained pursuant to Section 6 for that point of reception.

9. SOUND LEVEL LIMITS - SPECIFIC IMPULSIVE SOUNDS

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is an industrial metal working operation (including but not limited to forging, hammering, punching, stamping, cutting, forming and moulding), the sound level limit at a point of reception expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}) is 60 dBAI, if the stationary source were operating before January 1, 1980, and otherwise is 50 dBAI.

(2) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is the discharge of firearms on the premises of a licensed gun club, the sound level limit at a point of reception expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}) is:

- 70 dBAI if the gun club were operating before January 1, 1980; or
- 50 dBAI if the gun club began to operate after January 1, 1980; or
- the L_{LM} prior to expansion, alteration or conversion.

(3) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a stationary source which is not a blasting operation in a surface mine or quarry, characterized by impulses which are so infrequent that they cannot normally be measured using the procedure for frequent impulses of Reference [3] the sound level limit at a point of reception expressed in terms of the impulse sound level is 100 dBAI.

10. SOUND LEVEL LIMITS - PEST CONTROL DEVICES

(1) For impulsive sound, other than Quasi-Steady Impulsive Sound, from a pest control device employed solely to protect growing crops, the sound level limit at a point of reception expressed in terms of the Logarithmic Mean Impulse Sound Level (L_{LM}) is 70 dBAI.

(2) For sound, including Quasi-Steady Impulsive Sound but not including other impulsive sound, from a pest control device employed solely to protect growing crops, the sound level limit at a point of reception expressed in terms of the One Hour Equivalent Sound Level (L_{eq}) is 60 dBA.

11. PROHIBITION - PEST CONTROL DEVICES

The operation of a pest control device employed solely to protect growing crops outdoors during the hours of darkness, sunset to sunrise, is prohibited.

12. PRE-EMPTION

The least restrictive sound level limit of Sections 8, 9 and 10 applies.

13. EXCLUSION

No restrictions apply to a stationary source resulting in a One Hour Equivalent Sound Level (L_{eq}) or a Logarithmic Mean Impulse Sound Level (L_{LM}) lower than the minimum values for that time period specified in Table 205-1.

TABLE 205-1

Minimum Values of One Hour L_{eq} or L_{LM} by Time of Day

	One Hour L_{eq} (dBA) or L_{LM} (dBAI)	
Time of Day	Class 1 Area	Class 2 Area
0700 - 1900	50	50
1900 - 2300	47	45
2300 - 0700	45	45

May 21, 1999

Annex to Publication NPC-205
Sound Level Limits for Stationary Sources in Class 1 & 2 Areas (Urban)

October 1995

A.1. GENERAL

In general, noises are annoying because they are heard over and above the level of the so-called "background" or surrounding environmental noise climate at a particular location. The standard for environmental noise acceptability of stationary sources is therefore expressed as the difference between noise from the source and the background noise.

The background noise is essentially made up of the road traffic noise which creates an "urban hum". It may also include contributions from existing industry or commercial activity adjacent to the stationary source under investigation. Contributions of these secondary noise sources are considered to be a part of urban hum and may be included in the measurements or calculation of the background sound levels, provided that they are not under consideration for noise abatement by the Municipality or the Ministry of Environment and Energy.

The sound level limits specified in Section 8 of Publication NPC-205 represent the general limitation on noise produced by stationary sources. Some noises, however, are annoying no matter where or in what kind of environment they exist. High level impulsive noises represent a special category and, consequently, are restricted by an absolute limitation. Sections 9 and 10 of this Publication provide criteria of acceptability for specific impulsive noise sources.

A.2. APPLICATION

The limits presented in Publication NPC-205 are designed for the control of noise from sources located in industrial, commercial or residential areas. The limits apply to points of reception located in Class 1 and Class 2 Areas.

Sound level limits contained in Publication NPC-205 do not apply to the excluded noise sources listed in Section A.3.(2) and neither do they apply to any equipment, apparatus or device used in agriculture for food crop seeding, chemical spraying or harvesting. In addition, several specific noise sources have been addressed in separate Publications. Limits for residential air conditioners are contained in Publication NPC-216 - Residential Air Conditioning Devices, Reference [8] and the limits for blasting operations in quarries and surface mines are contained in Publication NPC-119 - Blasting, Reference [7].

A.3. STATIONARY SOURCES

The objective of the definition of a stationary source of sound is to address sources such as industrial and commercial establishments or ancillary transportation facilities. In order to further clarify the scope of the definition, the following list identifies examples of installations, equipment, activities or facilities that are included and those that are excluded as stationary sources.

(1) Included Sources

Individual stationary sources such as:

- Heating, ventilating and air conditioning (HVAC) equipment;
- Rotating machinery;
- Impacting mechanical sources;
- Generators;
- Burners;
- Grain dryers.

Facilities, usually comprising many sources of sound. In this case, the stationary source is understood to encompass all the activities taking place within the property boundary of the facility. The following are examples of such facilities:

Industrial facilities;
Commercial facilities;
Ancillary transportation facilities;
Aggregate extraction facilities;
Warehousing facilities;
Maintenance and repair facilities;
Snow disposal sites;
Routine loading and unloading facilities (supermarkets, assembly plants, etc.).

Other sources such as:

Car washes;
Race tracks;
Firearm Ranges.

(2) Excluded Sources

Secific sources or facilities:

Construction activities;
Transportation corridors, i.e. roadways and railways;
Residential air conditioning devices including air conditioners and heat pumps;
Gas stations;
Auditory warning devices required or authorized by law or in accordance with good safety practices;
Occasional movement of vehicles on the property such as infrequent delivery of goods to convenience stores, fast food restaurants, etc.

Other noise sources, normally addressed in a qualitative manner in municipal noise by-laws:

The operation of auditory signalling devices, including but not limited to the ringing of bells or gongs and the blowing of horns or sirens or whistles, or the production, reproduction or amplification of any similar sounds by electronic means;
Noise produced by animals kept as domestic pets such as dogs barking;
Tools and devices used by occupants for domestic purposes such as domestic power tools, radios and televisions, etc., or activities associated with domestic situations such as domestic quarrels, noisy parties, etc;
Noise resulting from gathering of people at facilities such as restaurants and parks.

Activities related to essential service and maintenance of public facilities such as but not limited to roadways, parks and sewers, including snow removal, road cleaning, road repair and maintenance, lawn mowing and maintenance, sewage removal, garbage collection, etc.

A.4. PREDICTABLE WORST CASE IMPACT

The assessment of noise impact requires the determination of the "predictable worst case" impact. The "predictable worst case" impact assessment should establish the largest noise excess produced by the source over the applicable limit. The assessment should reflect a planned and predictable mode of operation of the stationary source.

It is important to emphasize that the "predictable worst case" impact does not necessarily mean that the sound level of the source is highest; it means that the excess over the limit is largest. For example, the excess over the applicable limit at night may be larger even if the day-time sound level produced by the source is higher.

A.5. DEFINITIONS

In the interpretation of Publication NPC-205, the following definitions are of particular relevance:

- Ancillary Transportation Facilities
  "Ancillary transportation facilities" mean subsidiary locations where operations and activities associated with the housing of transportation equipment (or personnel) take place. Examples of ancillary transportation facilities include, but are not limited to, substations, vehicle storage and maintenance facilities, fans, fan and vent shafts, mechanical equipment plants, emergency services buildings, etc;

- Construction
  "Construction" includes erection, alteration, repair, dismantling, demolition, structural maintenance, painting, moving, land clearing, earth moving, grading, excavating, the laying of pipe and conduit, whether above or below ground level, street and highway building, concreting, equipment installation and alteration and the structural installation of construction components and materials in any form or for any purpose, and includes any work in connection therewith; "construction" excludes activities associated with the operation at waste and snow disposal sites;

- Construction Equipment
  "Construction equipment" means any equipment or device designed and intended for use in construction, or material handling including but not limited to, air compressors, pile drivers, pneumatic or hydraulic tools, bulldozers, tractors, excavators, trenchers, cranes, derricks, loaders, scrapers, pavers, generators, off-highway haulers or trucks, ditchers, compactors and rollers, pumps, concrete mixers, graders, or other material handling equipment;

- Conveyance
  "Conveyance" includes a vehicle and any other device employed to transport a person or persons or goods from place to place but does not include any such device or vehicle if operated only within the premises of a person;

- Highway
  "Highway" includes a common and public highway, street, avenue, parkway, driveway, square, place, bridge, viaduct or trestle designed and intended for, or used by, the general public for the passage of vehicles;

- Motor Vehicle
  "Motor vehicle" includes an automobile, motorcycle, and any other vehicle propelled or driven otherwise than by muscular power, but does not include the cars of diesel, electric or steam railways, or other motor vehicles running only upon rails, or a motorized snow vehicle, traction engine, farm tractor, self-propelled implement of husbandry or road-building machine within the meaning of the Highway Traffic Act;

- Motorized Conveyance
  "Motorized conveyance" means a conveyance propelled or driven otherwise than by muscular, gravitational or wind power;

- Noise
  "Noise" means unwanted sound;

- Point of Reception
  "Point of reception" means any point on the premises of a person where sound or vibration originating from other than those premises is received.

For the purpose of approval of new sources, including verifying compliance with Section 9 of the Environmental Protection Act, the point of reception may be located on any of the following existing or zoned for future use premises: permanent or seasonal residences, hotels/motels, nursing/retirement homes, rental residences, hospitals, camp grounds, and noise sensitive buildings such as schools and places of worship.

For equipment/facilities proposed on premises such as nursing/retirement homes, rental residences, hospitals, and schools, the point of reception may be located on the same premises;

- Stationary Source
  "Stationary source" means a source of sound which does not normally move from place to place and includes the premises of a person as one stationary source, unless the dominant source of sound on those premises is construction or a conveyance;

- Urban Hum
  means aggregate sound of many unidentifiable, mostly road traffic related noise sources.

May 21, 1999

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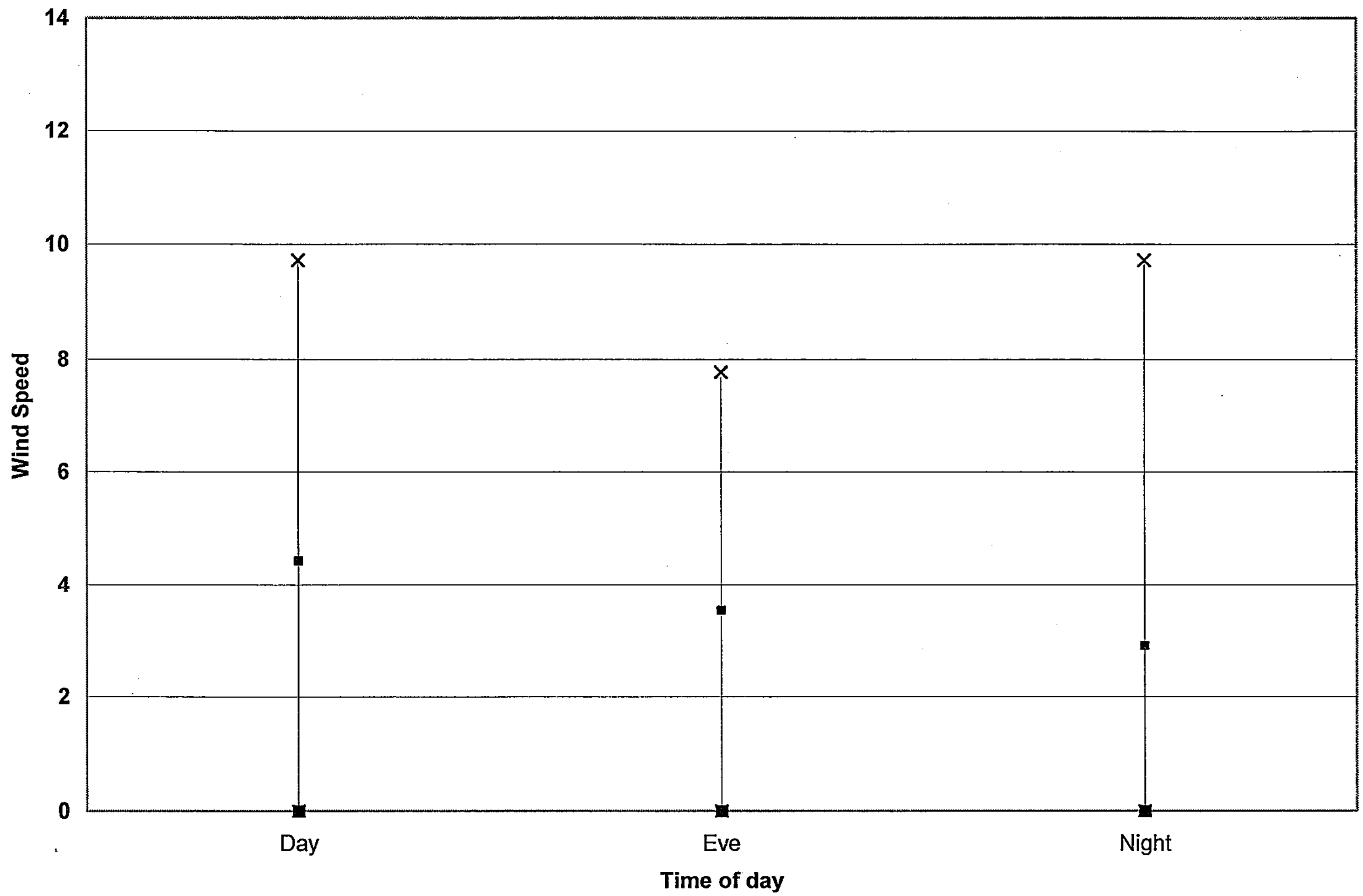
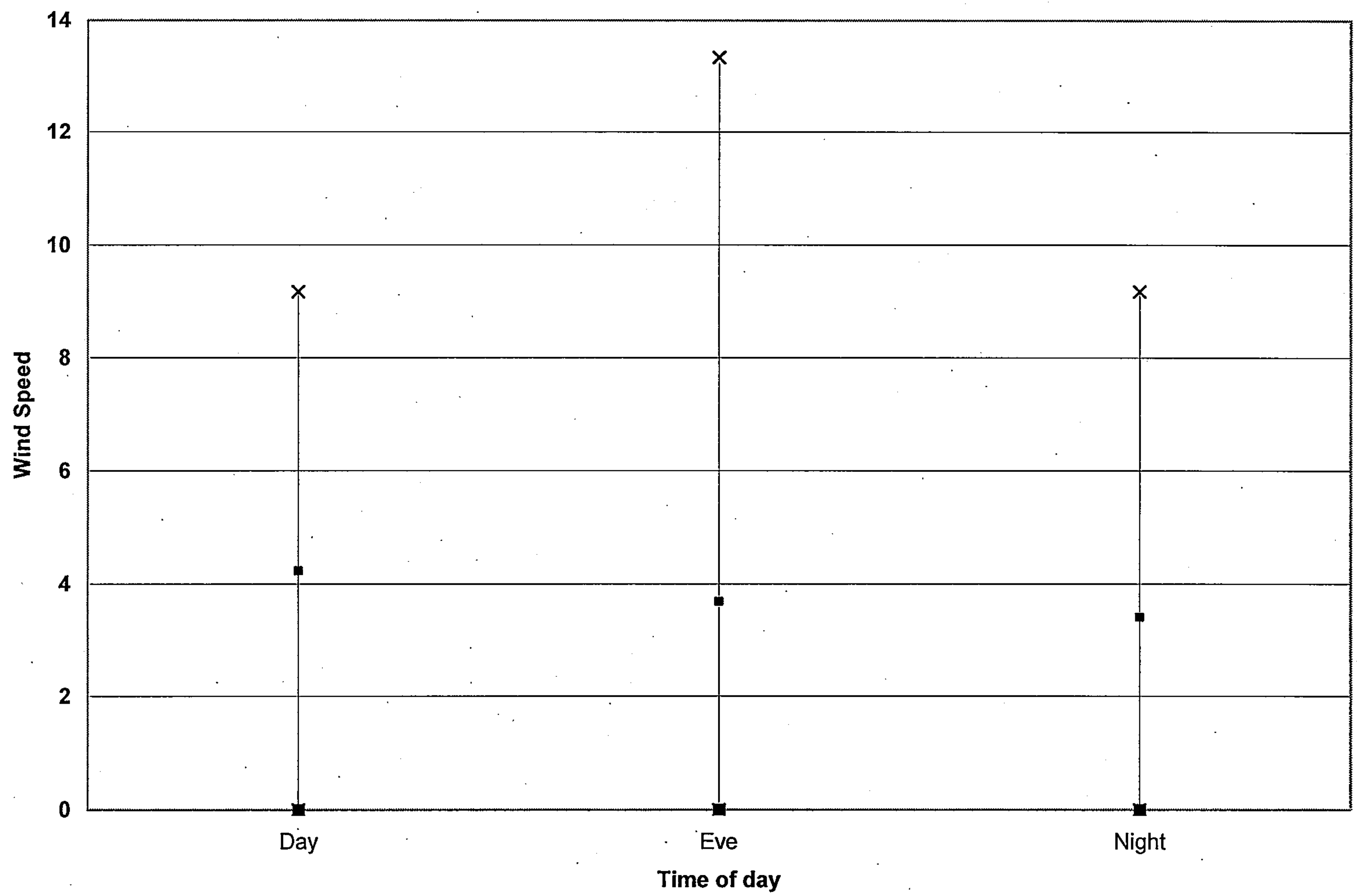
APPENDIX D

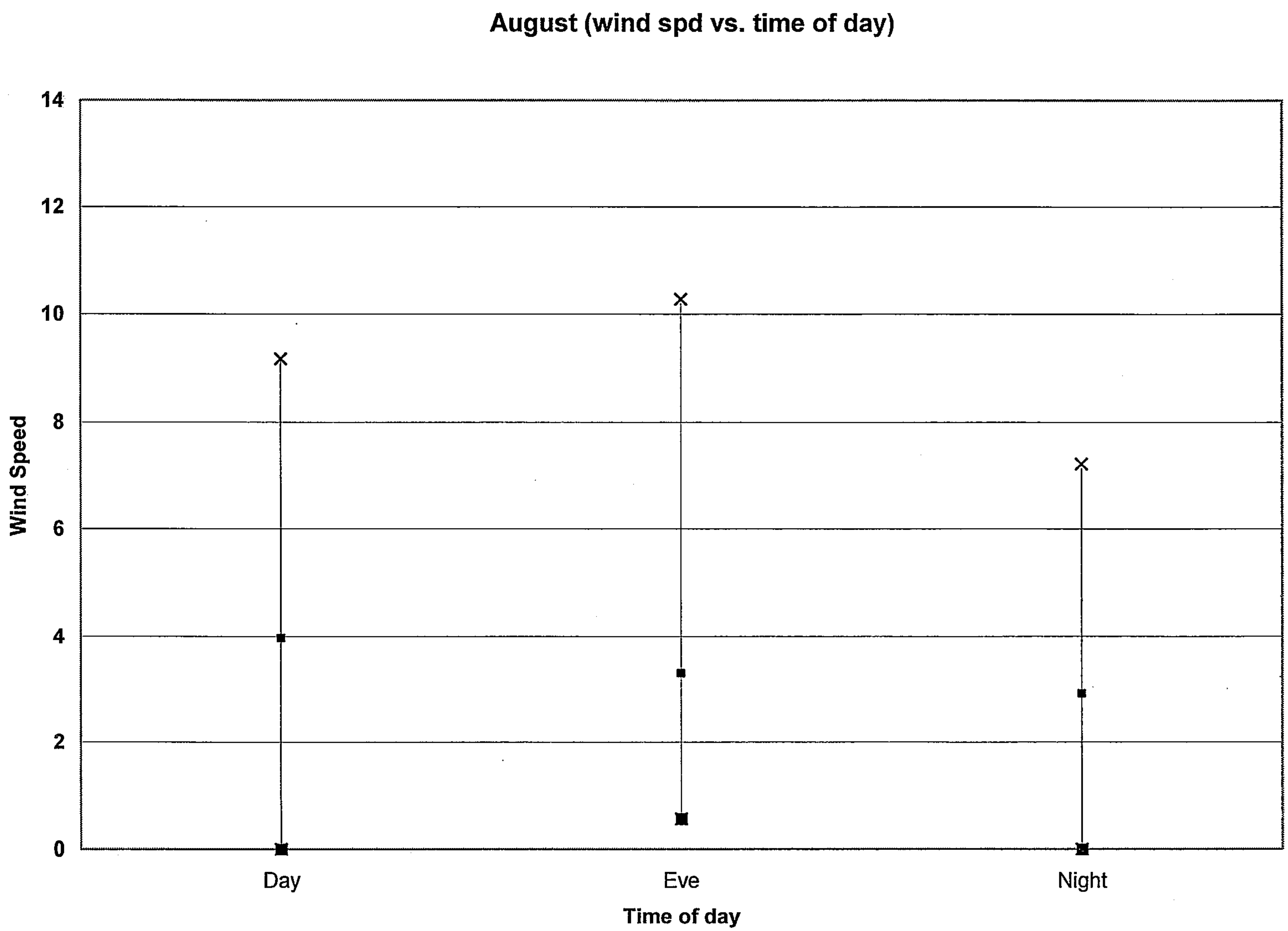
WEATHER DATA (GODERICH STATION) - WIND POWER OUTPUT DATA (KINGSBRIDGE WIND FARMS) FOR JUNE, JULY & AUGUST 2006

June (Wind Speed vs. time of day)

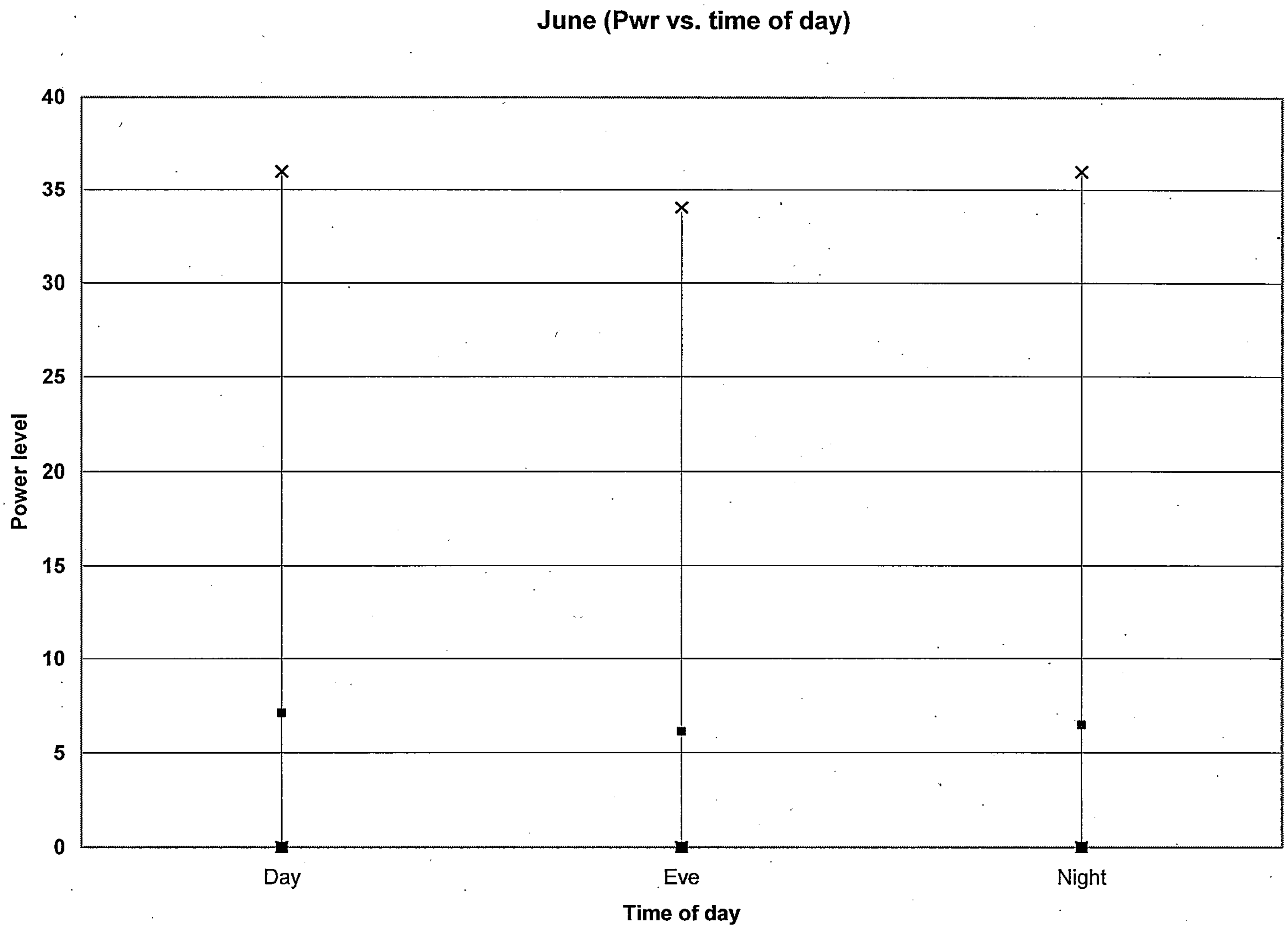


July (Wind Speed vs. time of day)

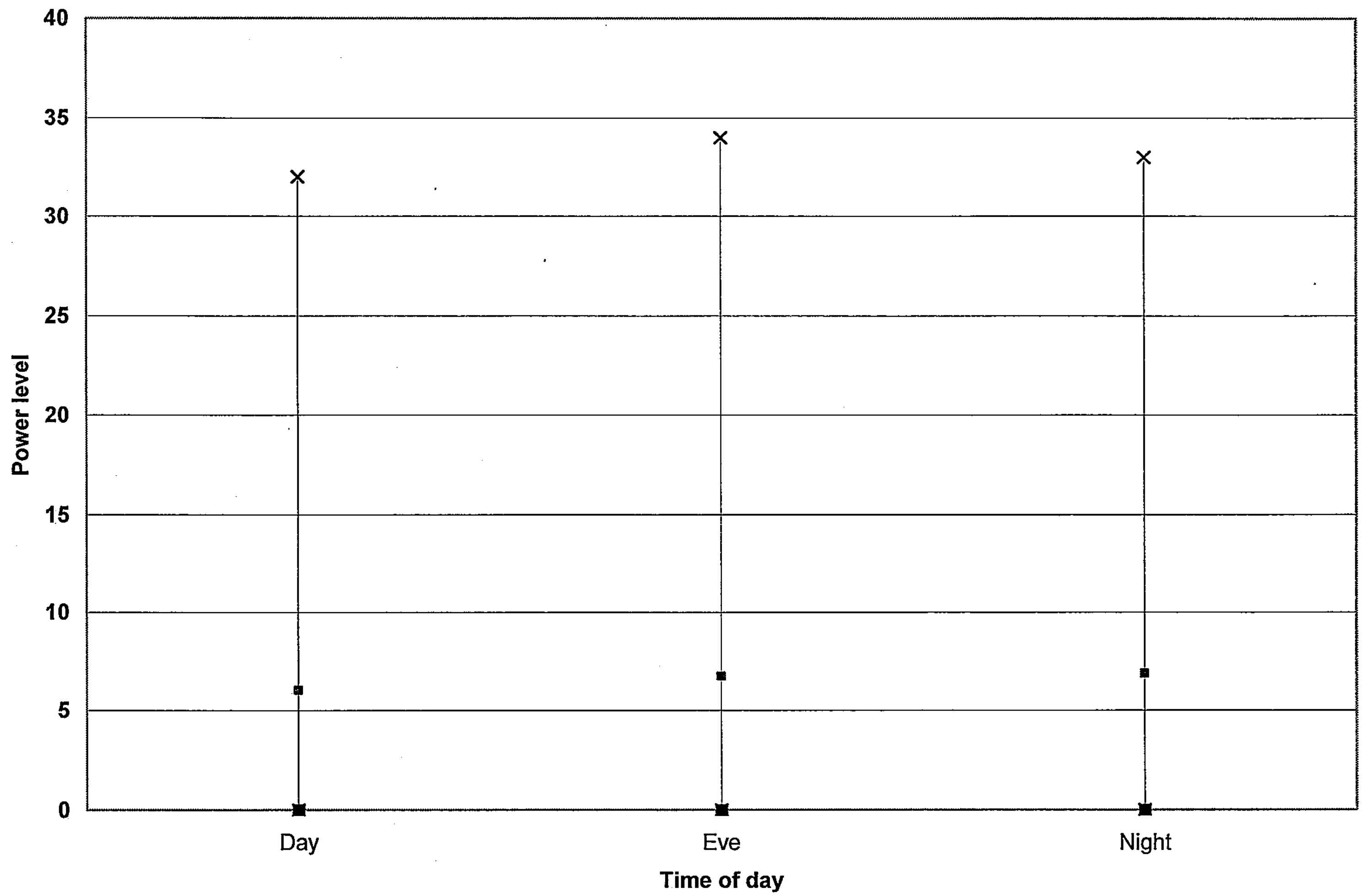


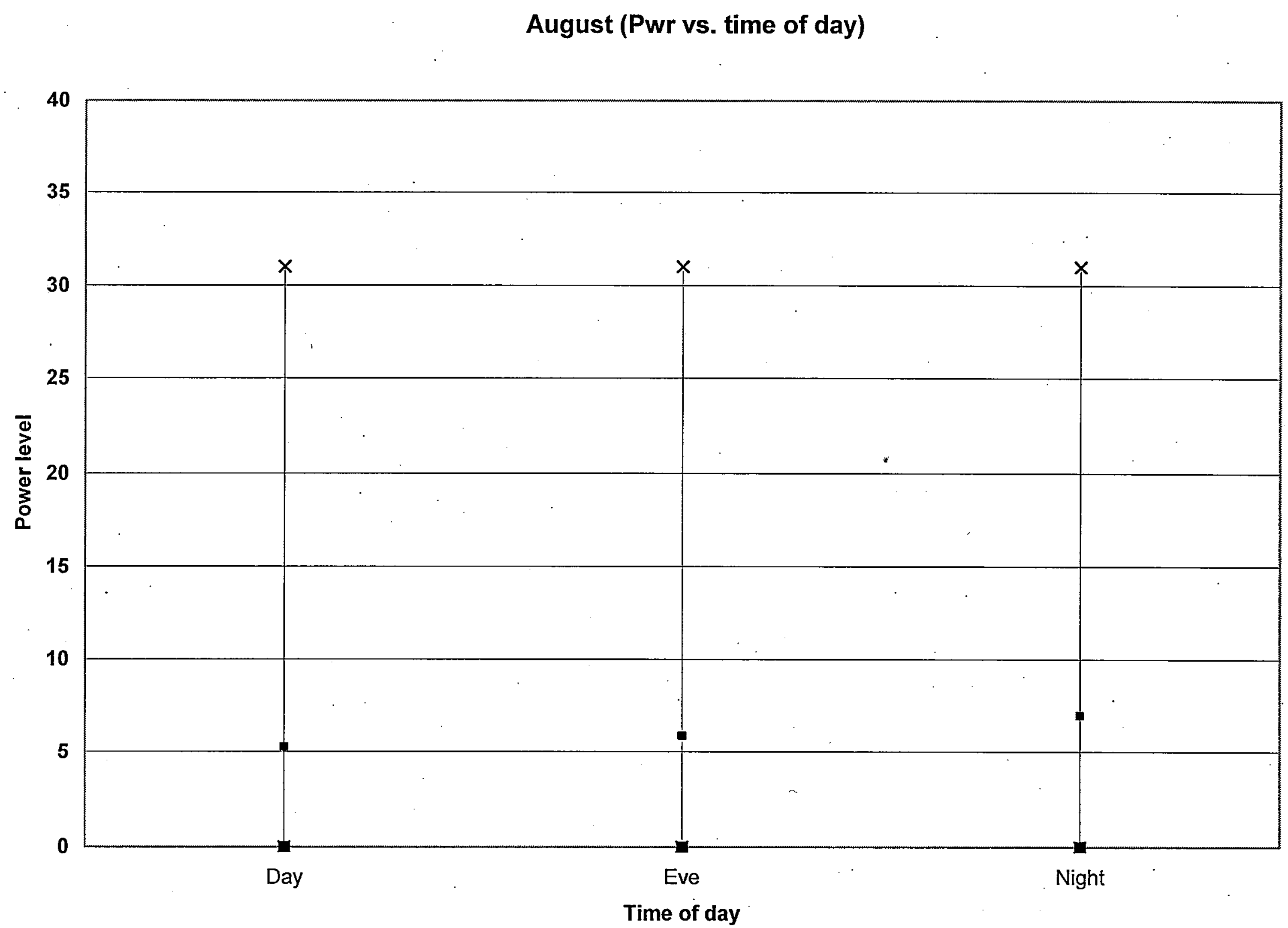

August (wind spd vs. time of day)
Wind Speed
14
12
10
8
6
4
2
0
Day
Eve
Night
Time of day

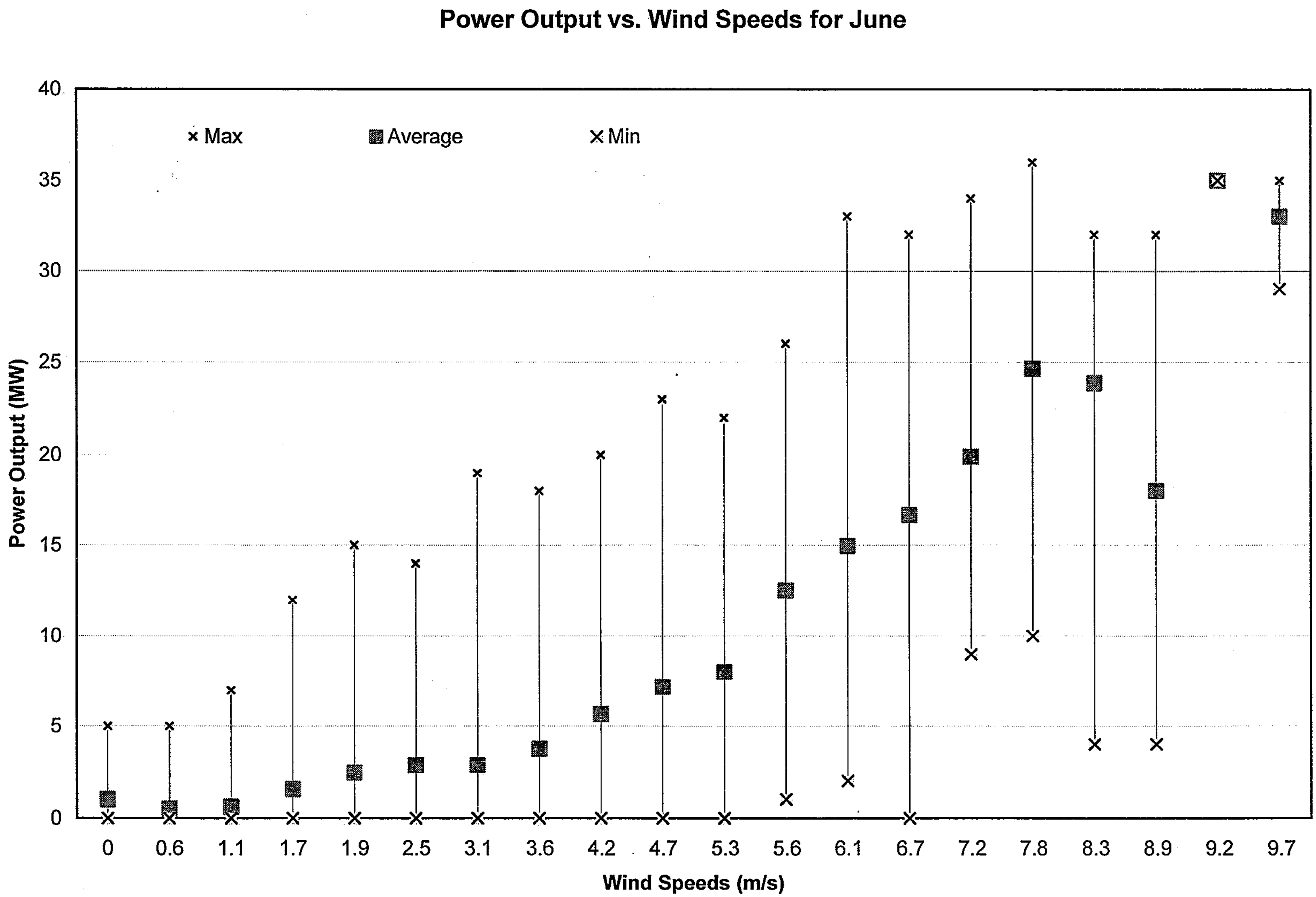
00003307


June (Pwr vs. time of day)
Power level
40
35
30
25
20
15
10
5
0
Day
Eve
Night
Time of day

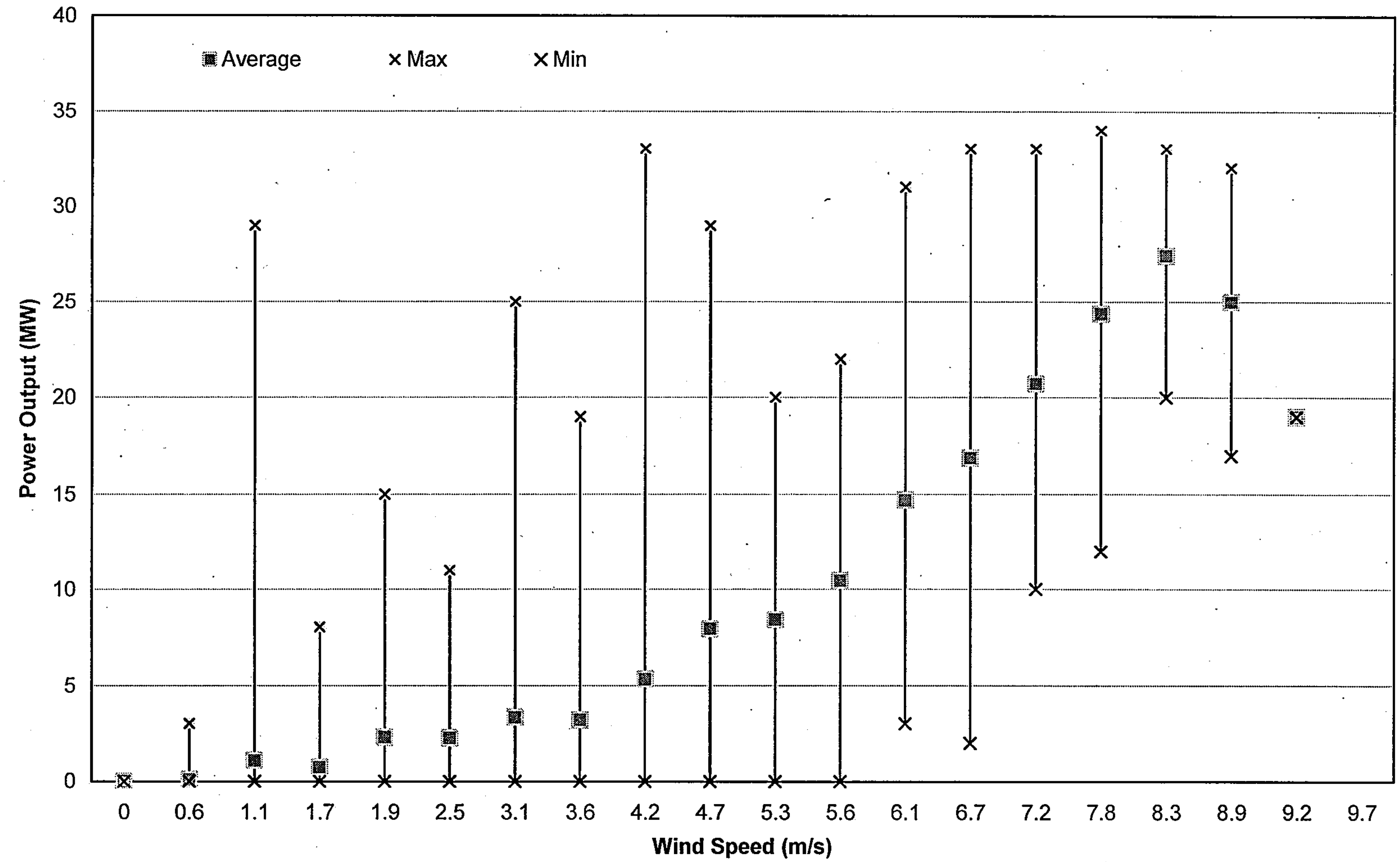
July (Pwr vs. time of day)



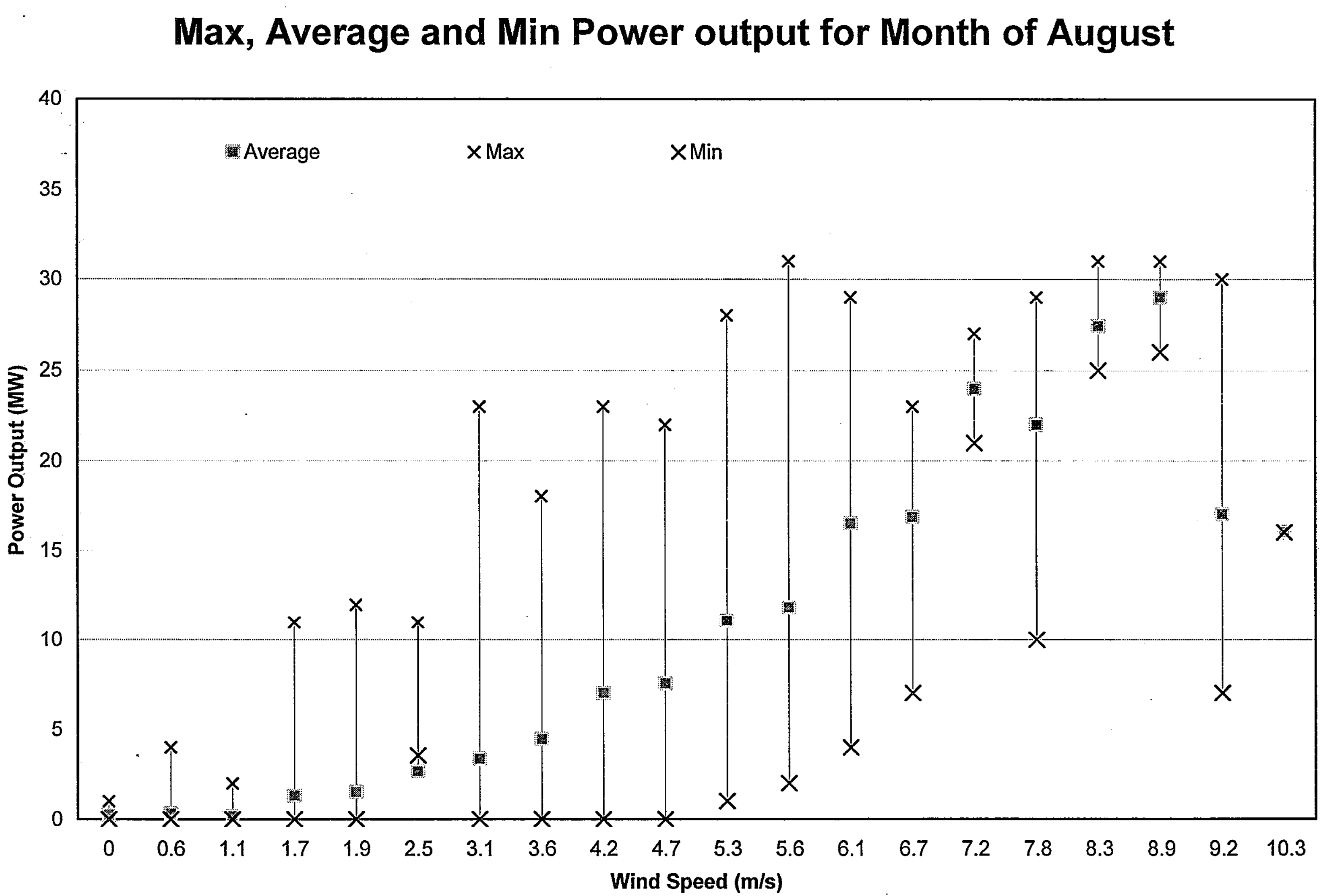

August (Pwr vs. time of day)
Power level
40
35
30
25
20
15
10
5
0
Day
Eve
Night
Time of day


Power Output vs. Wind Speeds for June
Max
Average
Min
Power Output (MW)
40
35
30
25
20
15
10
5
0
0
0.6
1.1
1.7
1.9
2.5
3.1
3.6
4.2
4.7
5.3
5.6
6.1
6.7
7.2
7.8
8.3
8.9
9.2
9.7
Wind Speeds (m/s)

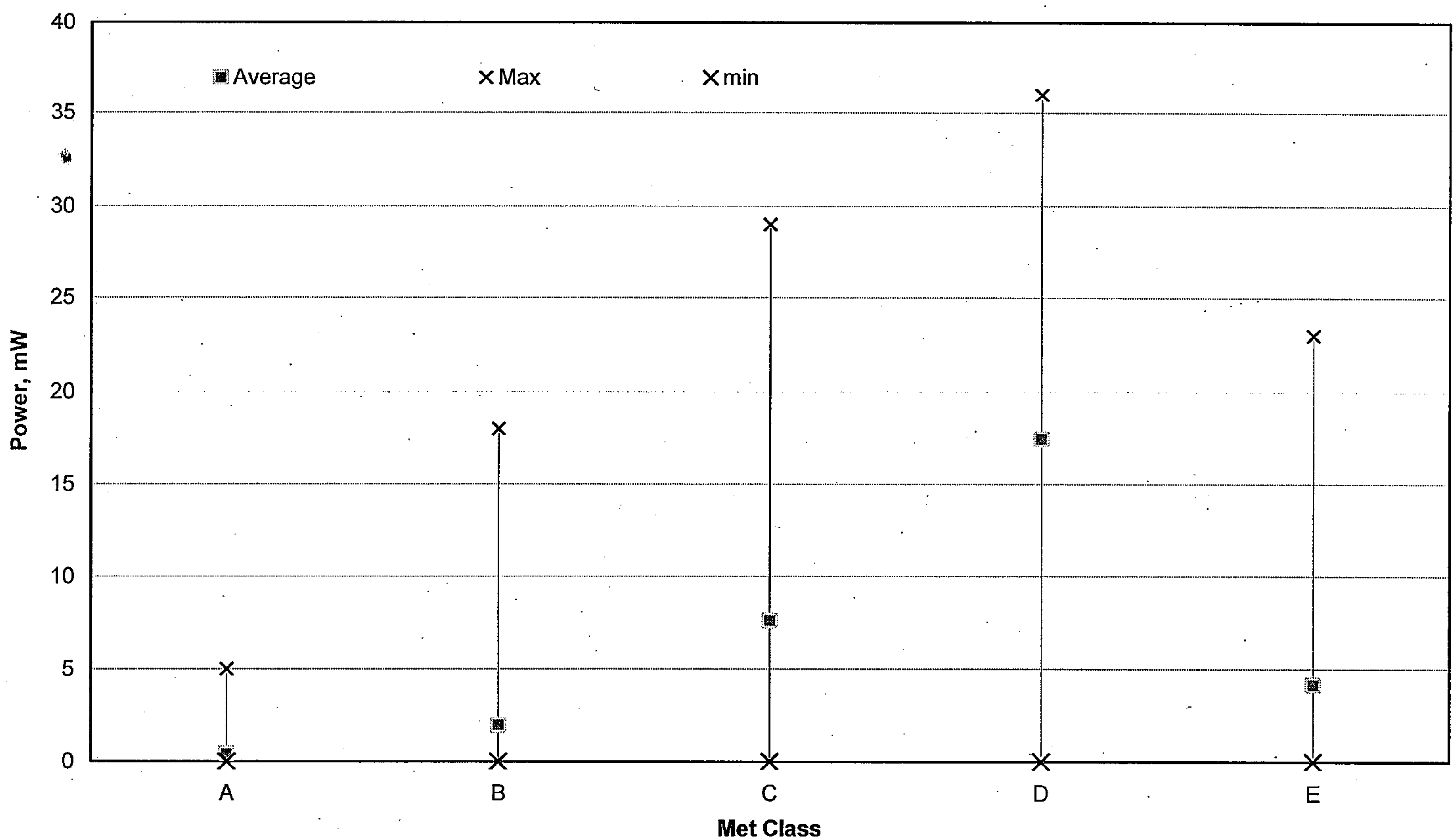
Max, Average and Min Power output for Month of July



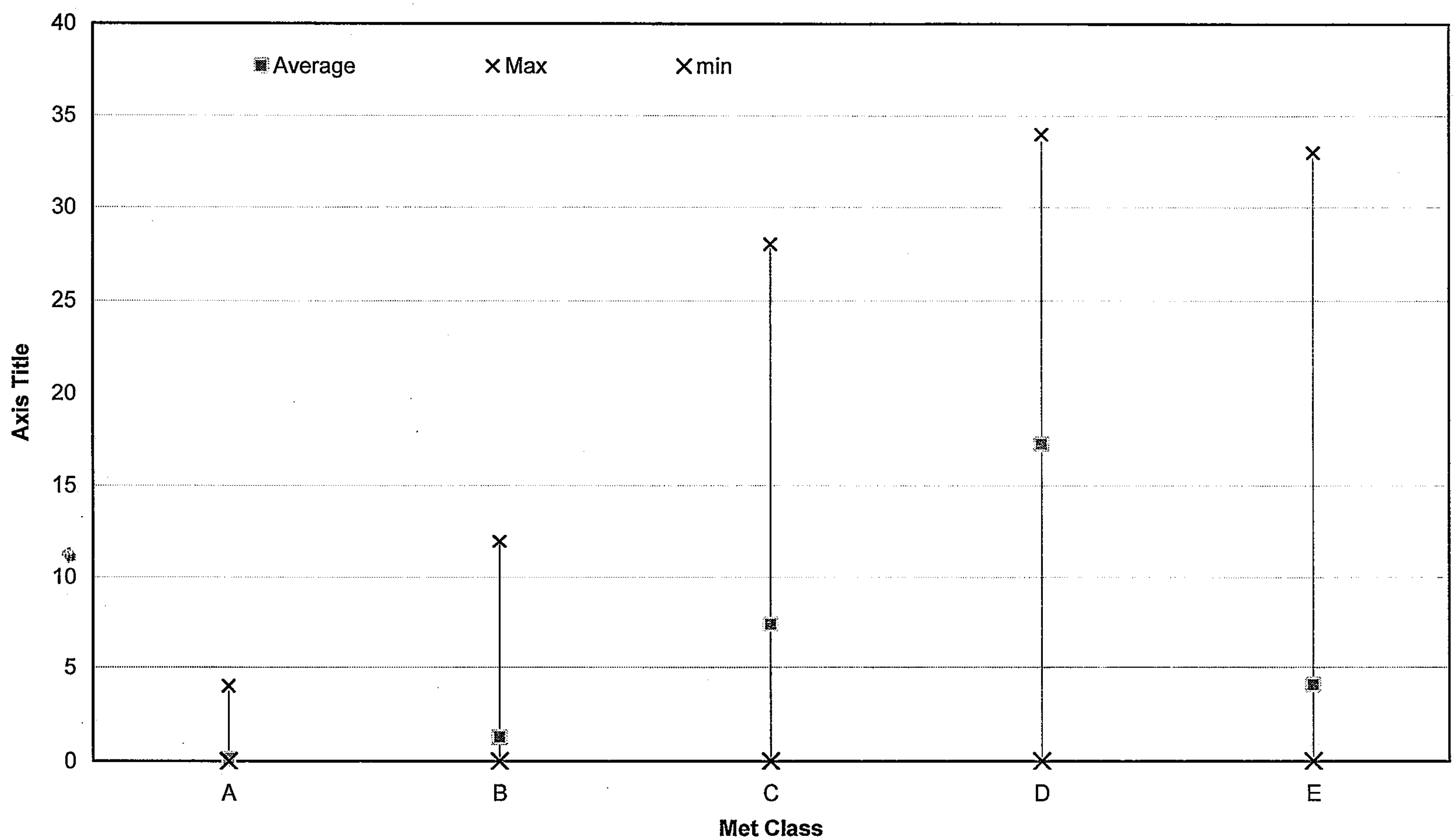
00003312


Max, Average and Min Power output for Month of August
Average
Max
Min
Power Output (MW)
40
35
30
25
20
15
10
5
0
0
0.6
1.1
1.7
1.9
2.5
3.1
3.6
4.2
4.7
5.3
5.6
6.1
6.7
7.2
7.8
8.3
8.9
9.2
10.3
Wind Speed (m/s)

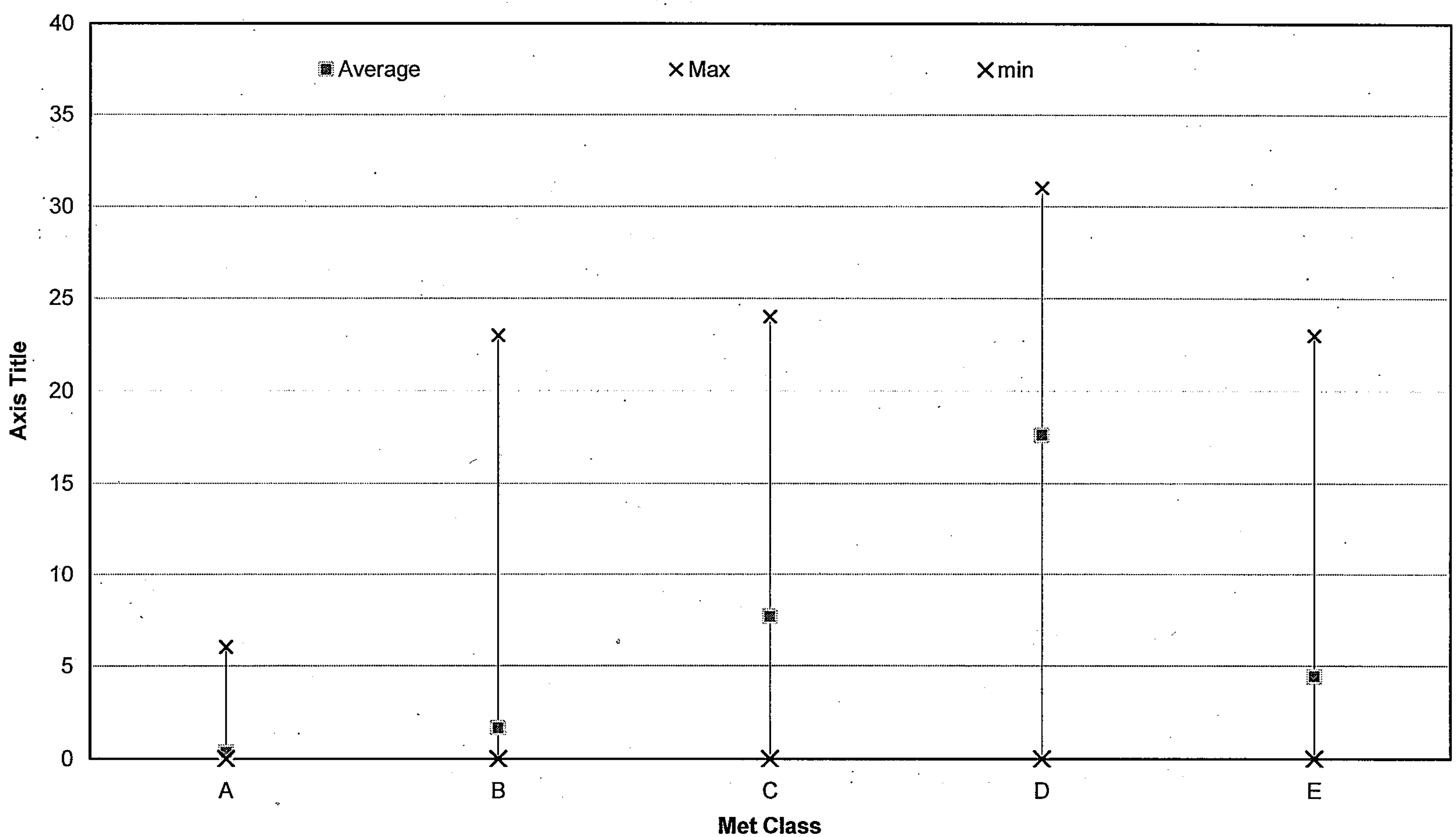
Max, Average and Min Power output for Month of June vs. Class

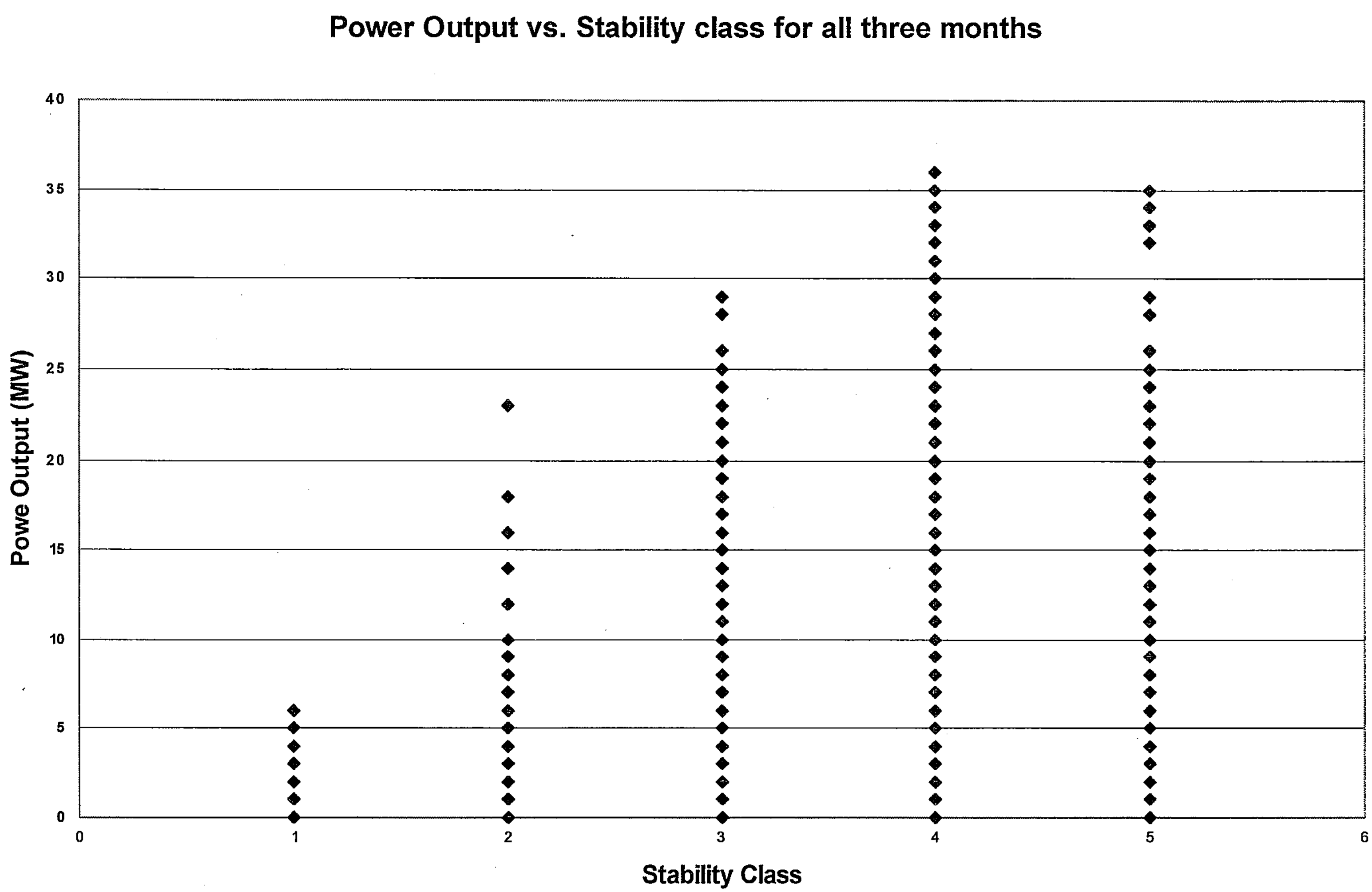


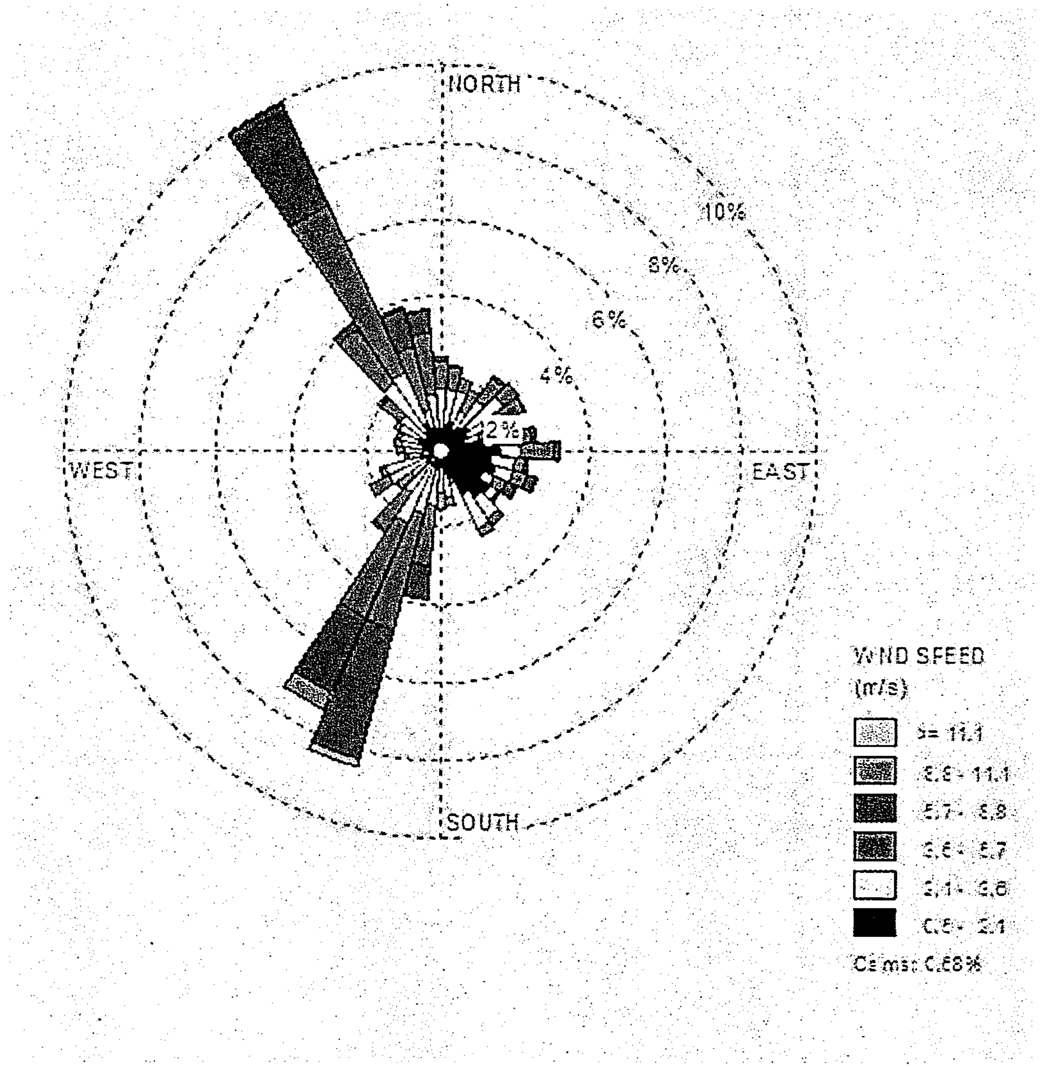
Max, Average and Min Power output for Month of July vs. Class



Max, Average and Min Power output for Month of August vs. Class




Power Output vs. Stability class for all three months
Powe Output (MW)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
Stability Class



Windrose data for Goderich Station for June, July and August 2006 combined.

APPENDIX E

THE BEATING PHENOMENON

E1. Background

One of the main source characteristics that has been attributed to wind turbine noise is they produce swishing sound. Alternate terminologies used for the swishing sound are; beating, thumping, hammer etc. etc. by people being exposed to the wind turbine noise.

G. P. van den berg in his doctoral dissertation, Chapter V-Page 61 (Reference 1) states, "Atmospheric stability is not only relevant for wind turbine sound *levels*, as we saw in he preceding chapter, but also for the *character* of the sound. In conditions where the atmosphere is stable, distant wind turbines can produce a beating or thumping sound that is not apparent in daytime."

A brief introduction is given in this appendix on the beating phenomenon in acoustics. Some salient points such as 'tuning process in music' as well as 'the subjective reaction' to beating are also highlighted. Clarification for beating in wind turbine noise is also given in this appendix and attempts will also be made to distinguish the 'swishing' phenomenon from 'the beating' phenomenon.

Two references are used extensively while preparing this appendix and are:

E1) *Fundamentals of Acoustics* by L. E. Kinsler and A. R. Frey, Second Edition, John Wiley & Sons, Inc. 1962. ISBN 0 471 46049 5; and

E2) Musical Acoustics – An Introduction by D. E. Hall, Wadsworth Publishing Co. 1980. ISBN 0-534-00758-9.

E2. Beats

A simple scientific definition of 'Beating' is: "the linear combination of two simple harmonic vibrations of nearly the same frequency results in the *phenomenon* of *beats*."

Without any loss of generality, each of the vibrating wave can be represented by,

$$\text{Wave}_1 = A_1 \sin(f_1 t) \quad \text{and} \quad \text{Wave}_2 = A_2 \sin(f_2 t) \qquad \text{(E1)}$$

Where, A_1 and A_2 are amplitudes of the two waves and f_1 and f_2 are the frequencies of the two the two waves. When the two waves are summed together, (i.e.) played together, the resulting vibration can be regarded as approximately simple harmonic, with a frequency that lies somewhere between f_1 and f_2 and the amplitude varying slowly at a frequency of $(f_1 - f_2)$ and we have assumed that f_1 is larger than f_2. The amplitude of the combined wave will 'wax' and 'wane' between the two limits $(A_1 + A_2)$ and $(A_1 - A_2)$.

In the case of sound waves, the simultaneous sounding of two pure tones of slightly different frequency, the above variation in amplitude results in a rhythmic pulsing of the loudness of the sound which occurs at a rate corresponding to the difference in frequency, $(f_1 - f_2)$, of the two sounds and is known as *beating*. Audible beats are heard whenever two sound of nearly the same frequency strike the ear, and when the frequency of each component is within the audible range. If the frequency difference is small, about 10 or less cycles per sec, the resulting sound waxes and wanes at this rate, with an apparent pitch corresponding to the average frequency. If, on the other hand, their frequency difference is about 200 cycles per sec or more, a combination tone may be observed whose frequency is equal to the difference between that of the two sounds. For intermediate frequency differences, the sound has a rough and discordant character.

A graphical representation of the onset and disappearance of the *beating* phenomenon is highlighted through a series of plots generated from two sounds and are shown in Figures E1 through E7 below.

Figure E1. The Beat Phenemenon

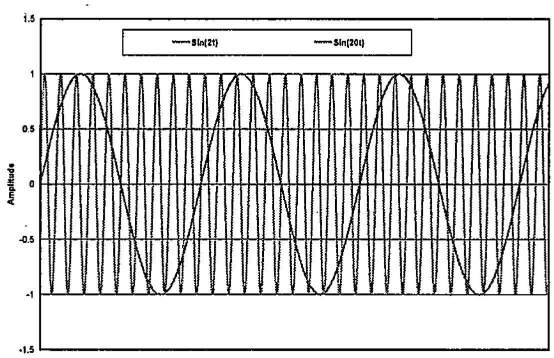


Figure E2. The Beat Phenemenon

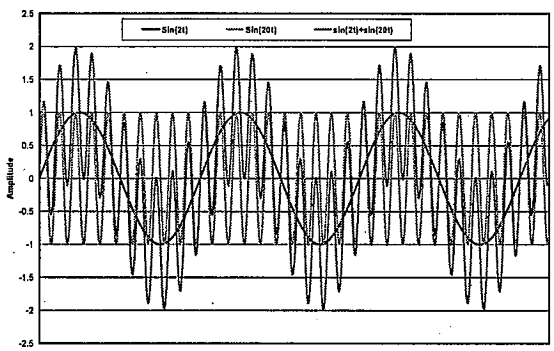


Figure E3. The Beat Phenemenon

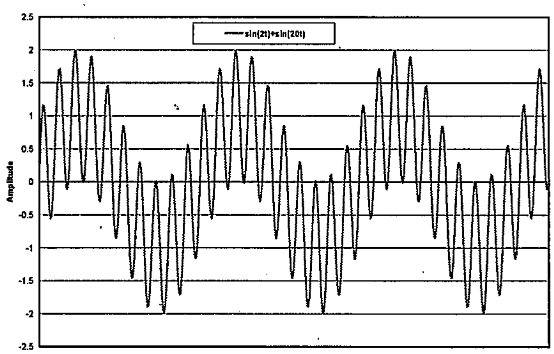


Figure E4. The Beat Phenemenon

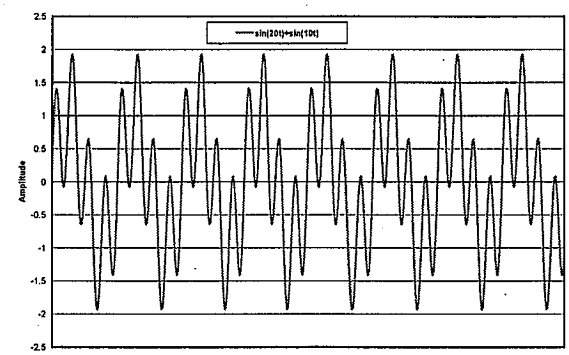


Figure E5. The Beat Phenemenon

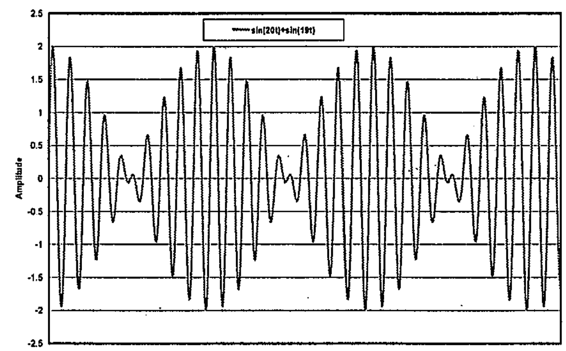


Figure E6. The Beat Phenemenon

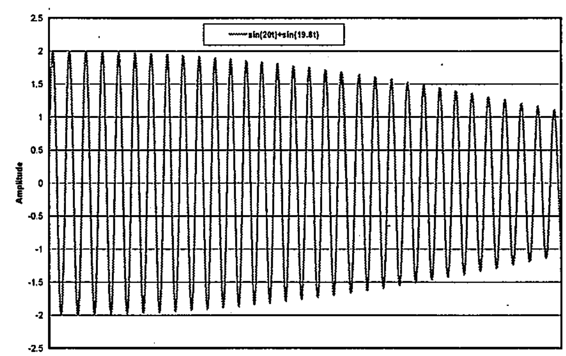


Figure E7. The Beat Phenemenon

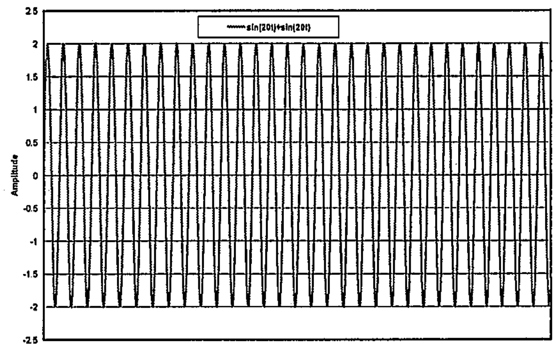


Figure E1 shows two simple sound waves at frequencies of 2 and 20 cycles per second, with their sum shown in Figure E2. One can see frequencies 2 and 20 as well as the beat frequency of 18. The *beat* is not as pronounced since the beat rate is close to the frequency of one of the two sounds as seen in Figure E3. The difference in the two frequencies is 10 in the 'beating' shown in Figure E4. The true 'beating' is not clear in Figure E4 since the beating rate is 10. Figures E5 and E6 show true *beat*. The amplitude is changing between 0 and 1 at a beat rate of 1 and 0.2.

E3. Subjective Response

If the sounds are within audible range, the resulting sound is heard as a single sound whose loudness varies smoothly and rhythmically at the beat rate, and it is said that the sounds *beat* with each other. Actually, the beating phenomenon is used by musical instrument tuners to tune, precisely by observing the beating and adjust for "zero" beat.

The main subjective effect of the 'beating phenomenon' is that the resulting sound appears harsh and discordant. The level of such a response is based on the beat rate as well as the level of the sound. At low levels of the sound, say less than 50 to 60 dB, the only effect is that waxing and waning of the sound.

APPENDIX F

AN ASSESSMENT PROCEDURE

F1. Background

One of the main concerns with the assessment procedures used by different jurisdictions, except New Zealand, is that the effects of meteorological conditions were not appropriately accounted for. Even the New Zealand approach accounts for the effect of wind shear by applying the wind speed data at each site, measured at the hub-height.

It was stated earlier that the current procedures in Ontario are very simple to apply and were similar to other jurisdiction in Europe. The procedure does not require the establishment of ambient sound levels at affected receptor locations before the installation of the wind farm. Neither is there a requirement to incorporate the prevailing meteorological conditions at the proposed wind farm site. Below is an example of one possible assessment process that could address the above concerns. Additional research and analysis would be required in order to develop an appropriate assessment process.

i. Following the standard procedures used in New Zealand, the ambient sound levels are to be monitored for a pre-set time, say for a month, at salient points of reception. The data should be collected in intervals of 10 minutes so as to be able to evaluate statistically valid analysis;
ii. The prevailing weather conditions, wind speed, direction, stability class are also measured at the wind farm site for the same duration and time intervals;
iii. The meteorological data is collected at a minimum of two heights (say 10 m and at hub-height);
iv. The analysis would involve correlation between wind profiles, determination of shear coefficients (similar to the schemes reported in Reference 22), support for the argument of hub-height wind speeds;
v. The noise prediction models, for the proposed wind farm, will include the effect of dominant scenarios of meteorological conditions and evaluate the potential range of noise levels;

vi. One would then assign suitable assessment conditions, based on appropriate statistical parameters, for the range of noise levels that can be expected at the salient points of receptions. Some preliminary concepts of this are:

a) Establish the noise levels at all salient receptor locations by applying the current MOE procedures;
b) Establish the expected increase in turbine sound power levels, by using the measured Meteorological (MET) data, and re-evaluate the noise levels at all the receptor locations;
c) Establish the dominant wind direction from the MET data and its percentage of occurrence. Most of the commercially available propagation models are able to incorporate basic MET data. Using the wind direction data, re-evaluate the noise levels at all salient receptor locations;
d) The results of Steps (a) thru' (c) would aid in setting up statistical analysis of noise levels, its variability and the number of affected residents. Average conclusions about the noise impact and potential mitigation methods if necessary can be established.

vii. Compliance of the wind farm site and potential adverse noise effects, based on acceptable annoyance criterion, can thus be included in the impact analysis to determine the suitability of the wind farm proposal.

The above process is one possible suggestion of the ways in which the current procedures can be revised to incorporate local meteorological conditions at the proposed wind farm sites.

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UMATILLA COUNTY
PLANNING DEPARTMENT

Tom and Maureen Rugg
PO Box 209
45422 Stewart Cr. Rd.
Pilot Rock, Oregon 97868

Commissioner Dennis Doherty
Umatilla County Courthouse
Pendleton, Oregon 97801

Dear Commissioner Doherty;

We would like to offer you this expose of the wind energy industry in Europe. We hope you find it informative and useful in planning for Umatilla Countys' coming industrialization of our Blue Mountains and their foothills. We need to determine if the cost is really worth the purported gain. Idaho Power is already planning a large transmission line through this area (85% on private ground) to balance generation between Wyoming wind farms and those in Eastern Oregon at a huge cost to taxpayer and rate payers, and will do so with a great deal of loss of that generated electricity. Our position is that these outlays are not prudent investments in our future energy needs, when present generation can be upgraded for much less with the same results. Our local agricultural and overall economy can ill afford the huge rate increases coming with this inefficient energy generation.

Sincerely,

Tom and Maureen Rugg

Tom Rugg

541-969-9058 c
541-443-6982 h
ruggrancheslIc@gmail.com

And book

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