

## Property Values

Some commenters stated concerns regarding the impact of the Bowers Project on property values, although no reports or evidence of such adverse impacts were submitted. Studies have been conducted on this issue and have found that there is no evidence that proximity to wind power projects has a measurable adverse impact on property values.

The most extensive and rigorous study to date on the relationship between wind energy projects and property values is a December, 2009 report entitled The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis (the “Berkeley Report”). The study was conducted by a U.S. Department of Energy (“DOE”) national laboratory that conducts a wide variety of unclassified scientific research for DOE and is managed by the University of California. The Berkeley Study analyzed nearly 7,500 home sales within 10 miles of 24 wind projects in nine states throughout the country, including the Northeast states of New York and Pennsylvania. The study provides an in-depth assessment on whether residential property values in the United States have been affected, in a statistically measurable way, by views of and proximity to wind power projects. Specifically, the study evaluated the potential for area stigma, scenic vista stigma, and nuisance stigma, and all three potential stigmas were investigated by exploring the potential impact of wind projects on home values based both on distance to and view of the projects from the homes. Berkeley Report at 10. Field visits were made to every house in the study to clearly determine the extent to which there was project visibility and to collect other essential data, and a number of statistical analyses and modeling were undertaken to evaluate the potential impact of wind turbines on residential property values.

The results demonstrated that there was no evidence “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.” Id. at xvii and 75. The Berkeley Report is attached as Exhibit B-1.

The results of the Berkeley Study are consistent with two other studies of note. The first is a 2006 study that examined the effect of a 20-turbine wind power facility in rural New York State on the value of properties within five miles. See Ben Hoen, Impacts of Windmill Visibility on Property Values in Madison County, New York (April 30, 2006). The Hoen study found that the visibility of wind turbines had no measurable effect on home prices. Id. at 34. The second is a 2003 study that analyzed property values within five miles of 10 different wind energy projects, also concluding that “there is no support for the claim that wind development will harm property values.” Sterzinger et al., The Effect of Wind Development on Local Property Values (May 2003) at 9. The Hoen and Sterzinger reports are attached as Exhibits B-2 and B-3.

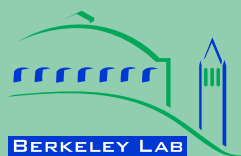
## Health Effects

There were also some general concerns articulated regarding perceived health effects of wind power project operations. This issue has been raised and rejected in several prior permitting proceedings, before both LURC and the DEP. The peer-reviewed medical and public health literature demonstrates that there is no evidence of any adverse health effects due to the types of noise and vibrations generated by projects such as Bowers. See Wind Turbine Neuro-

Acoustical Issues, Dora Ann Mills, MD, MPH, Maine CDC/DHHS, June, 2009 at 3 (“MCDC Report,” attached as Exhibit B-4). The MCDC Report also considered the potential health effects of low-frequency vibrations and infrasound, concluding that the sound levels associated with projects such as Bowers do not pose any health risk. MCDC Report at 4.

The conclusions of the MCDC are consistent with numerous credible studies on this issue. See, e.g., Roberts et al., Evaluation of the Scientific Literature on the Health Effects Associated with Wind Turbines and Low Frequency Sound, October 20, 2009 (“Roberts Report”); The Potential Health Impact of Wind Turbines, Chief Medical Officer of Health, Ontario, Canada, May, 2010 (“CMOH Report”); Colby et al., Wind Turbine Sound and Health Effects, an Expert Panel Review, December 2009 (“AWEA/CanWEA Report”) (attached as Exhibits B-5 through B-7). All three of the cited reports conclude that no scientific evidence exists showing any causal link between wind turbine noise and adverse health effects. Roberts Report at 44; CMOH Report at 10; AWEA/CanWEA Report at E-1.

Furthermore, the fact that commercial wind power projects do not pose a risk of adverse health effects on Maine residents has been reviewed and consistently affirmed in multiple permitting proceedings, administrative appeals and judicial reviews. See, e.g., Martha A. Powers Trust v. Bd. of Env'tl. Prot., 2011 ME 40, 15 A.3d 1273; Concerned Citizens to Save Roxbury v. Bd. of Env'tl. Prot., 2011 ME 39, 15 A.3d 1263; Friends of Lincoln Lakes v. Bd. of Env'tl. Prot., 2010 ME 18, 989 A.2d 1128.



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# **The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis**

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**Environmental Energy  
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**December 2009**

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United States: A Multi-Site Hedonic Analysis**

Prepared for the

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Wind & Hydropower Technologies Program  
U.S. Department of Energy  
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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.

## Table of Contents

|  |      |
|--|------|
| List of Tables .....   | vi   |
| List of Figures .....  | vii  |
| Acknowledgements .....   | viii |
| Executive Summary .....  | ix   |
| 1. Introduction .....  | 1    |
| 2. Previous Research .....   | 4    |
| 2.1. Hedonic Models and Environmental Disamenities .....                 | 4    |
| 2.2. Impacts of Wind Projects on Property Values .....                   | 6    |
| 3. Data Overview .....   | 10   |
| 3.1. Site Selection .....  | 10   |
| 3.2. Data Collection .....   | 13   |
| 3.2.1. Tabular Data .....  | 13   |
| 3.2.2. GIS Data .....  | 15   |
| 3.2.3. Field Data .....  | 15   |
| 3.2.4. Field Data Collection .....                                       | 18   |
| 3.3. Data Summary .....  | 18   |
| 4. Base Hedonic Model .....  | 23   |
| 4.1. Dataset .....   | 23   |
| 4.2. Model Form .....  | 24   |
| 4.3. Analysis of Results .....   | 28   |
| 5. Alternative Hedonic Models .....                                      | 33   |
| 5.1. View and Distance Stability Models .....                            | 33   |
| 5.1.1. Dataset and Model Form .....                                      | 34   |
| 5.1.2. Analysis of Results .....   | 35   |
| 5.2. Continuous Distance Model .....                                     | 36   |
| 5.2.1. Dataset and Model Form .....                                      | 36   |
| 5.2.2. Analysis of Results .....   | 37   |
| 5.3. All Sales Model .....   | 37   |
| 5.3.1. Dataset and Model Form .....                                      | 38   |
| 5.3.2. Analysis of Results .....   | 39   |
| 5.4. Temporal Aspects Model .....  | 42   |
| 5.4.1. Dataset and Model Form .....                                      | 42   |
| 5.4.2. Analysis of Results .....   | 44   |
| 5.5. Orientation Model .....   | 47   |
| 5.5.1. Dataset and Model Form .....                                      | 47   |
| 5.5.2. Analysis of Results .....   | 49   |
| 5.6. Overlap Model .....   | 50   |
| 5.6.1. Dataset and Model Form .....                                      | 51   |
| 5.6.2. Analysis of Results .....   | 52   |
| 6. Repeat Sales Analysis .....   | 55   |
| 6.1. Repeat Sales Models and Environmental Disamenities Literature ..... | 55   |

|      |   |     |
|------|---|-----|
| 6.2. | Dataset.....  | 56  |
| 6.3. | Model Form .....  | 57  |
| 6.4. | Analysis of Results .....   | 59  |
| 7.   | Sales Volume Analysis .....   | 63  |
| 7.1. | Dataset.....  | 63  |
| 7.2. | Model Form .....  | 65  |
| 7.3. | Analysis of Results .....   | 66  |
| 8.   | Wind Projects and Property Values: Summary of Key Results.....  | 69  |
| 8.1. | Area Stigma .....   | 69  |
| 8.2. | Scenic Vista Stigma .....   | 71  |
| 8.3. | Nuisance Stigma .....   | 73  |
| 9.   | Conclusions.....  | 75  |
|      | References.....   | 76  |
|      | Appendix A : Study Area Descriptions .....  | 82  |
|      | A.1 WAOR Study Area: Benton and Walla Walla Counties (Washington), and Umatilla<br>County (Oregon)..... | 84  |
|      | A.2 TXHC Study Area: Howard County (Texas).....   | 87  |
|      | A.3 OKCC Study Area: Custer County (Oklahoma).....  | 90  |
|      | A.4 IABV Study Area: Buena Vista County (Iowa) .....  | 93  |
|      | A.5 ILLC Study Area: Lee County (Illinois).....   | 96  |
|      | A.6 WIKCDC Study Area: Kewaunee and Door Counties (Wisconsin) .....                                     | 99  |
|      | A.7 PASC Study Area: Somerset County (Pennsylvania).....  | 102 |
|      | A.8 PAWC Study Area: Wayne County (Pennsylvania).....   | 105 |
|      | A.9 NYMCOC Study Area: Madison and Oneida Counties (New York).....                                      | 108 |
|      | A.10 NYMC Study Area: Madison County (New York).....  | 111 |
|      | Appendix B : Methodology for Calculating Distances with GIS .....                                       | 114 |
|      | Appendix C : Field Data Collection Instrument .....   | 117 |
|      | Appendix D : Vista Ratings with Photos .....  | 120 |
|      | Appendix E : View Ratings with Photos .....   | 122 |
|      | Appendix F : Selecting the Primary (“Base”) Hedonic Model.....  | 124 |
|      | F.1 Discussion of Fully Unrestricted Model Form .....   | 124 |
|      | F.2 Analysis of Alternative Model Forms .....   | 127 |
|      | F.3 Selecting a Base Model .....  | 131 |
|      | Appendix G : OLS Assumptions, and Tests for the Base Model .....  | 132 |
|      | Appendix H : Alternative Models: Full Hedonic Regression Results .....                                  | 139 |

## List of Tables

|   |     |
|---|-----|
| Table 1: Summary of Existing Literature on Impacts of Wind Projects on Property Values..... | 9   |
| Table 2: Summary of Study Areas.....  | 12  |
| Table 3: Definition of VIEW Categories.....   | 16  |
| Table 4: Definition of VISTA Categories.....  | 17  |
| Table 5: Summary of Transactions across Study Areas and Development Periods.....            | 19  |
| Table 6: Summary Statistics: All Sales and Post-Construction Sales.....                     | 21  |
| Table 7: Summary of Variables of Interest: All Sales and Post-Construction Sales.....       | 22  |
| Table 8: List of Variables of Interest Included in the Base Model.....                      | 25  |
| Table 9: List of Home and Site Characteristics Included in the Base Model.....              | 27  |
| Table 10: Results from the Base Model.....  | 32  |
| Table 11: Frequency Crosstab of VIEW and DISTANCE Parameters.....                           | 35  |
| Table 12: Results from Distance and View Stability Models.....                              | 35  |
| Table 13: Results from Continuous Distance Model.....                                       | 37  |
| Table 14: Frequency Summary for DISTANCE in All Sales Model.....                            | 39  |
| Table 15: Results from All Sales Model.....   | 41  |
| Table 16: Results from Equality Test of VIEW Coefficients in the All Sales Model.....       | 41  |
| Table 17: Results from Equality Test of DISTANCE Coefficients in the All Sales Model.....   | 42  |
| Table 18: Frequency Crosstab of DISTANCE and PERIOD.....                                    | 44  |
| Table 19: Results from Temporal Aspects Model.....  | 45  |
| Table 20: Results from Equality Test of Temporal Aspects Model Coefficients.....            | 47  |
| Table 21: Frequency Crosstab of VIEW and ORIENTATION.....                                   | 49  |
| Table 22: Percentage Crosstab of VIEW and ORIENTATION.....                                  | 49  |
| Table 23: Results from Orientation Model.....   | 50  |
| Table 24: Definition of OVERLAP Categories.....   | 51  |
| Table 25: Frequency Crosstab of OVERLAP and VIEW.....                                       | 52  |
| Table 26: Results from Overlap Model.....   | 54  |
| Table 27: List of Variables Included in the Repeat Sales Model.....                         | 57  |
| Table 28: Results from Repeat Sales Model.....  | 60  |
| Table 29: Sales Volumes by PERIOD and DISTANCE.....   | 64  |
| Table 30: Equality Test of Sales Volumes between PERIODS.....                               | 67  |
| Table 31: Equality Test of Volumes between DISTANCES using 3-5 Mile Reference.....          | 67  |
| Table 32: Equality Test of Sales Volumes between DISTANCES using 1-3 Mile Reference.....    | 67  |
| Table 33: Impact of Wind Projects on Property Values: Summary of Key Results.....           | 69  |
| Table A - 1: Summary of Study Areas.....  | 83  |
| Table A - 2: Summarized Results of Restricted and Unrestricted Model Forms.....             | 128 |
| Table A - 3: Summary of VOI Standard Errors for Restricted and Unrestricted Models.....     | 130 |
| Table A - 4: Summary of VOI Coefficients for Restricted and Unrestricted Models.....        | 130 |
| Table A - 5: Summary of Significant VOI Above and Below Zero in Unrestricted Models.....    | 131 |
| Table A - 6: Full Results for the Distance Stability Model.....                             | 139 |
| Table A - 7: Full Results for the View Stability Model.....                                 | 140 |
| Table A - 8: Full Results for the Continuous Distance Model.....                            | 141 |
| Table A - 9: Full Results for the All Sales Model.....                                      | 142 |
| Table A - 10: Full Results for the Temporal Aspects Model.....                              | 143 |
| Table A - 11: Full Results for the Orientation Model.....                                   | 145 |
| Table A - 12: Full Results for the Overlap Model.....                                       | 146 |

## List of Figures

|   |     |
|---|-----|
| Figure 1: Map of Study Areas and Potential Study Areas .....                          | 12  |
| Figure 2: Frequency of VISTA Ratings for All and Post-Construction Transactions ..... | 20  |
| Figure 3: Frequency of DISTANCE Ratings for Post-Construction Transactions.....       | 20  |
| Figure 4: Frequency of VIEW Ratings for Post-Construction Transactions .....          | 21  |
| Figure 5: Results from the Base Model for VISTA.....                                  | 29  |
| Figure 6: Results from the Base Model for VIEW .....                                  | 30  |
| Figure 7: Results from the Base Model for DISTANCE.....                               | 31  |
| Figure 8: Results from the Temporal Aspects Model.....                                | 46  |
| Figure 9: Repeat Sales Model Results for VIEW .....                                   | 61  |
| Figure 10: Repeat Sales Model Results for DISTANCE.....                               | 61  |
| Figure 11: Sales Volumes by PERIOD and DISTANCE .....                                 | 65  |
| Figure A - 1: Map of Study Areas .....  | 83  |
| Figure A - 2: Map of WAOR Study Area.....   | 84  |
| Figure A - 3: Map of TXHC Study Area .....  | 87  |
| Figure A - 4: Map of OKCC Study Area.....   | 90  |
| Figure A - 5: Map of IABV Study Area .....  | 93  |
| Figure A - 6: Map of ILLC Study Area .....  | 96  |
| Figure A - 7: Map of WIKCDC Study Area.....   | 99  |
| Figure A - 8: Map of PASC Study Area.....   | 102 |
| Figure A - 9: Map of PAWC Study Area .....  | 105 |
| Figure A - 10: Map of NYMCOC Study Area .....   | 108 |
| Figure A - 11: Map of NYMC Study Area .....   | 111 |
| Figure A - 12: Field Data Collection Instrument .....                                 | 117 |
| Figure A - 13: Field Data Collection Instrument - Instructions - Page 1.....          | 118 |
| Figure A - 14: Field Data Collection Instrument - Instructions - Page 2.....          | 119 |
| Figure A - 15: Histogram of Standardized Residuals for Base Model .....               | 133 |
| Figure A - 16: Histogram of Mahalanobis Distance Statistics for Base Model.....       | 133 |
| Figure A - 17: Histogram of Standardized Residuals for All Sales Model .....          | 134 |
| Figure A - 18: Histogram of Mahalanobis Distance Statistics for All Sales Model.....  | 134 |

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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<sup>1</sup> 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.

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<sup>1</sup> 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.<sup>2</sup>

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

### **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.

<sup>2</sup> 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**

| <b>Statistical Model</b>          | <b>Description</b>  |
|-----------------------------------|---|
| <b>Base Hedonic Model</b>         | Using only "post-construction" transactions (those that occurred after the wind facility was built), this model investigates all three stigmas in a straightforward manner  |
| <b>Alternative Hedonic Models</b> |   |
| 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   |
| <b>Repeat Sales Model</b>         | 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 |
| <b>Sales Volume Model</b>         | 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: |                      |                  | Section Reference |
|---------------------|-----------------------------------|----------------------|------------------|-------------------|
|                     | Area Stigma?                      | Scenic Vista Stigma? | Nuisance Stigma? |                   |
| 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**

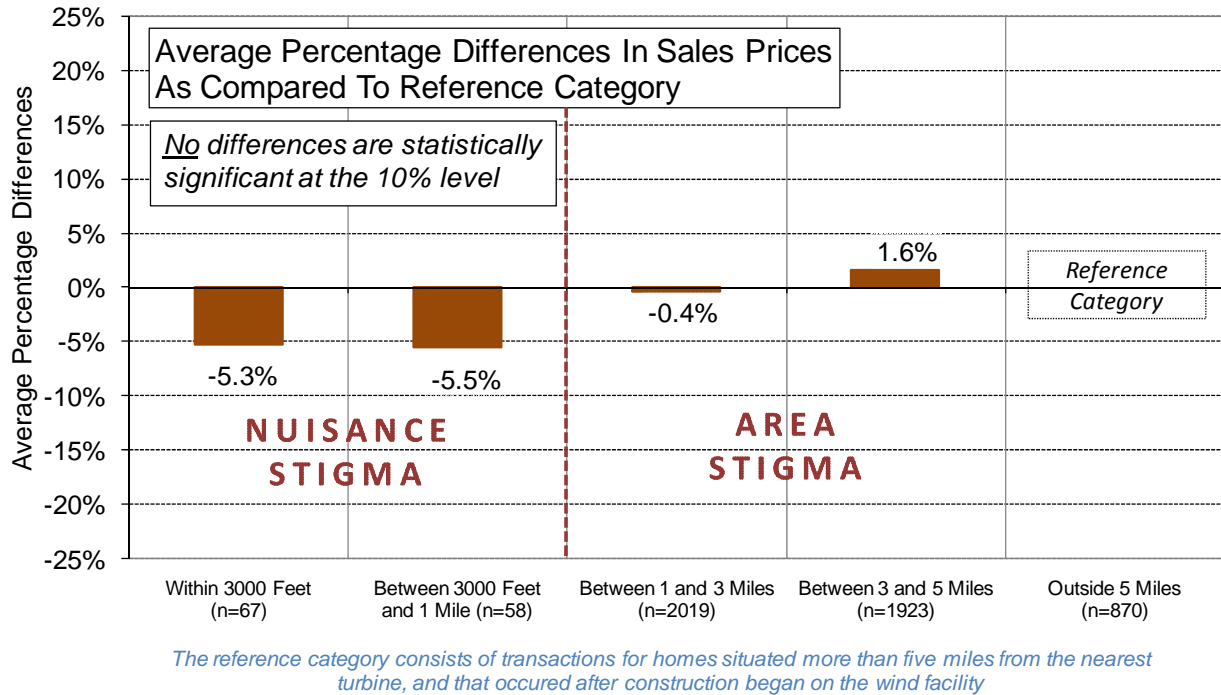
The Base Model serves as the primary model and allows all three stigmas to be explored. In sum, this model finds no persuasive evidence of any of the three potential stigmas: neither the view of the wind facilities nor the distance of the home to those facilities is found to have any consistent, measurable, 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,<sup>3</sup> the model again finds no persuasive statistical evidence that wind

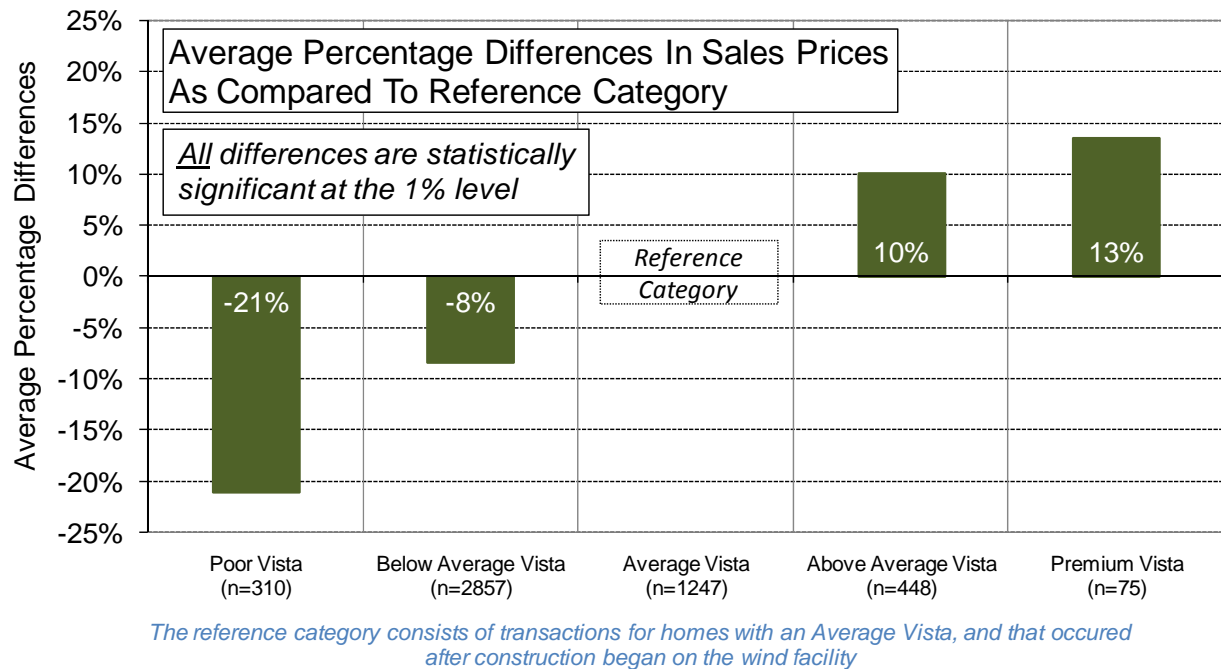
<sup>3</sup> 125 homes were located inside of one mile of the nearest wind facility and sold post-construction.

facilities measurably and broadly impact residential sales prices (see Figure ES-1 and later results).

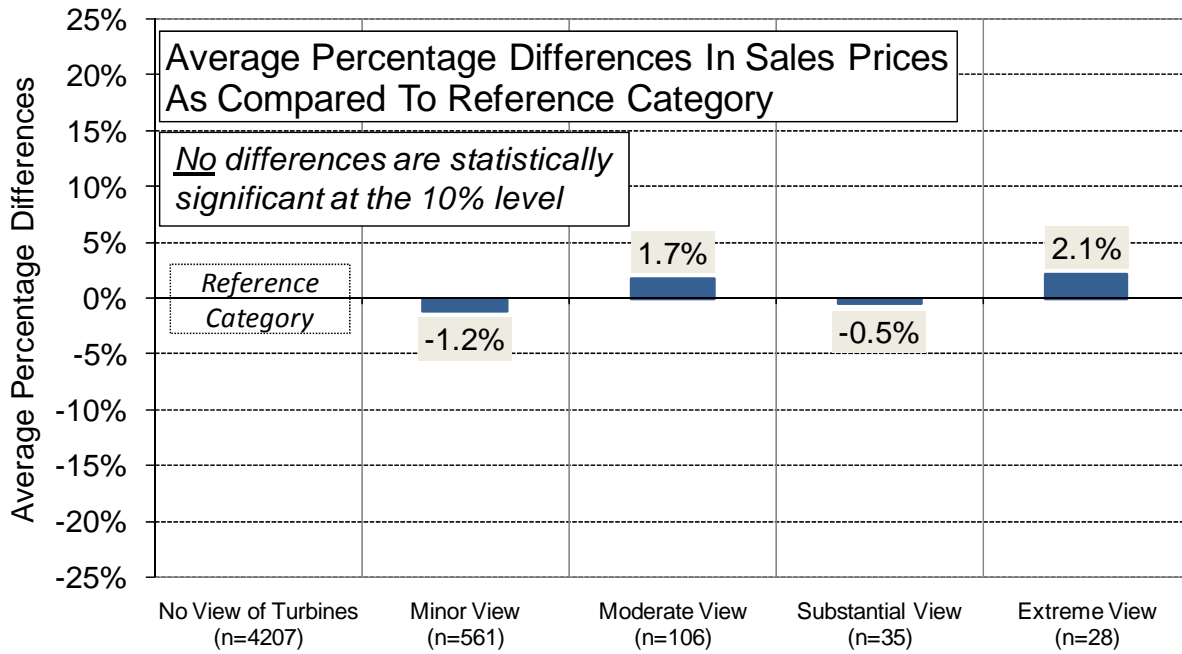
**Figure ES-1: Base Model Results: Area and Nuisance Stigma**



**Figure ES-2: Base Model Results: Scenic Vista**



**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 occurred 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,<sup>4</sup> 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

<sup>4</sup> 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.

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.

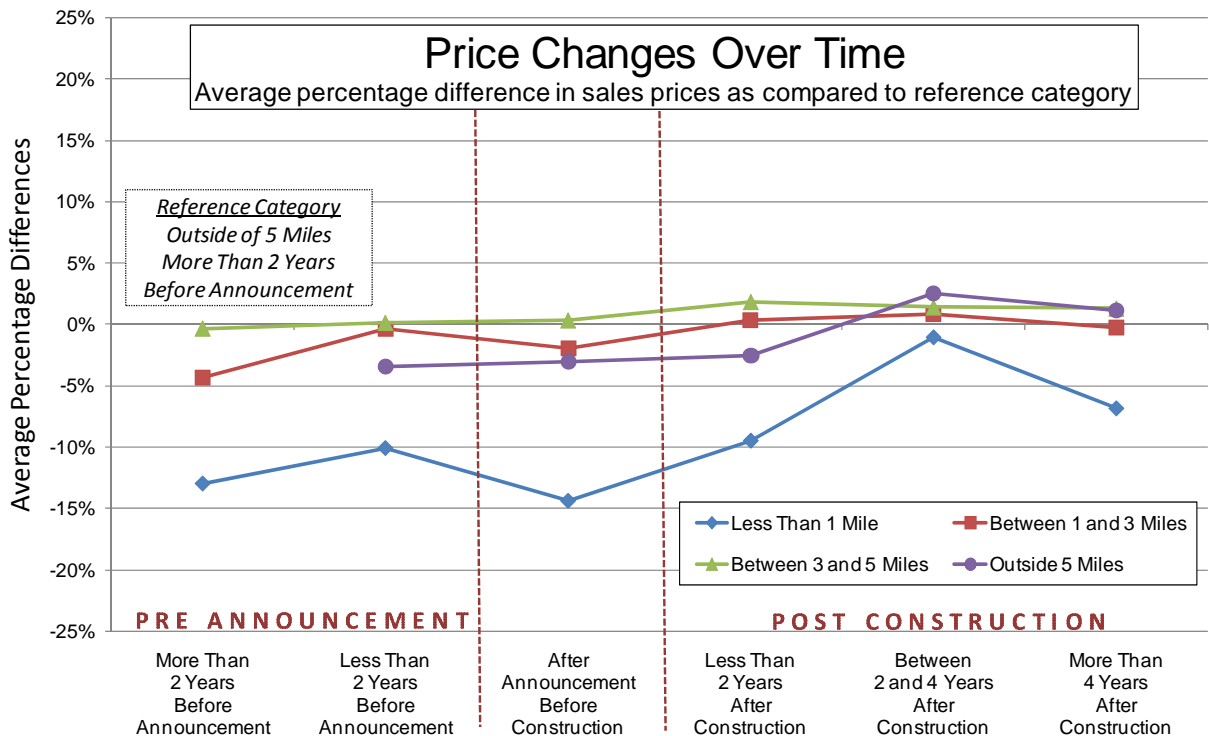
### ***Nuisance Stigma: Other Model Results***

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,

shadow flicker,<sup>5</sup> 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.<sup>6</sup> 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

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<sup>5</sup> 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).

<sup>6</sup> The majority of the analysis only includes homes that sold after wind facility construction began, totaling 4,937 transactions.

model<sup>7</sup> 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<sup>8</sup> and a sales volume model<sup>9</sup> 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.

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<sup>7</sup> The hedonic regression model, which was briefly described in a sidebar in the Executive Summary, is described in detail in Section 2.1.

<sup>8</sup> 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.

<sup>9</sup> 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:

$$\text{Sales price} = f(\text{house structural characteristics, other factors})$$

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.<sup>10</sup> 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.<sup>11</sup>

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<sup>10</sup> 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.

<sup>11</sup> 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

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).<sup>12</sup> 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.

<sup>12</sup> 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 lessened (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.<sup>13</sup>

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<sup>13</sup> 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).<sup>14, 15</sup> 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.<sup>16</sup> A survey of local residents, 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).<sup>17</sup> Similarly, some surveys of real estate experts conducted after facility

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<sup>14</sup> A *t*-Test is used to compare two sample means by discerning if one is significantly different from the other.

<sup>15</sup> 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.

<sup>16</sup> 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.

<sup>17</sup> 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.<sup>18</sup> 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.

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<sup>18</sup> 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**

| <u>Document Type</u><br>Author(s)  | Year | Number of Transactions or Respondents | Before or After Wind Facility Construction Commenced | Area Stigma | Scenic Vista Stigma | Nuisance Stigma |
|--|------|---------------------------------------|--|-------------|---------------------|-----------------|
| <b>Homeowner Survey</b>  |      |                                       |  |             |                     |                 |
| Haughton et al.  | 2004 | 501                                   | Before   | - *         | - *                 |                 |
| Goldman  | 2006 | 50                                    | After  | none        |                     |                 |
| Firestone et al.   | 2007 | 504                                   | Before   | - *         | - *                 |                 |
| Bond   | 2008 | ~300                                  | After  |             | - ?                 | - ?             |
| <b>Expert Survey</b>   |      |                                       |  |             |                     |                 |
| Grover   | 2002 | 13                                    | After  | none        |                     | none            |
| Haughton et al.  | 2004 | 45                                    | Before   | - *         | - *                 |                 |
| Khatri   | 2004 | 405                                   | Before <sup>†</sup>                                  | - ?         |                     | - ?             |
| Goldman  | 2006 | 50                                    | After  | none        |                     | none            |
| Kielisch   | 2009 | 57                                    | Before <sup>‡</sup>                                  |             |                     | - ?             |
| <b>Transaction Analysis - Simple Statistics</b>  |      |                                       |  |             |                     |                 |
| 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 <sup>†</sup>                                  | none        |                     |                 |
| Goldman  | 2006 | 4                                     | After  | none        |                     |                 |
| Poletti  | 2007 | 256                                   | After  | none        |                     | none            |
| McCann   | 2008 | 2                                     | After  |             |                     | - ?             |
| Kielisch   | 2009 | 103                                   | After  |             |                     | - ?             |
| <b>Transaction Analysis - Hedonic Model</b>  |      |                                       |  |             |                     |                 |
| Jordal-Jorgensen   | 1996 | ?                                     | After  |             |                     | - ?             |
| Hoehn  | 2006 | 280                                   | After  |             | none                |                 |
| Sims & Dent  | 2007 | 919                                   | After  |             |                     | - *             |
| Sims et al.  | 2008 | 199                                   | After  |             | -/+ *               |                 |
| <i>" 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)</i> |      |                                       |  |             |                     |                 |
| <i>" - ? " indicates a negative effect without statistical significance provided</i>   |      |                                       |  |             |                     |                 |
| <i>" - * " indicates statistically significant negative effect at 10% significance level</i>   |      |                                       |  |             |                     |                 |
| <i>" -/+ * " indicates positive and negative statistically significant effects at 10% significance level</i>   |      |                                       |  |             |                     |                 |
| <i>† Sales were collected after facility announcement but before construction</i>  |      |                                       |  |             |                     |                 |
| <i>‡ Some respondents had experience with valuations near facilities while others did not</i>  |      |                                       |  |             |                     |                 |

### 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.<sup>19</sup> 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.<sup>20</sup> 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.

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<sup>19</sup> A thorough discussion of this “pooled” approach is contained in Section 4.2 and in Appendix F.

<sup>20</sup> 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.

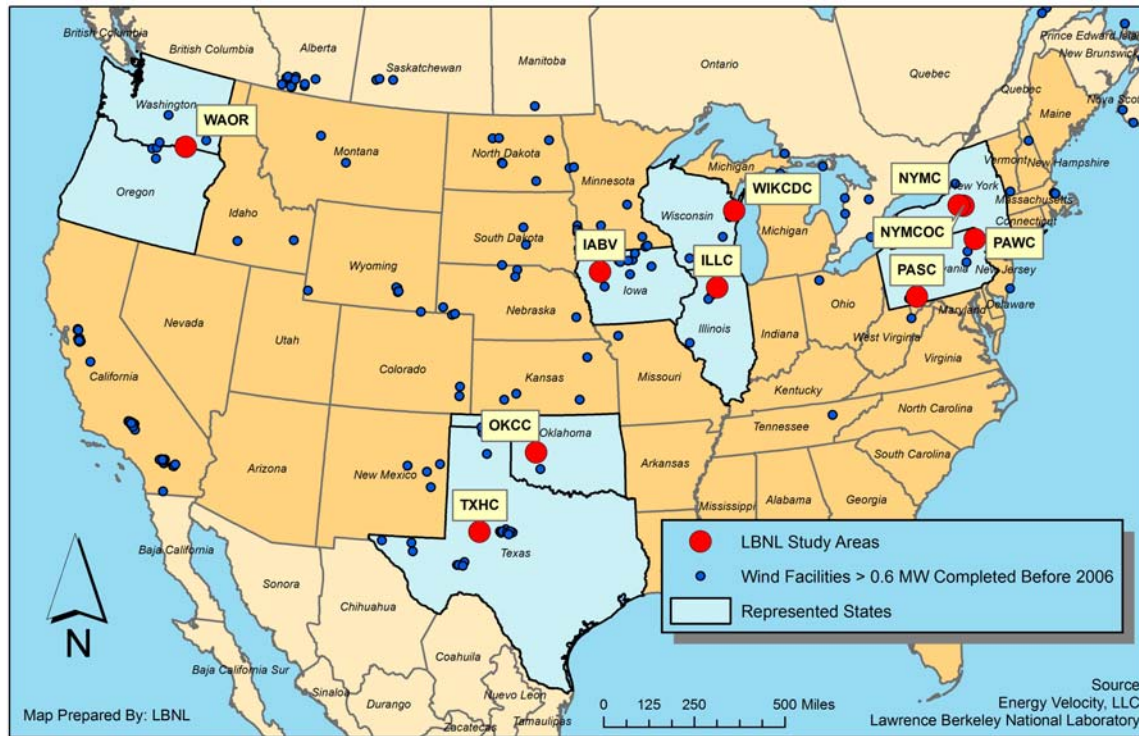
By using a variety of different GIS sorting techniques involving nearby towns with populations greater than, for example, 2,500 people, using census tract population densities, and having discussions with wind energy stakeholders, a prospective list of 56 possible study areas was generated, which were then ranked using two scales: “highly desirable” to “least desirable,” and “feasible” to “potentially unfeasible.”<sup>21</sup> 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).<sup>22</sup> A full description of each study area is provided in Appendix A.

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<sup>21</sup> “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.

<sup>22</sup> 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                   |
| ILIC            | 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                   |
| NYMCO           | Madison and Oneida Counties, NY                             | Madison  | 7                  | 12           | 67                      | 220                   |
| NYMC            | Madison County, NY  | Fenner   | 20                 | 30           | 66                      | 218                   |
|                 |   | <b>TOTAL</b>   | <b>1345</b>        | <b>1286</b>  |                         |                       |

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).<sup>23</sup>

### 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.<sup>24</sup> 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).<sup>25</sup> 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<sup>26</sup> containing 7,459 “valid”<sup>27</sup> transactions of single family residential homes, on less than 25 acres,<sup>28</sup> which were

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<sup>23</sup> Some areas, such as PASC, had both a ridgeline and rolling hills on which wind facilities were located.

<sup>24</sup> 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.

<sup>25</sup> 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.

<sup>26</sup> 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.

<sup>27</sup> 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,<sup>29</sup> which occurred after January 1, 1996,<sup>30</sup> 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,<sup>31</sup> if the home had exterior walls that were 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.<sup>32</sup> Finally, market-specific quarterly housing inflation indexes were obtained from Freddie Mac, which allowed nominal sales prices to be adjusted to 1996 dollars.<sup>33</sup>

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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.

<sup>28</sup> 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.

<sup>29</sup> 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.

<sup>30</sup> 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.

<sup>31</sup> “Year Built” was used to construct a variable for the age of the home at the time of the sale.

<sup>32</sup> These data were used to calculate the “Sales Volume” percentages referred to in Section 7.

<sup>33</sup> 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.<sup>34</sup> GIS data were obtained on water courses, water bodies, land elevations, and satellite imagery, as was necessary, from the U.S. Department of Agriculture.<sup>35</sup> 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.<sup>36</sup> 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”)<sup>37</sup> 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.<sup>38</sup> 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”)<sup>39</sup> 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),<sup>40</sup> but, at the time this project began, few measures had

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<sup>34</sup> 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](http://www.census.gov/geo/www/cob/bdy_files.html).

<sup>35</sup> These data were sourced from the USDA Geospatial Data Gateway: <http://datagateway.nrcs.usda.gov/GatewayHome.html>.

<sup>36</sup> 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.

<sup>37</sup> Distance measures are collectively and individually referred to as “DISTANCE” from this point forward.

<sup>38</sup> 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.

<sup>39</sup> View of turbines ratings are collectively and individually referred to as “VIEW” from this point forward.

<sup>40</sup> 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:<sup>41</sup>

**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.*

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.

<sup>41</sup>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<sup>2</sup> 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”)<sup>42</sup> 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:<sup>43</sup>

**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.*

<sup>42</sup> Scenic vista ratings are individually and collectively referred to as “VISTA” from this point forward.

<sup>43</sup> 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 were 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 ranking that 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.<sup>44</sup> 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.<sup>45</sup>

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).<sup>46</sup> 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 ( $n=767$ ),

---

<sup>44</sup> 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.

<sup>45</sup> 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.

<sup>46</sup> See description of “valid” in footnote 27 on page 13.

with the rest of the transactions occurring after construction commenced (66%,  $n=4,937$ ).<sup>47</sup> 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**

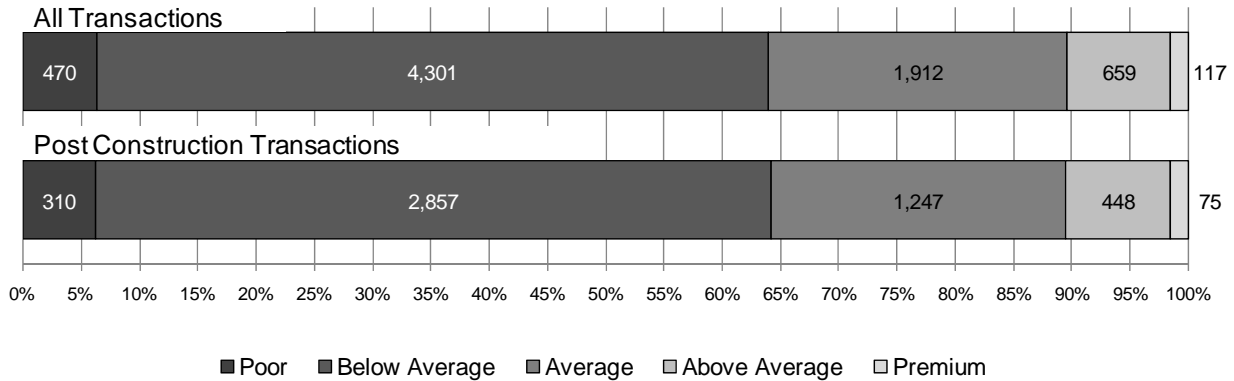
|   | Pre Announcement | Post Announcement Pre Construction | 1st Year After Construction | 2nd Year After Construction | 2+ Years After Construction | Total       |
|---|------------------|------------------------------------|-----------------------------|-----------------------------|-----------------------------|-------------|
| <b>Benton/Walla Walla, WA &amp; Umatilla, OR (WAOR)</b> | 226              | 45                                 | 76                          | 59                          | 384                         | <b>790</b>  |
| <b>Howard, TX (TXHC)</b>                                | 169              | 71                                 | 113                         | 131                         | 827                         | <b>1311</b> |
| <b>Custer, OK (OKCC)</b>                                | 484              | 153                                | 193                         | 187                         | 96                          | <b>1113</b> |
| <b>Buena Vista, IA (IABV)</b>                           | 152              | 65                                 | 80                          | 70                          | 455                         | <b>822</b>  |
| <b>Lee, IL (ILLC)</b>                                   | 115              | 84                                 | 62                          | 71                          | 80                          | <b>412</b>  |
| <b>Kewaunee/Door, WI (WIKCDC)</b>                       | 44               | 41                                 | 68                          | 62                          | 595                         | <b>810</b>  |
| <b>Somerset, PA (PASC)</b>                              | 175              | 28                                 | 46                          | 60                          | 185                         | <b>494</b>  |
| <b>Wayne, PA (PAWC)</b>                                 | 223              | 106                                | 64                          | 71                          | 87                          | <b>551</b>  |
| <b>Madison/Oneida, NY (MYMCOC)</b>                      | 108              | 9                                  | 48                          | 30                          | 268                         | <b>463</b>  |
| <b>Madison, NY (NYMC)</b>                               | 59               | 165                                | 74                          | 70                          | 325                         | <b>693</b>  |
| <b>TOTAL</b>  | <b>1755</b>      | <b>767</b>                         | <b>824</b>                  | <b>811</b>                  | <b>3302</b>                 | <b>7459</b> |

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

<sup>47</sup> 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.

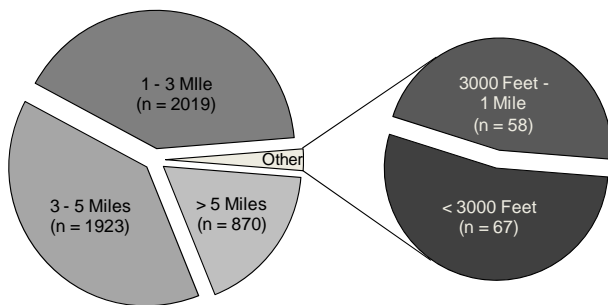
slightly better than average condition.<sup>48</sup> Within the full sample, 6% and 58% of homes had a poor or below average VISTA rating, respectively; 26% of homes received an average rating on this scale, with 9% above average and 2% experiencing premium vistas (see Figure 2).

**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).<sup>49</sup> 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.

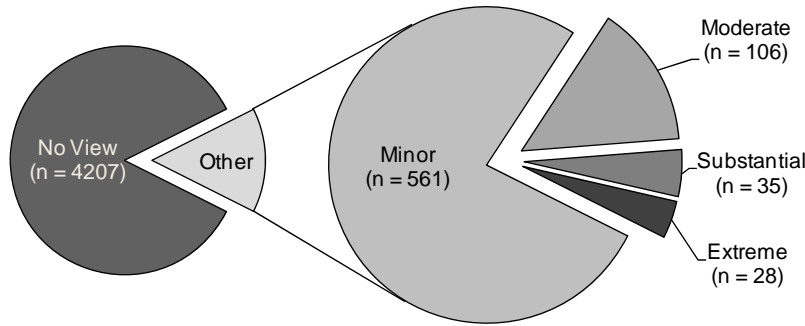
**Figure 3: Frequency of DISTANCE Ratings for Post-Construction Transactions**



<sup>48</sup> 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.

<sup>49</sup> 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**

| Variable Name  | Description  | All Sales |         |           | Post Construction Sales |         |           |
|----------------|--|-----------|---------|-----------|-------------------------|---------|-----------|
|                |  | 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

**Table 7: Summary of Variables of Interest: All Sales and Post-Construction Sales**

| Variable Name           | Description  | All Sales |      |           | Post Construction Sales |      |           |
|-------------------------|--|-----------|------|-----------|-------------------------|------|-----------|
|                         |  | Freq. *   | Mean | Std. Dev. | Freq. *                 | Mean | Std. Dev. |
| <b>View_None</b>        | 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      |
| <b>View_Minor</b>       | 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      |
| <b>View_Mod</b>         | 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      |
| <b>View_Sub</b>         | 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      |
| <b>View_Extrm</b>       | If the home sold after construction began and had an Extreme View of the turbines (Yes = 1, No = 0)                                | 28        | -    | 0.06      | 28                      | 0.01 | 0.08      |
| <b>DISTANCE †</b>       | 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      |
| <b>Mile_Less_0.57 †</b> | 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      |
| <b>Mile_0.57to1 †</b>   | 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      |
| <b>Mile_1to3 †</b>      | 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      |
| <b>Mile_3to5 †</b>      | 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      |
| <b>Mile_Gtr5 †</b>      | 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 occurred 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.<sup>50</sup> 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.

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<sup>50</sup> 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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_d \beta_5 \text{DISTANCE} + \varepsilon \quad (1)$$

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.),

$\beta_0$  is the constant or intercept across the full sample,

$\beta_1$  is a parameter estimate for the spatially weighted neighbor's predicted sales price,

$\beta_2$  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,

$\beta_3$  is a vector of  $k$  parameter estimates for the home and site characteristics,

$\beta_4$  is a vector of  $v$  parameter estimates for the VIEW variables as compared to homes sold with no view of the turbines,

$\beta_5$  is a vector of  $d$  parameter estimates for the DISTANCE variables as compared to homes sold situated outside of five miles, and

$\varepsilon$  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 ( $\beta_4$  and  $\beta_5$ ) 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.<sup>51</sup> This form of variable was used to

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<sup>51</sup> "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.<sup>52</sup> 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.<sup>53</sup>

**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 through 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

<sup>52</sup> 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.

<sup>53</sup> 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 ( $\epsilon$ ). 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  $\beta_1$  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  $\beta_2$  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.<sup>54</sup> 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"),<sup>55</sup> discrete ("D"),<sup>56</sup> binary ("B"),<sup>57</sup> 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.<sup>58</sup> Variables included are age

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<sup>54</sup> 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.

<sup>55</sup> See discussion in footnote 52 on previous page.

<sup>56</sup> 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).

<sup>57</sup> 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."

<sup>58</sup> 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.<sup>59</sup>

**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_BAveg      | 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_BAveg    | 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."

<sup>59</sup> 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<sup>60</sup>), 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.<sup>61</sup>

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.<sup>62</sup>

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).<sup>63</sup> The model performs well, with an adjusted  $R^2$  of 0.77.<sup>64</sup> The spatial adjustment coefficient ( $\beta_1$ ) 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 ( $\beta_2$ ) variables are all significant at the one percent level, demonstrating important differences in home valuations

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<sup>60</sup> The Schwarz information criterion measures relative parsimony between similar models (Schwarz, 1978).

<sup>61</sup> 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.

<sup>62</sup> 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.

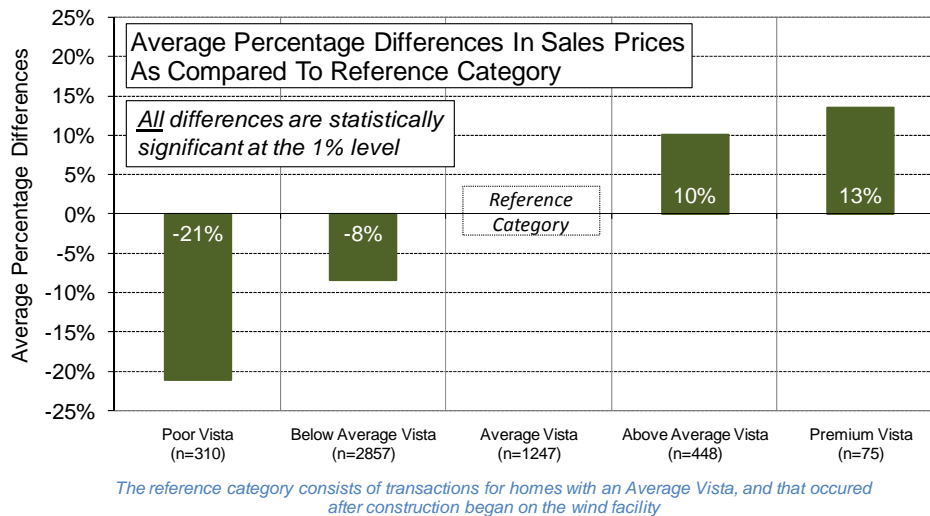
<sup>63</sup> This model and all subsequent models were estimated using the PROC REG procedure of SAS Version 9.2 TS1M0, which produces White's corrected standard errors.

<sup>64</sup> 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.<sup>65</sup> 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.<sup>66</sup>

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.<sup>67</sup>

**Figure 5: Results from the Base Model for VISTA**



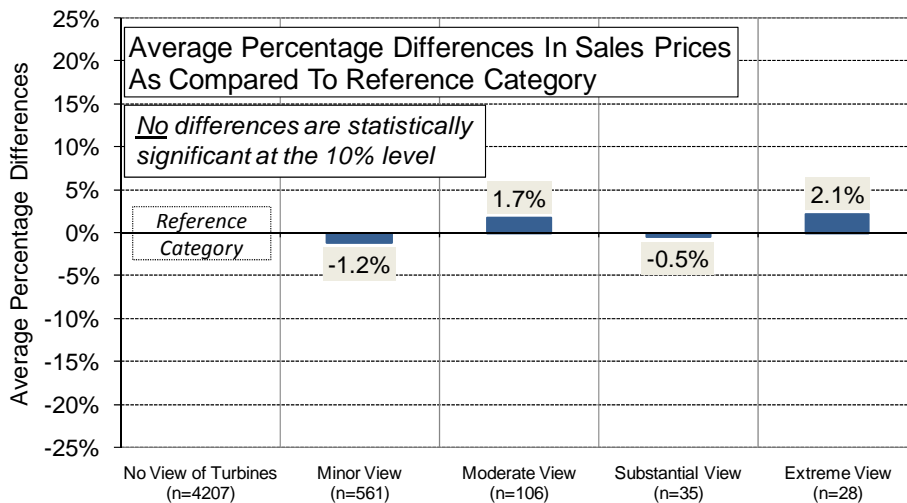
<sup>65</sup> The reference category WAOR study area has the highest mean and median house values in the sample (as shown in Appendix A) so the negative coefficients for all the study area fixed effect variables are appropriate.

<sup>66</sup> 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.

<sup>67</sup> 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.<sup>68</sup> The coefficients for the VIEW parameters ( $\beta_4$ ) 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**

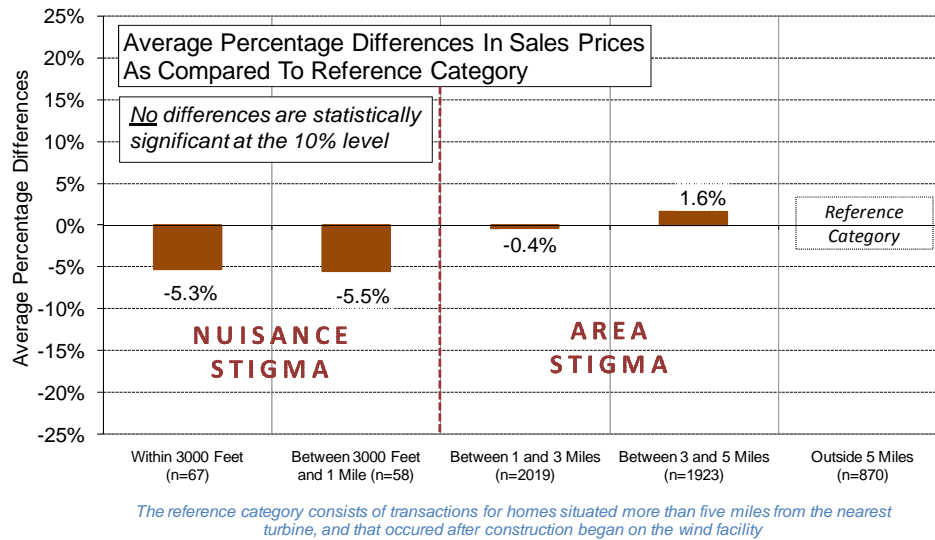


*The reference category consists of transactions for homes without a view of the turbines, and that occurred after construction began on the wind facility*

The coefficients for the DISTANCE parameters ( $\beta_5$ ) 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).

<sup>68</sup> 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.

**Figure 7: Results from the Base Model for DISTANCE**



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.<sup>69</sup> 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.

<sup>69</sup> 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**

|                               | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|-------------------------------|--------------|-----------|----------------|----------|
| <b>Intercept</b>              | 7.62         | 0.18      | 0.00           |          |
| <b>Nbr LN SalePrice96 hat</b> | 0.29         | 0.02      | 0.00           | 4,937    |
| <b>AgeatSale</b>              | -0.006       | 0.0004    | 0.00           | 4,937    |
| <b>AgeatSale Sqrd</b>         | 0.00002      | 0.000003  | 0.00           | 4,937    |
| <b>Sqft 1000</b>              | 0.28         | 0.01      | 0.00           | 4,937    |
| <b>Acres</b>                  | 0.02         | 0.00      | 0.00           | 4,937    |
| <b>Baths</b>                  | 0.09         | 0.01      | 0.00           | 4,937    |
| <b>ExtWalls Stone</b>         | 0.21         | 0.02      | 0.00           | 1,486    |
| <b>CentralAC</b>              | 0.09         | 0.01      | 0.00           | 2,575    |
| <b>Fireplace</b>              | 0.11         | 0.01      | 0.00           | 1,834    |
| <b>FinBsmnt</b>               | 0.08         | 0.02      | 0.00           | 673      |
| <b>Cul De Sac</b>             | 0.10         | 0.01      | 0.00           | 992      |
| <b>Water Front</b>            | 0.33         | 0.04      | 0.00           | 87       |
| <b>Cnd Low</b>                | -0.45        | 0.05      | 0.00           | 69       |
| <b>Cnd BAvg</b>               | -0.24        | 0.02      | 0.00           | 350      |
| <b>Cnd Avg</b>                | Omitted      | Omitted   | Omitted        | 2,727    |
| <b>Cnd AAvg</b>               | 0.14         | 0.01      | 0.00           | 1,445    |
| <b>Cnd High</b>               | 0.23         | 0.02      | 0.00           | 337      |
| <b>Vista Poor</b>             | -0.21        | 0.02      | 0.00           | 310      |
| <b>Vista BAvg</b>             | -0.08        | 0.01      | 0.00           | 2,857    |
| <b>Vista Avg</b>              | Omitted      | Omitted   | Omitted        | 1,247    |
| <b>Vista AAvg</b>             | 0.10         | 0.02      | 0.00           | 448      |
| <b>Vista Prem</b>             | 0.13         | 0.04      | 0.00           | 75       |
| <b>WAOR</b>                   | Omitted      | Omitted   | Omitted        | 519      |
| <b>TXHC</b>                   | -0.75        | 0.03      | 0.00           | 1,071    |
| <b>OKCC</b>                   | -0.44        | 0.02      | 0.00           | 476      |
| <b>IABV</b>                   | -0.24        | 0.02      | 0.00           | 605      |
| <b>ILLC</b>                   | -0.09        | 0.03      | 0.00           | 213      |
| <b>WIKCDC</b>                 | -0.14        | 0.02      | 0.00           | 725      |
| <b>PASC</b>                   | -0.31        | 0.03      | 0.00           | 291      |
| <b>PAWC</b>                   | -0.07        | 0.03      | 0.01           | 222      |
| <b>NYMCOC</b>                 | -0.20        | 0.03      | 0.00           | 346      |
| <b>NYMC</b>                   | -0.15        | 0.02      | 0.00           | 469      |
| <b>Post Con NoView</b>        | Omitted      | Omitted   | Omitted        | 4,207    |
| <b>View Minor</b>             | -0.01        | 0.01      | 0.40           | 561      |
| <b>View Mod</b>               | 0.02         | 0.03      | 0.58           | 106      |
| <b>View Sub</b>               | -0.01        | 0.07      | 0.94           | 35       |
| <b>View Extrm</b>             | 0.02         | 0.09      | 0.80           | 28       |
| <b>Mile Less 0 57</b>         | -0.05        | 0.06      | 0.40           | 67       |
| <b>Mile 0 57to1</b>           | -0.05        | 0.05      | 0.30           | 58       |
| <b>Mile 1to3</b>              | 0.00         | 0.02      | 0.80           | 2,019    |
| <b>Mile 3to5</b>              | 0.02         | 0.01      | 0.23           | 1,923    |
| <b>Mile Gtr5</b>              | Omitted      | Omitted   | Omitted        | 870      |

"Omitted" = reference category for fixed effects variables

"n" indicates number of cases in category when category = "1"

**Model Information**

|                                 |                       |
|---------------------------------|-----------------------|
| <b>Model Equation Number</b>    | <b>1</b>              |
| <b>Dependent Variable</b>       | <b>LN SalePrice96</b> |
| <b>Number of Cases</b>          | <b>4937</b>           |
| <b>Number of Predictors (k)</b> | <b>37</b>             |
| <b>F Statistic</b>              | <b>442.8</b>          |
| <b>Adjusted R Squared</b>       | <b>0.77</b>           |



## 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.<sup>70</sup>
- 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.

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<sup>70</sup> 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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_d \beta_5 \text{DISTANCE} + \varepsilon \quad (2)$$

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.),

$\text{DISTANCE}$  is a vector of  $d$  categorical distance variables (e.g., less than 3000 feet, between one and three miles, etc.),

$\beta_0$  is the constant or intercept across the full sample,

$\beta_1$  is a parameter estimate for the spatially weighted neighbor's predicted sales price,

$\beta_2$  is a vector of  $s$  parameter estimates for the study area fixed effects as compared to transactions of homes in the WAOR study area,

$\beta_3$  is a vector of  $k$  parameter estimates for the home and site characteristics,

$\beta_5$  is a vector of  $d$  parameter estimates for the DISTANCE variables as compared to transactions of homes situated outside of five miles, and

$\varepsilon$  is a random disturbance term.

The parameters of primary interest are  $\beta_5$ , 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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \varepsilon \quad (3)$$

where

$\text{VIEW}$  is a vector of  $v$  categorical view variables (e.g., MINOR, MODERATE, etc.),

$\beta_4$  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  $\beta_4$ , 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          |
| <b>TOTAL</b>     | <b>67</b>        | <b>58</b>                    | <b>2019</b>           | <b>1923</b>           | <b>870</b>      | <b>4937</b> |

### 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<sup>2</sup> 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,  $\beta_5$  and  $\beta_4$ , 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**

| Variables of Interest        | n    | Base Model |         |         | Distance Stability |         |         | View Stability |         |         |
|------------------------------|------|------------|---------|---------|--------------------|---------|---------|----------------|---------|---------|
|                              |      | 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.<sup>71</sup> 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:

$$\text{InvDISTANCE} = 1 / \text{DISTANCE} \quad (4)$$

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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \beta_5 \text{InvDISTANCE} + \varepsilon \quad (5)$$

where

InvDISTANCE<sub>*i*</sub> is the inverse of the distance to the nearest turbine,

$\beta_5$  is a parameter estimate for the inverse of the distance to the nearest turbine, and

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<sup>71</sup> 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  $\beta_5$ , 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 ( $\beta_5$ ) 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.<sup>72</sup>

**Table 13: Results from Continuous Distance Model**

| Variables of Interest        | Base Model |         |         |          | Continuous Distance |         |         |          |
|------------------------------|------------|---------|---------|----------|---------------------|---------|---------|----------|
|                              | Coef       | SE      | p Value | <i>n</i> | Coef                | SE      | p Value | <i>n</i> |
| 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

|                          |                |
|--------------------------|----------------|
| 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              |
| LN_SalePrice96 |
| 4937           |
| 34             |
| 481.3          |
| 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

<sup>72</sup> 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.<sup>73</sup> 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.<sup>74</sup> 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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_d \beta_5 \text{DISTANCE} + \varepsilon \quad (6)$$

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.),

$\beta_4$  is a vector of  $v$  parameter estimates for the VIEW variables as compared to pre-construction transactions,

$\beta_5$  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.<sup>75</sup> In the All Sales Model, on the other hand, the coefficients for VIEW ( $\beta_4$ ) are estimated in reference to all pre-construction transactions (spanning the pre-announcement and post-announcement-pre-construction periods) and the coefficients for DISTANCE ( $\beta_5$ ) 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

<sup>73</sup> This might be the case if there is an Area Stigma that includes the reference homes.

<sup>74</sup> 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.

<sup>75</sup> 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.<sup>76</sup>

**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       |
|---|--------------|----------------|-------------|-------------|-------------|-------------|
| <b>Post-Construction</b>                  | 67           | 58             | 2019        | 1923        | 870         | <b>4937</b> |
| <b>Post-Announcement-Pre-Construction</b> | 13           | 7              | 340         | 277         | 130         | <b>767</b>  |
| <b>TOTAL</b>                              | <b>80</b>    | <b>65</b>      | <b>2359</b> | <b>2200</b> | <b>1000</b> | <b>5704</b> |

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<sup>2</sup> 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-

<sup>76</sup> 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.<sup>77</sup> 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 ( $\beta_4$ ) 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.<sup>78</sup> 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 ( $\beta_5$ ) 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

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<sup>77</sup> 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.

<sup>78</sup> 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**

| Variables of Interest        | Base Model |         |         |       | All Sales |         |         |       |
|------------------------------|------------|---------|---------|-------|-----------|---------|---------|-------|
|                              | 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**

|                          |                |                |
|--------------------------|----------------|----------------|
| 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 |
|--------------------------|------------------|------------------------------|-----------------------|-----------------------|-----------------|
| <i>n</i>                 | 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             |
| <i>t</i> 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:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_y \beta_5 (\text{DISTANCE} \cdot \text{PERIOD}) + \varepsilon \quad (7)$$

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.),

$\beta_5$  is a vector of  $\gamma$  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

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.<sup>79</sup>

The number of transactions in each of the DISTANCE and PERIOD categories is presented in Table 18.

The coefficients of interest are  $\beta_5$ , 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.<sup>80</sup>

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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<sup>79</sup> 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 than being spread widely apart.

<sup>80</sup> 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"

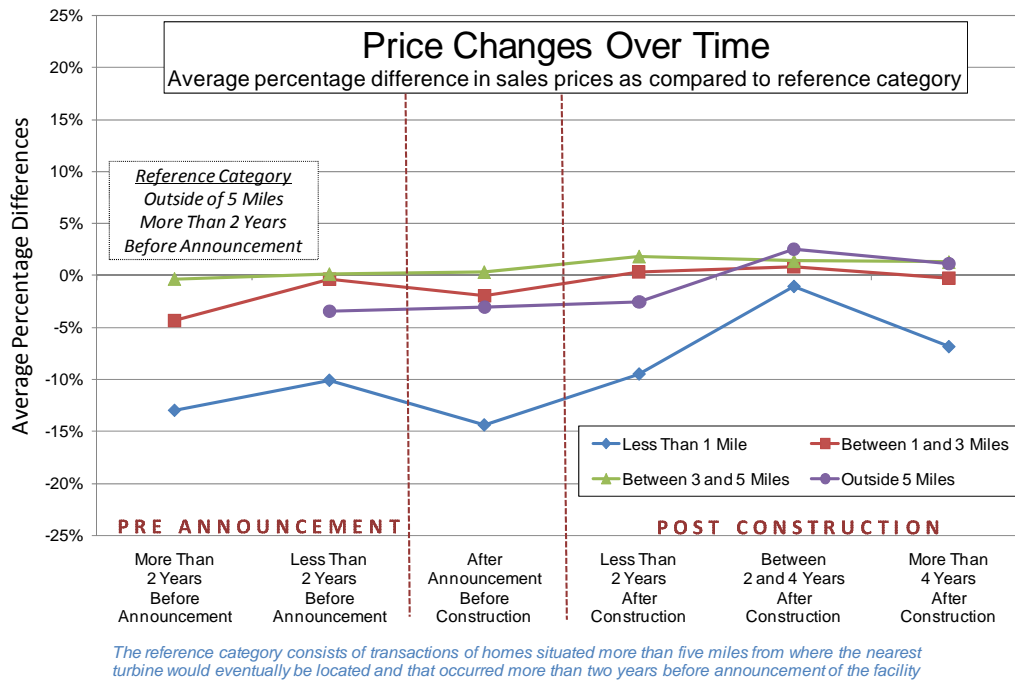
**Model Information**

|                          |                |
|--------------------------|----------------|
| 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.<sup>81</sup> 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.

<sup>81</sup> 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.<sup>82</sup>

<sup>82</sup> 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 greater 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:<sup>83</sup>

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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.

<sup>83</sup> The various possible orientations of the home to the view of turbines will be, individually and collectively, referred to as “ORIENTATION” in this report.

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_d \beta_5 \text{DISTANCE} + \sum_o \beta_6 \text{ORIENTATION} + \varepsilon \quad (8)$$

where

ORIENTATION is a vector of  $o$  ORIENTATION variables (e.g., SIDE, FRONT, and BACK),  $\beta_6$  is a vector of  $o$  parameter estimates for ORIENTATION variables, and all other components are as defined in equation (1).<sup>84</sup>

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).<sup>85</sup>

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.<sup>86</sup>

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<sup>84</sup> 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.

<sup>85</sup> 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.

<sup>86</sup> 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       |            |             |           | Total      |
|-------------|-------|------------|------------|-------------|-----------|------------|
|             |       | Minor      | Moderate   | Substantial | Extreme   |            |
| ORIENTATION | Front | 217        | 33         | 17          | 27        | <b>294</b> |
|             | Back  | 164        | 67         | 24          | 25        | <b>280</b> |
|             | Side  | 194        | 17         | 15          | 27        | <b>253</b> |
|             | Total | <b>561</b> | <b>106</b> | <b>35</b>   | <b>28</b> | <b>730</b> |

*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  |          |             |         | Total      |
|-------------|-------|-------|----------|-------------|---------|------------|
|             |       | Minor | Moderate | Substantial | Extreme |            |
| ORIENTATION | Front | 39%   | 31%      | 49%         | 96%     | <b>40%</b> |
|             | Back  | 29%   | 63%      | 69%         | 89%     | <b>38%</b> |
|             | Side  | 35%   | 16%      | 43%         | 96%     | <b>35%</b> |

*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 ( $\beta_6$ ) and VIEW ( $\beta_4$ ).  $\beta_6$  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 ( $\beta_6$ ) 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**

| Variables of Interest        | Base Model |         |         |          | Orientation Model |         |         |          |
|------------------------------|------------|---------|---------|----------|-------------------|---------|---------|----------|
|                              | Coef       | SE      | p Value | <i>n</i> | Coef              | SE      | p Value | <i>n</i> |
| 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**

|                          |                |
|--------------------------|----------------|
| 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           |

|                |
|----------------|
| 8              |
| LN_SalePrice96 |
| 4937           |
| 40             |
| 410.0          |
| 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.<sup>87</sup> The categories for OVERLAP included NONE, BARELY, SOMEWHAT, and STRONGLY, and are described in Table 24:<sup>88</sup>

**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:<sup>89</sup>

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_d \beta_5 \text{DISTANCE} + \sum_t \beta_6 \text{VISTA} + \sum_p \beta_7 \text{OVERLAP} + \varepsilon \quad (9)$$

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.),

<sup>87</sup> 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.

<sup>88</sup> "...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.

<sup>89</sup> 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.

$\beta_4$  is a vector of  $v$  parameter estimates for VIEW fixed effects variables as compared to transactions of homes without a view of the turbines,  
 $\beta_6$  is a vector of  $t$  parameter estimates for VISTA fixed effect variables as compared to transactions of homes with an AVERAGE scenic vista,  
 $\beta_7$  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  $\beta_4$ ,  $\beta_6$ , and  $\beta_7$  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  |       |          |             |         | Total |
|---------|----------|-------|-------|----------|-------------|---------|-------|
|         |          | None  | Minor | Moderate | Substantial | Extreme |       |
| 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 increase 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% increase in value over a home with NO VIEW of the turbines but a 5% increase 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.<sup>90</sup>

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.

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<sup>90</sup> 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**

|                          |                |
|--------------------------|----------------|
| 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           |

|                          |                |
|--------------------------|----------------|
| Model Equation Number    | 9              |
| Dependent Variable       | LN_SalePrice96 |
| Number of Cases          | 4937           |
| Number of Predictors (k) | 40             |
| F Statistic              | 409.7          |
| Adjusted R Squared       | 0.77           |

## 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:

$$\text{AAR} = \exp \left[ \frac{\ln(P_1 / P_2)}{t_1 - t_2} \right] - 1 \quad (10)$$

where

$P_1$  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.<sup>91</sup> 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.<sup>92</sup>

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.

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<sup>91</sup> 752 pairs occurred after construction began, whereas 133 pairs occurred before announcement.

<sup>92</sup> 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:

$$AAR = \beta_0 + \sum_s \beta_1 S + \sum_k \beta_2 X + \sum_v \beta_3 VIEW + \sum_d \beta_4 DISTANCE + \varepsilon \quad (11)$$

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.),

$\beta_0$  is the constant or intercept across the full sample,

$\beta_1$  is a vector of  $s$  parameter estimates for the study area fixed effects as compared to sales that occurred in the WAOR study area,

$\beta_2$  is a vector of  $k$  parameter estimates for the home, site, and sale characteristics,

$\beta_3$  is a vector of  $v$  parameter estimates for the VIEW variables as compared to transactions of homes with no view of the turbines,

$\beta_4$  is a vector of  $d$  parameter estimates for the DISTANCE variables as compared to transactions of homes outside of five miles, and

$\varepsilon$  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  $\beta_3$  and  $\beta_4$  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 ( $\beta_l$ ) 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

adjustment, and represent another test for Area Stigma; if effects exist, it is expected that the  $\beta_0$  and  $\beta_1$  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.<sup>93</sup>

#### 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.<sup>94</sup> 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 ( $\beta_0$ ) 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.

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<sup>93</sup> 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.

<sup>94</sup> 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**

|                                 | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|---------------------------------|--------------|-----------|----------------|----------|
| <b>Intercept</b>                | 0.005        | 0.02      | 0.81           | 354      |
| <b>WAOR</b>                     | Omitted      | Omitted   | Omitted        | 6        |
| <b>TXHC</b>                     | -0.01        | 0.02      | 0.63           | 57       |
| <b>OKCC</b>                     | 0.03         | 0.02      | 0.11           | 102      |
| <b>IABV</b>                     | 0.02         | 0.02      | 0.14           | 59       |
| <b>ILLC</b>                     | -0.01        | 0.02      | 0.38           | 18       |
| <b>WIKCDC</b>                   | 0.02         | 0.03      | 0.50           | 8        |
| <b>PASC</b>                     | -0.01        | 0.02      | 0.67           | 32       |
| <b>PAWC</b>                     | 0.02         | 0.02      | 0.16           | 35       |
| <b>NYMCOC</b>                   | 0.02         | 0.02      | 0.23           | 24       |
| <b>NYMC</b>                     | 0.03         | 0.02      | 0.13           | 13       |
| <b>SalePrice96 Pre</b>          | -0.000001    | 0.0000002 | 0.00           | 354      |
| <b>SalePrice96 Pre Sqr</b>      | 0.0000000    | 0.0000000 | 0.00           | 354      |
| <b>Acres</b>                    | 0.002        | 0.001     | 0.10           | 354      |
| <b>Sqft 1000</b>                | 0.02         | 0.01      | 0.00           | 354      |
| <b>No View</b>                  | Omitted      | Omitted   | Omitted        | 305      |
| <b>Minor View</b>               | -0.02        | 0.01      | 0.02           | 35       |
| <b>Moderate View</b>            | 0.03         | 0.03      | 0.29           | 5        |
| <b>Substantial/Extreme View</b> | -0.02        | 0.01      | 0.09           | 9        |
| <b>Less than 1 Mile</b>         | 0.03         | 0.01      | 0.01           | 14       |
| <b>Between 1 and 3 Miles</b>    | 0.01         | 0.01      | 0.59           | 199      |
| <b>Between 3 and 5 Miles</b>    | 0.01         | 0.01      | 0.53           | 116      |
| <b>Outside 5 Miles</b>          | Omitted      | Omitted   | Omitted        | 25       |

"Omitted" = reference category for fixed effects variables

"n" indicates number of cases in category when category = "1"

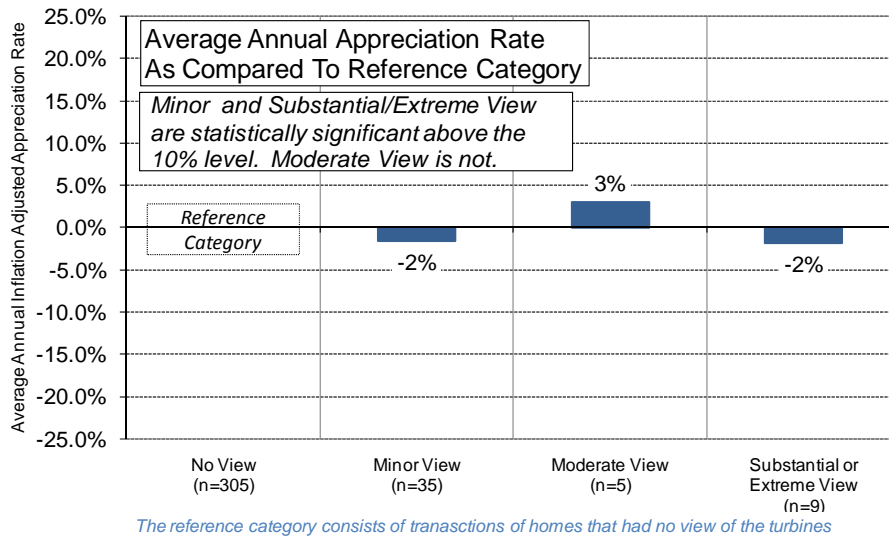
**Model Information**

|                                 |                        |
|---------------------------------|------------------------|
| <b>Model Equation Number</b>    | <b>11</b>              |
| <b>Dependent Variable</b>       | <b>SalePrice96 AAR</b> |
| <b>Number of Cases</b>          | <b>354</b>             |
| <b>Number of Predictors (k)</b> | <b>19</b>              |
| <b>F Statistic</b>              | <b>5.2</b>             |
| <b>Adjusted R2</b>              | <b>0.19</b>            |

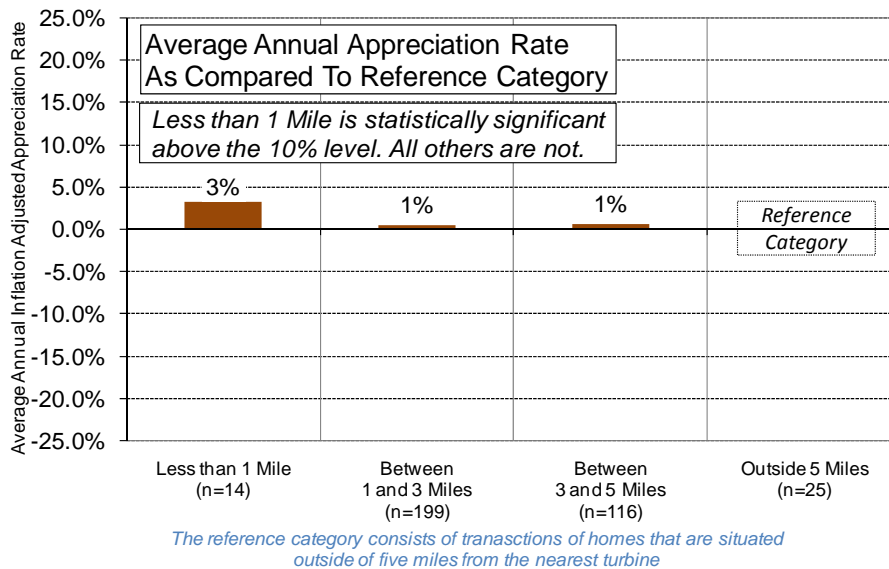
Turning to the variables of interest, mixed results (see Figure 9 and Figure 10) are found. For homes with MINOR or SUBSTANTIAL/EXTREME VIEWS, despite small sample sizes, appreciation rates after adjusting for inflation are found to decrease by roughly 2% annually ( $p$  values of 0.02 and 0.09, respectively) 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**



**Figure 10: Repeat Sales Model Results for DISTANCE**



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.<sup>95</sup> 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 ( $n \sim 1,250$ ). 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.<sup>96</sup> The resulting

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<sup>95</sup> “Market value” is the estimated price at which a home would sell as of a given point in time.

<sup>96</sup> 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.<sup>97</sup>

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.<sup>98</sup> 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.<sup>99</sup> 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**

|   | <b>Inside<br/>1 Mile</b> | <b>Between<br/>1 and 3 Miles</b> | <b>Between<br/>3 and 5 Miles</b> |
|---|--------------------------|----------------------------------|----------------------------------|
| <b>Less Than 3 Years Before Announcement</b>    | 2.2%                     | 1.8%                             | 2.3%                             |
| <b>After Announcement Before Construction</b>   | 3.0%                     | 2.5%                             | 3.7%                             |
| <b>Less Than 2 Years After Construction</b>     | 2.1%                     | 3.0%                             | 4.2%                             |
| <b>Between 2 and 4 Years After Construction</b> | 2.8%                     | 2.8%                             | 4.2%                             |

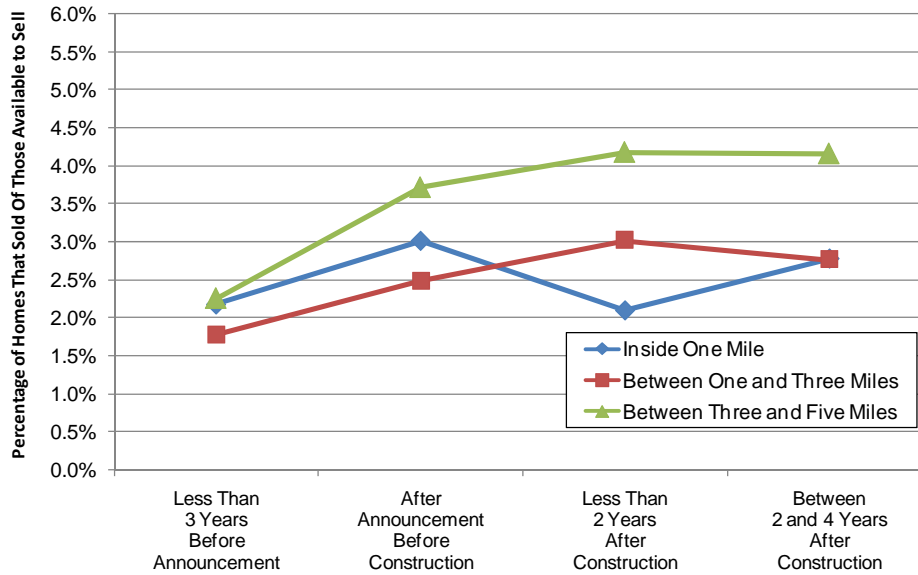
<sup>97</sup> The number of homes “available to sell” is constructed for each year after 1996 based on the year the homes in each study area were built. For many homes in the sample, the year built occurred more than three years before wind facility announcement, and therefore those homes are “available 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.

<sup>98</sup> 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.

<sup>99</sup> 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:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad (12)$$

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.<sup>100</sup>

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

<sup>100</sup> 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.<sup>101</sup>

### 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.<sup>102</sup>

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

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<sup>101</sup> 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.

<sup>102</sup> 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**

|   | <b>Inside<br/>1 Mile</b> | <b>Between<br/>1 and 3 Miles</b> | <b>Between<br/>3 and 5 Miles</b> |
|---|--------------------------|----------------------------------|----------------------------------|
| <b>Less Than 3 Years Before Announcement</b>    | Reference                | Reference                        | Reference                        |
| <b>After Announcement Before Construction</b>   | 0.8% (0.72)              | 0.7% (0.99)                      | 1.5% (1.49)                      |
| <b>Less Than 2 Years After Construction</b>     | -0.1% (-0.09)            | 1.2% (2.45) *                    | 1.9% (2.4) *                     |
| <b>Between 2 and 4 Years After Construction</b> | 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**

|   | <b>Inside<br/>1 Mile</b> | <b>Between<br/>1 and 3 Miles</b> | <b>Between<br/>3 and 5 Miles</b> |
|---|--------------------------|----------------------------------|----------------------------------|
| <b>Less Than 3 Years Before Announcement</b>    | -0.1% (-0.09)            | -0.5% (-0.88)                    | Reference                        |
| <b>After Announcement Before Construction</b>   | -0.7% (-0.56)            | -1.2% (-1.13)                    | Reference                        |
| <b>Less Than 2 Years After Construction</b>     | -2.1% (-2.41) *          | -1.2% (-1.48)                    | Reference                        |
| <b>Between 2 and 4 Years After Construction</b> | -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**

|   | <b>Inside<br/>1 Mile</b> | <b>Between<br/>1 and 3 Miles</b> | <b>Between<br/>3 and 5 Miles</b> |
|---|--------------------------|----------------------------------|----------------------------------|
| <b>Less Than 3 Years Before Announcement</b>    | 0.4% (0.49)              | Reference                        | 0.5% (0.88)                      |
| <b>After Announcement Before Construction</b>   | 0.5% (0.47)              | Reference                        | 1.2% (1.13)                      |
| <b>Less Than 2 Years After Construction</b>     | -0.9% (-1.38)            | Reference                        | 1.2% (1.48)                      |
| <b>Between 2 and 4 Years After Construction</b> | 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**

| Statistical Model   | <u>Is there statistical evidence of:</u> |                      |                  | Section Reference  |
|---------------------|--|----------------------|------------------|--------------------|
|                     | Area Stigma?                             | Scenic Vista Stigma? | Nuisance Stigma? |                    |
| Base Model          | No                                       | No                   | No               | <i>Section 4</i>   |
| View Stability      | Not tested                               | No                   | Not tested       | <i>Section 5.1</i> |
| Distance Stability  | No                                       | Not tested           | No               | <i>Section 5.1</i> |
| Continuous Distance | No                                       | No                   | No               | <i>Section 5.2</i> |
| All Sales           | No                                       | No                   | Limited          | <i>Section 5.3</i> |
| Temporal Aspects    | No                                       | No                   | No               | <i>Section 5.4</i> |
| Orientation         | No                                       | No                   | No               | <i>Section 5.5</i> |
| Overlap             | No                                       | Limited              | No               | <i>Section 5.6</i> |
| Repeat Sales        | No                                       | Limited              | No               | <i>Section 6</i>   |
| Sales Volume        | No                                       | Not tested           | No               | <i>Section 7</i>   |

"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 Wayne, 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.<sup>103</sup>

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<sup>103</sup> 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.”<sup>104</sup> 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.

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<sup>104</sup> 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.<sup>105</sup>

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<sup>105</sup> 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 not 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 improves 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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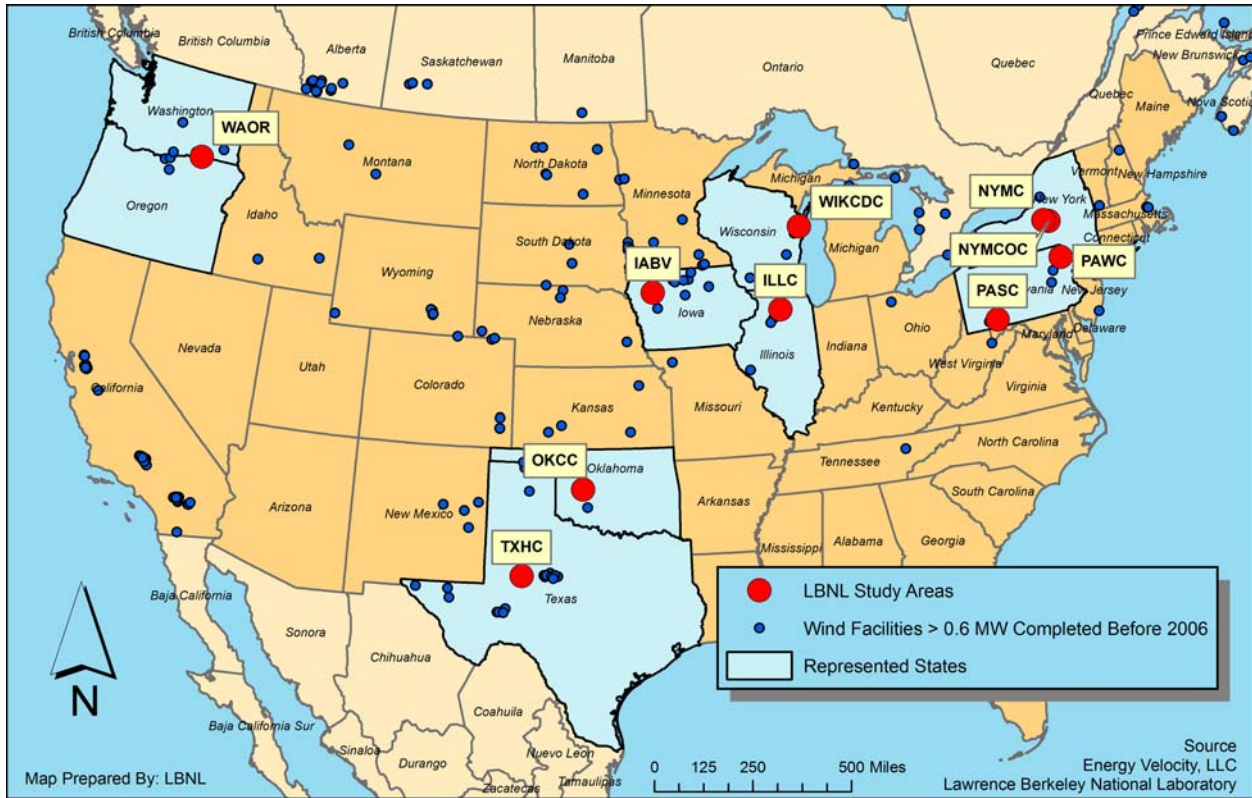


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## **Appendix A: Study Area Descriptions**

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**

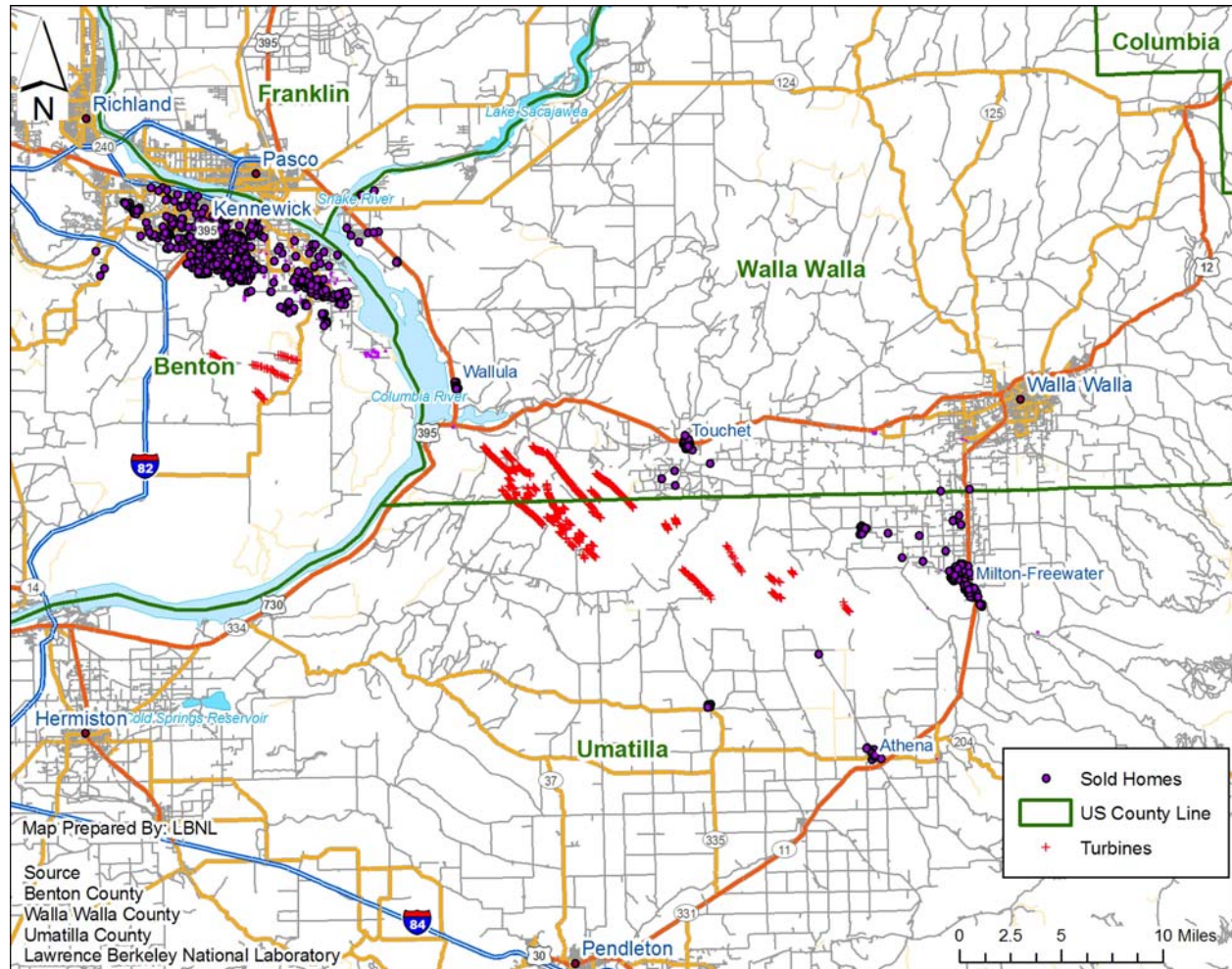


**Table A - 1: Summary of Study Areas**

| 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                   |
| ILCC            | 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                   |
| NYMCO           | Madison and Oneida Counties, NY                             | Madison  | 7                  | 12           | 67                      | 220                   |
| NYMCO           | Madison County, NY  | Fenner   | 20                 | 30           | 66                      | 218                   |
|                 |   | <b>TOTAL</b>   | <b>1345</b>        | <b>1286</b>  |                         |                       |

## 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

|  |                         |   |                                    |                                    |                                    |                     |              |
|--|-------------------------|---|------------------------------------|------------------------------------|------------------------------------|---------------------|--------------|
| <b>Development Period</b>                    | <b>Pre Announcement</b> | <b>Post Announcement Pre Construction</b> | <b>1st Year After Construction</b> | <b>2nd Year After Construction</b> | <b>2+ Years After Construction</b> | <b>Total</b>        |              |
| Benton/Walla Walla, WA & Umatilla, OR (WAOR) | 226                     | 45  | 76                                 | 59                                 | 384                                | 790                 |              |
| <b>View of Turbines</b>                      | <b>Pre Construction</b> | <b>None</b>                               | <b>Minor</b>                       | <b>Moderate</b>                    | <b>Substantial</b>                 | <b>Extreme</b>      | <b>Total</b> |
| Benton/Walla Walla, WA & Umatilla, OR (WAOR) | 271                     | 409                                       | 106                                | 4                                  | 0                                  | 0                   | 790          |
| <b>Distance to Nearest Turbine</b>           | <b>Pre Construction</b> | <b>&lt; 0.57 Miles</b>                    | <b>0.57 - 1 Miles</b>              | <b>1 - 3 Miles</b>                 | <b>3 - 5 Miles</b>                 | <b>&gt; 5 Miles</b> | <b>Total</b> |
| Benton/Walla Walla, WA & Umatilla, OR (WAOR) | 271                     | 0   | 0                                  | 20                                 | 277                                | 222                 | 790          |

### Census Statistics

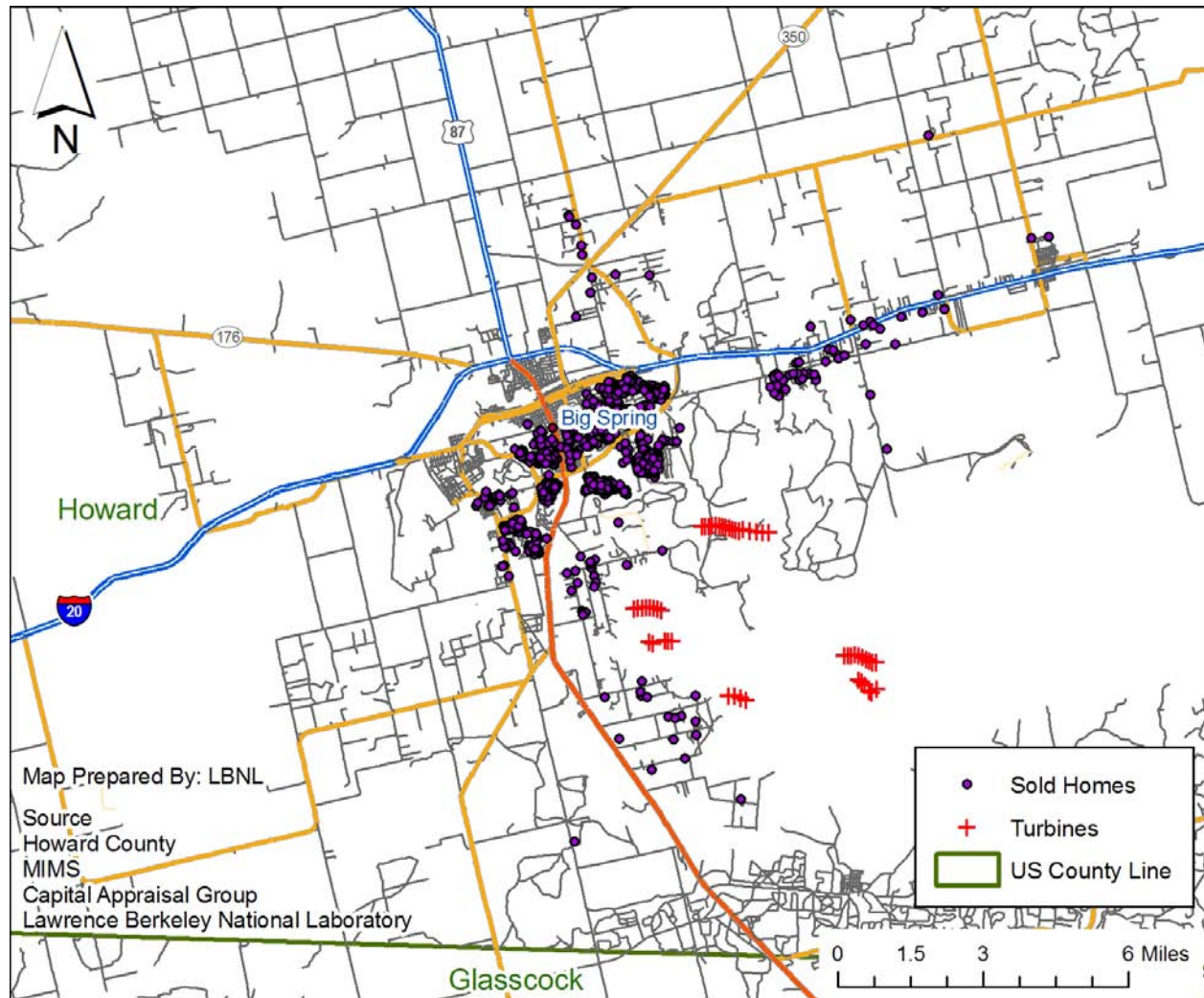
| Name                 | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | Median Age | Median Income | Median House 2007 | % Change Since 2000 |
|----------------------|---------|-----------------|---------------------|----------------------------------|------------|---------------|-------------------|---------------------|
| 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 Forсан (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.<sup>106</sup> 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  |

<sup>106</sup> If parcels intersected the five mile boundary, they were included in the sample, but were coded as being outside of five miles.



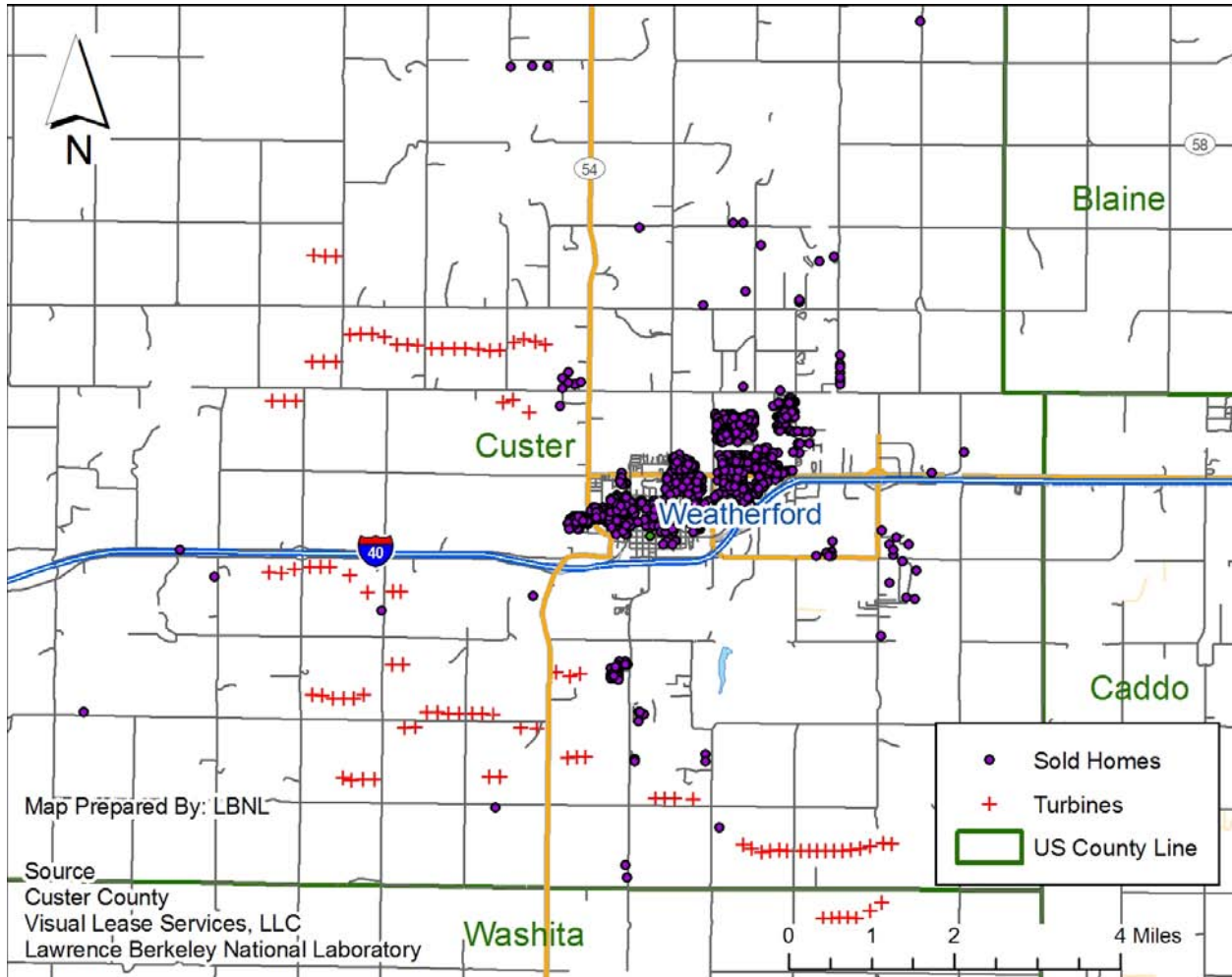
## Census Statistics

| Name       | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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.

### 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 OK Assessor, 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.<sup>107</sup> 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  |

<sup>107</sup> 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.

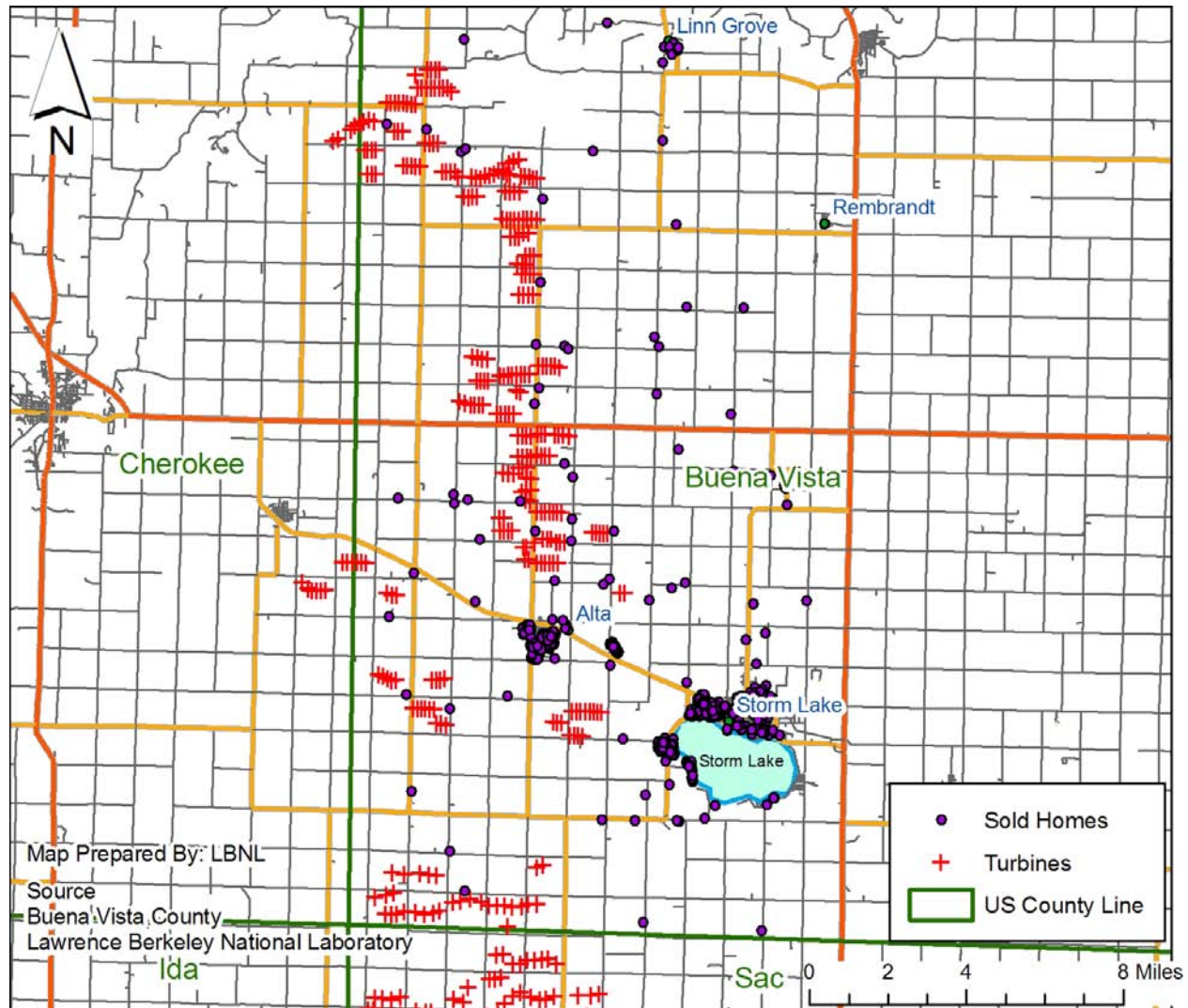
## Census Statistics

| Name        | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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 - that is 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   |

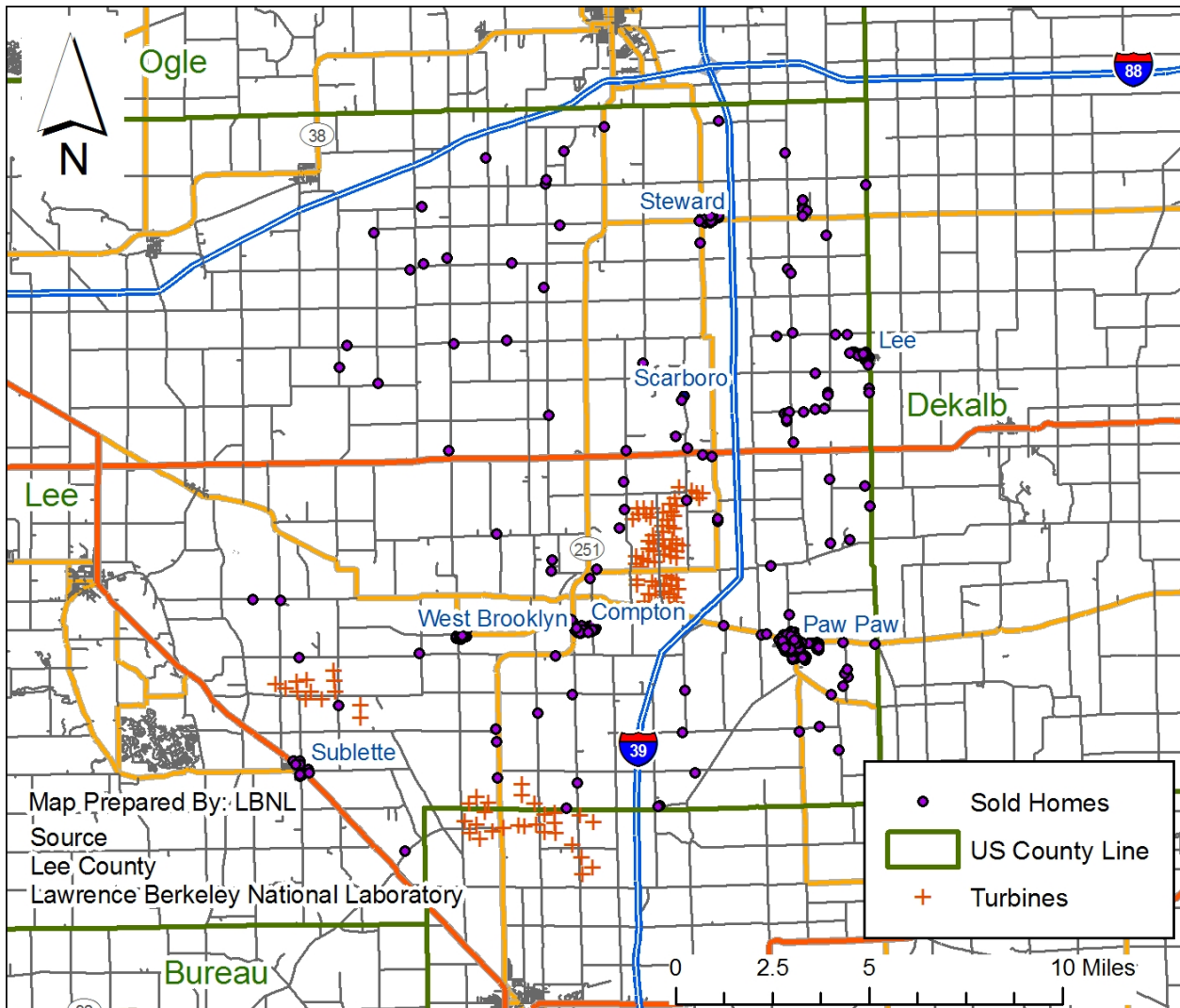
### Census Statistics

| Name        | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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 Grevengeod 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.<sup>108</sup> 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.

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<sup>108</sup> 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   |

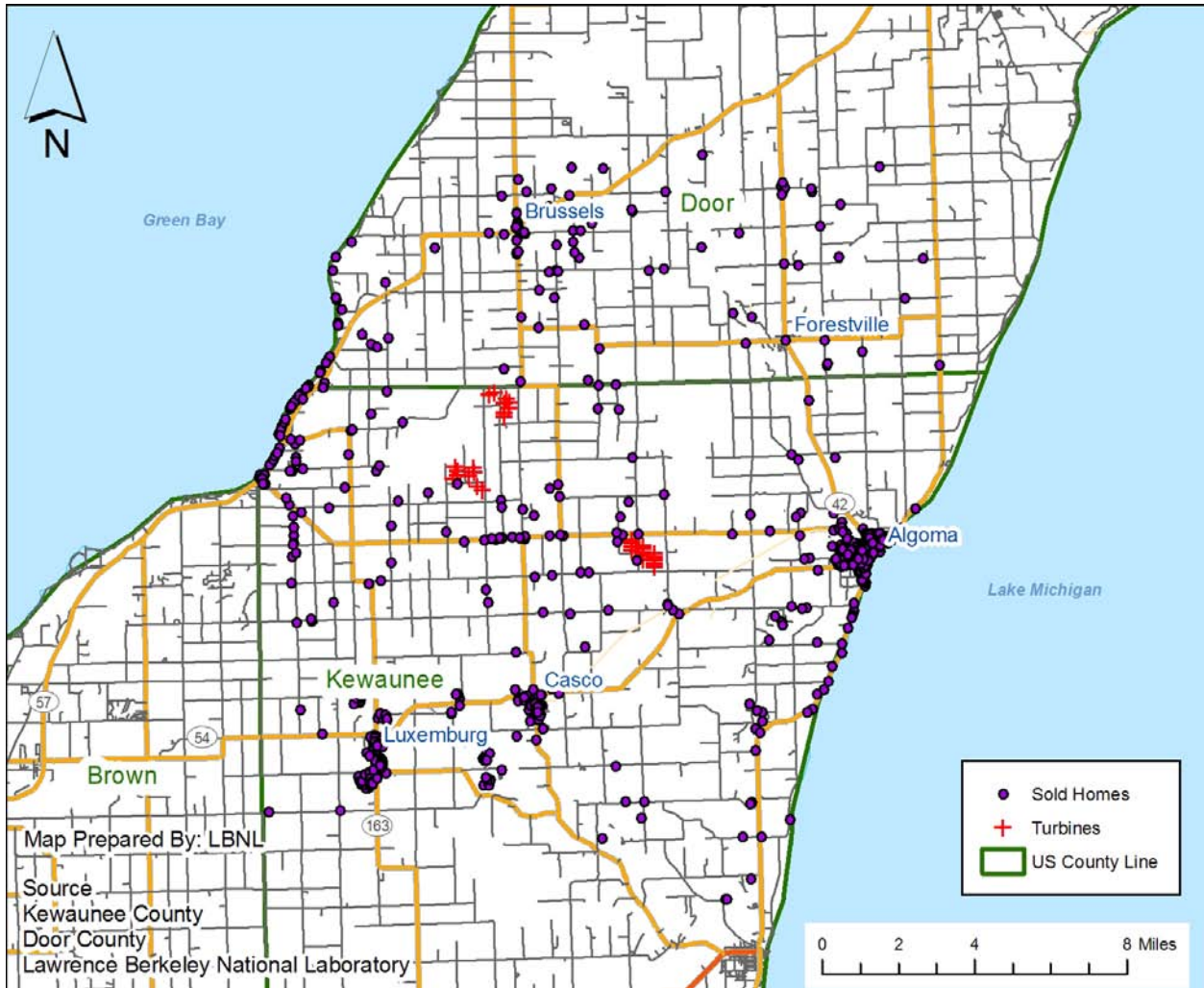
### Census Statistics

| Name     | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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 Tennesen 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   |

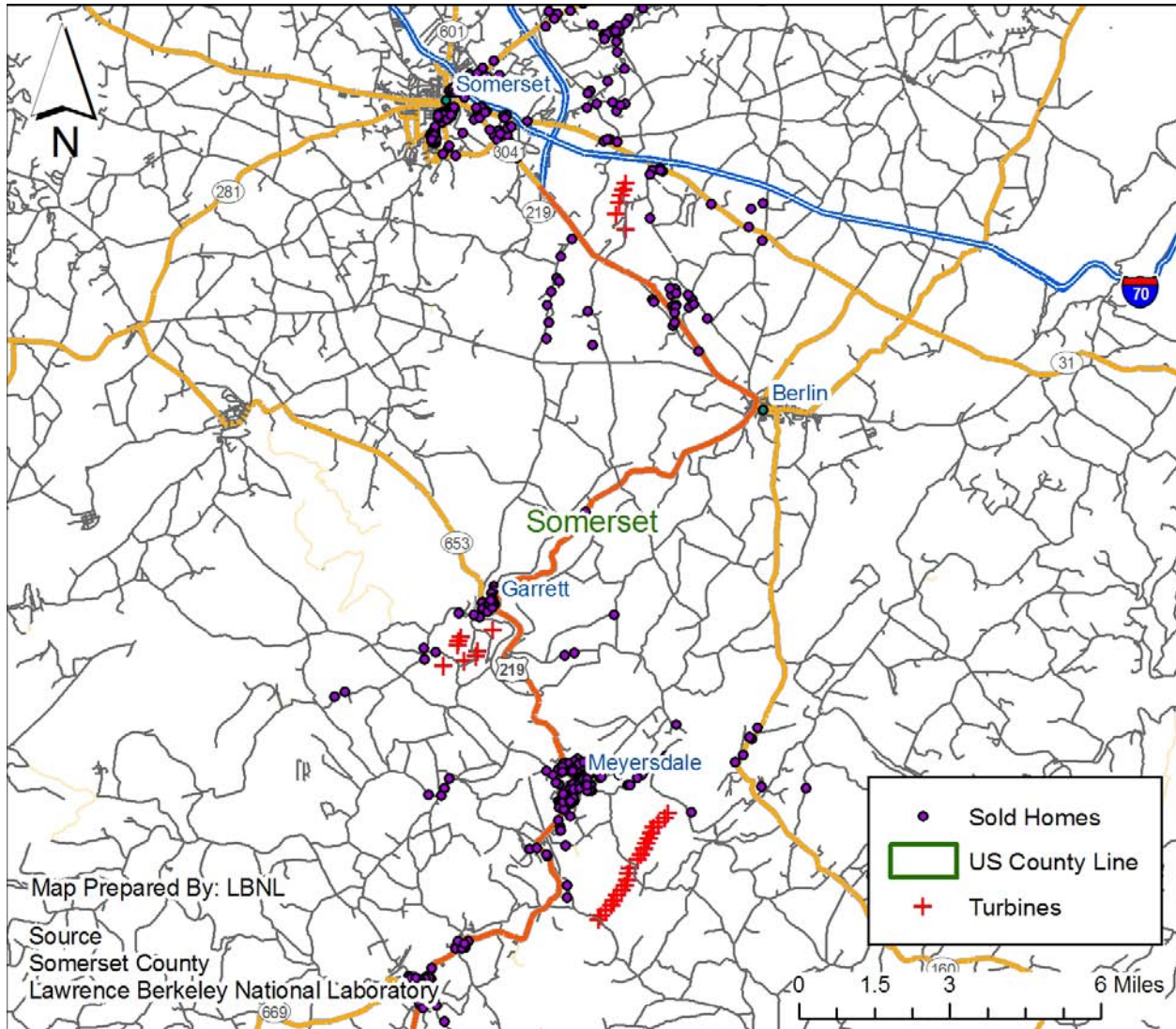
### Census Statistics

| Name      | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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.

### Area Description

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 Pittsburgh 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.<sup>109</sup>

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.

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<sup>109</sup> 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

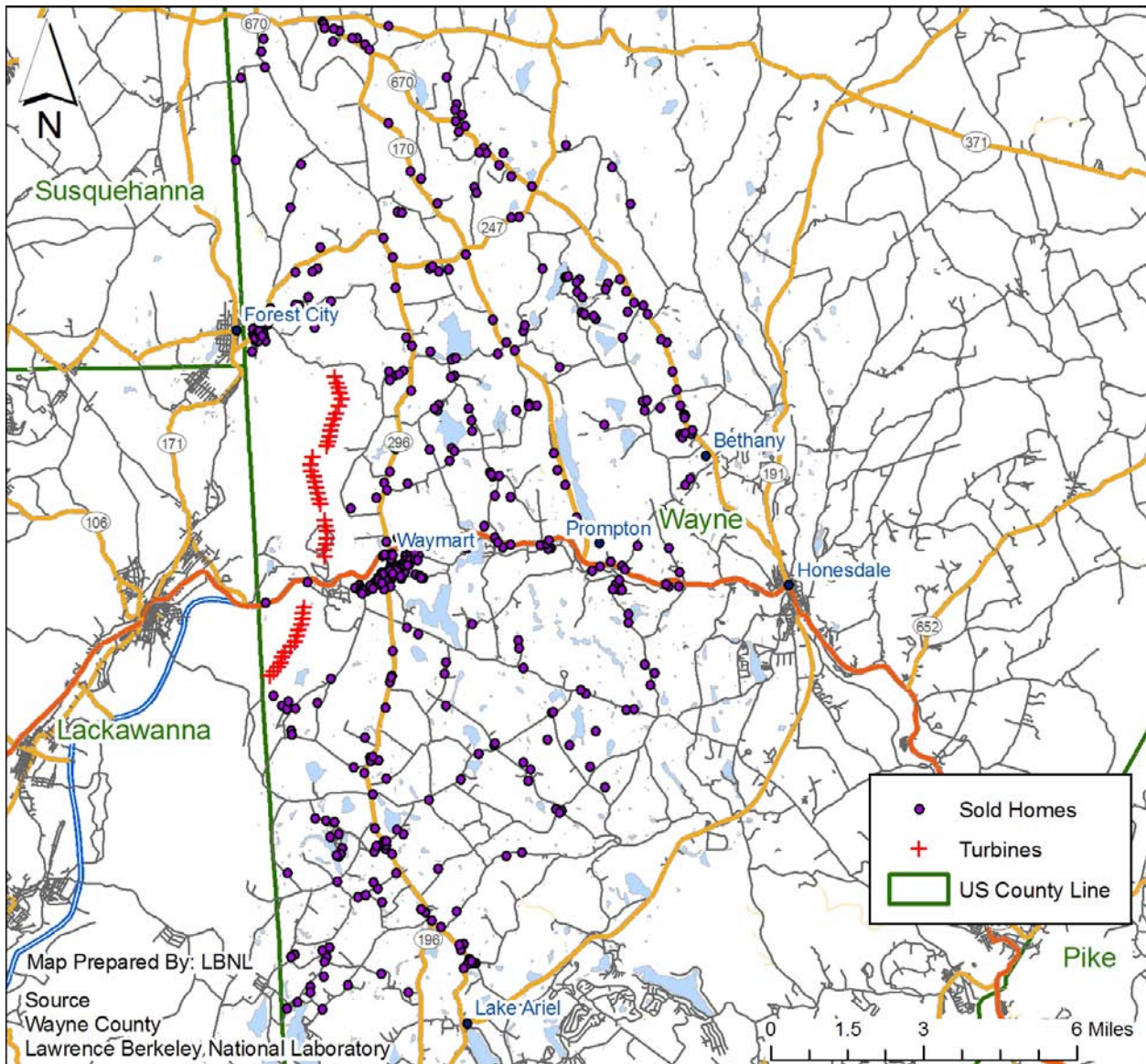
| Name         | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | Median Age | Median Income | Median House 2007 | % Change Since 2000 |
|--------------|---------|-----------------|---------------------|----------------------------------|------------|---------------|-------------------|---------------------|
| 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   |

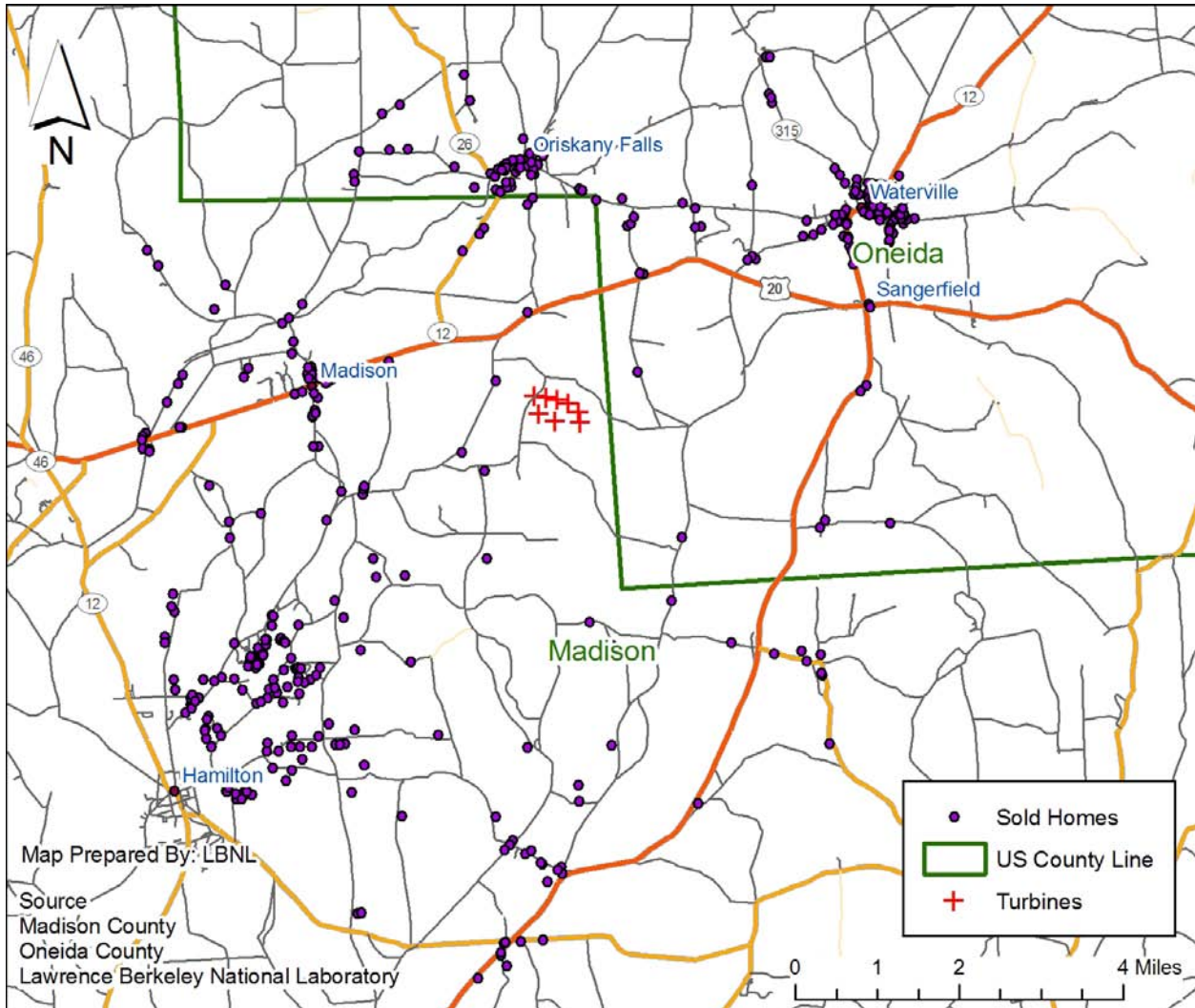
## Census Statistics

| Name         | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | 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

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

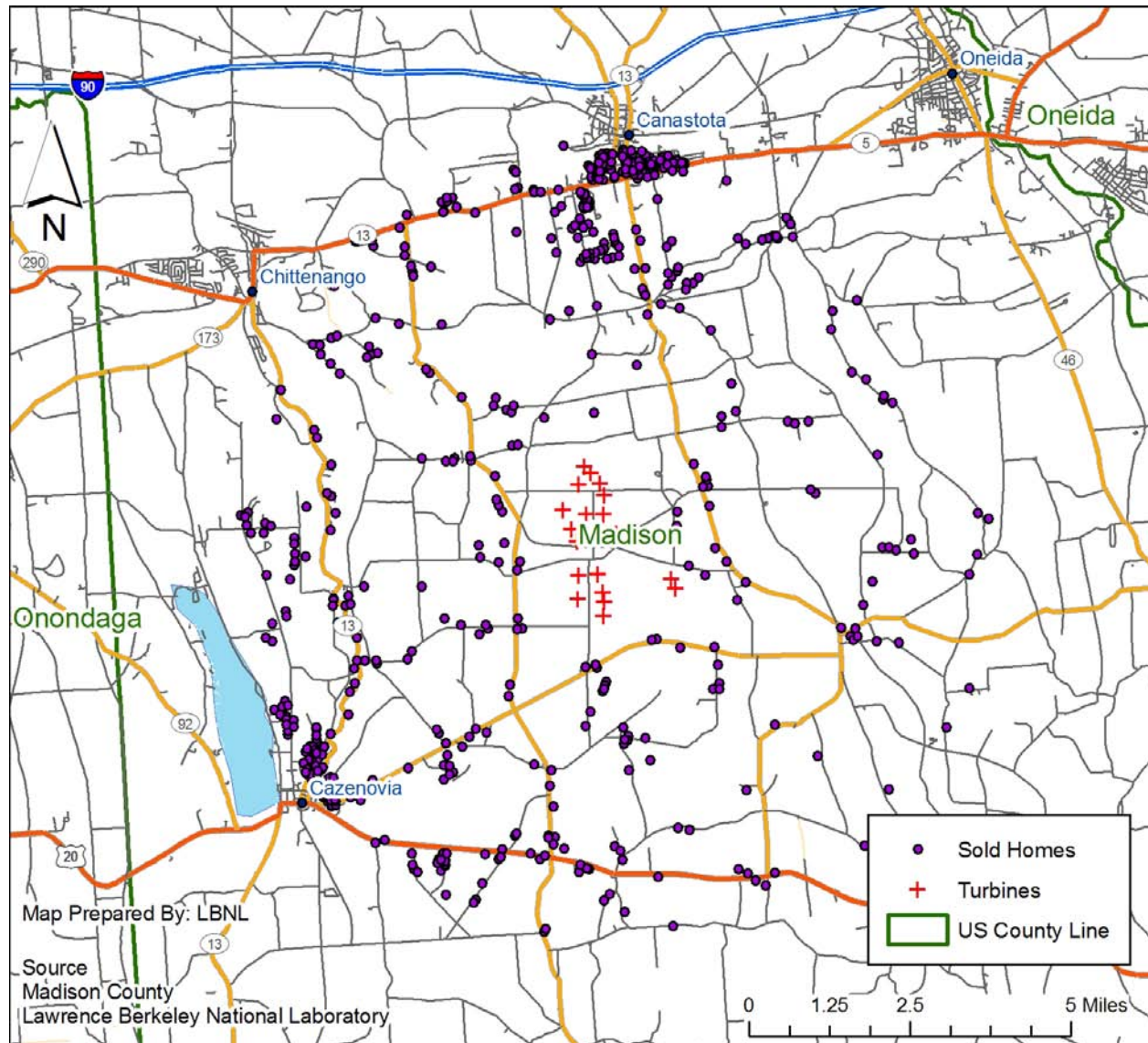
| Name           | Type    | 2007 Population | % Change Since 2000 | Population Per Mile <sup>2</sup> | Median Age | Median Income | Median House 2007 | % Change Since 2000 |
|----------------|---------|-----------------|---------------------|----------------------------------|------------|---------------|-------------------|---------------------|
| 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                 |
| Oriskany Falls | 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 <sup>2</sup> | 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.<sup>110</sup> 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.<sup>111</sup> 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

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<sup>110</sup> A newer FAA database is now available that clears up many of these earlier concerns.

<sup>111</sup> A “parcel centroid” is the mathematical center point of a polygon, and was determined by XTools Pro ([www.xtoolspro.com](http://www.xtoolspro.com)).

account, combined with the determination of which turbines were in existence at what time.<sup>112</sup> 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.<sup>113</sup> 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.<sup>114</sup> 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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<sup>112</sup> 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 lessen 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.

<sup>113</sup> 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).

<sup>114</sup> 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.<sup>115</sup>

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<sup>115</sup> 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   |                |        |   |                |
| <b><u>Home Characteristics</u></b>  |                |        | <b>House Photo Number(s)</b>              |                |
| Cul-De-Sac?   | No(0) / Yes(1) |        | Waterfront?                               | No(0) / Yes(1) |
|   |                |        |   |                |
| <b><u>Scenic Vista Characteristics</u></b>  |                |        | <b>Vista Photo Numbers</b>                |                |
| Overall Quality of Scenic Vista: Poor (1), Below Average (2), Average (3), Above Average (4), Premium (5) |                |        |   |                |
|   |                |        |   |                |
| <b><u>View of Turbines Characteristics</u></b>  |                |        | <b>View Photo Numbers</b>                 |                |
| 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)                                      |                |        |   |                |
|   |                |        |   |                |
| <b><u>Notes:</u></b>  |                |        |   |                |
|   |                |        |   |                |

## 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:<br>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:<br>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:<br>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:<br>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:<br>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<br>Vista? Not at all (0) | The vista does not contain any view of the turbines.  |
| Degree Turbines Overlap Prominent<br>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<br>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<br>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<br>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 from 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.<sup>116</sup> This fully interacted – or unrestricted – model would take the following form:

$$\ln(P) = \beta_0 + \sum_s \beta_1(N \cdot S) + \sum_c \beta_2(Y) + \sum_k \beta_3(X \cdot S) + \sum_v \beta_4(\text{VIEW} \cdot S) + \sum_d \beta_5(\text{DISTANCE} \cdot S) + \varepsilon \quad (\text{F13})$$

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.),

$\beta_0$  is the constant or intercept across the full sample,

$\beta_1$  is a vector of  $s$  parameter estimates for the spatially weighted neighbor’s predicted sale price for  $S$  study areas,

$\beta_2$  is a vector of  $c$  parameter estimates for the study area locational fixed effect variables,

$\beta_3$  is a vector of  $k$  parameter estimates for the home and site characteristics for  $S$  study areas,

$\beta_4$  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,

<sup>116</sup> 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.

$\beta_5$  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  $\varepsilon$  is a random disturbance term.

To refresh, the fully restricted equation (1) takes the following form:

$$\ln(P) = \beta_0 + \beta_1 N + \sum_s \beta_2 S + \sum_k \beta_3 X + \sum_v \beta_4 \text{VIEW} + \sum_d \beta_5 \text{DISTANCE} + \varepsilon \quad (1)$$

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.),

$\text{VIEW}$  is a vector of  $v$  categorical view of turbine variables (e.g., MINOR, MODERATE, etc.),

$\text{DISTANCE}$  is a vector of  $d$  categorical distance to turbine variables (e.g., less than 3000 feet, between one and three miles, etc.),

$\beta_0$  is the constant or intercept across the full sample,

$\beta_1$  is a parameter estimate for the spatially weighted neighbor's predicted sale price,

$\beta_2$  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,

$\beta_3$  is a vector of  $k$  parameter estimates for the home and site characteristics,

$\beta_4$  is a vector of  $v$  parameter estimates for the VIEW variables as compared to homes sold with no view of the turbines,

$\beta_5$  is a vector of  $d$  parameter estimates for the DISTANCE variables as compared to homes sold situated outside of five miles, and

$\varepsilon$  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.).<sup>117</sup> 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.<sup>118</sup> These latter coefficients represent not only effects that are presumed

<sup>117</sup> 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.

<sup>118</sup> 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

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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 Alternative 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 ( $k$ ).<sup>119</sup> All models were run using the post-construction data subset of the sample of home sales transactions ( $n = 4,937$ ).

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<sup>119</sup> 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 <sup>1</sup> | Study Area <sup>2</sup> | 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



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, unrestricted 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, unrestricted 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).<sup>120</sup> 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.<sup>121</sup> 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 unrestricted the variables of interest.

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<sup>120</sup> 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.

<sup>121</sup> 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 |      |      | Unrestricted Models |      |      |
|------------------------------|-------------------|------|------|---------------------|------|------|
|                              | Standard Errors   |      |      | 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 |       |       | Unrestricted Models |       |      |
|------------------------------|-------------------|-------|-------|---------------------|-------|------|
|                              | Coefficients      |       |       | 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.<sup>122</sup> 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.<sup>123</sup> 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.<sup>124</sup>

**Table A - 5: Summary of Significant VOI Above and Below Zero in Unrestricted Models**

| <b>Significant Variables</b>        | <b>Unrestricted Models</b> |                   |                   |
|-------------------------------------|----------------------------|-------------------|-------------------|
|                                     | <b>Total</b>               | <b>Below Zero</b> | <b>Above Zero</b> |
| <b>Minor View</b>                   | 32%                        | 14%               | 18%               |
| <b>Moderate View</b>                | 23%                        | 11%               | 13%               |
| <b>Substantial View</b>             | 4%                         | 4%                | 0%                |
| <b>Extreme View</b>                 | 0%                         | 0%                | 0%                |
| <b>Inside 3000 Feet</b>             | 23%                        | 15%               | 8%                |
| <b>Between 3000 Feet and 1 Mile</b> | 30%                        | 14%               | 16%               |
| <b>Between 1 and 3 Miles</b>        | 56%                        | 32%               | 24%               |
| <b>Between 3 and 5 Miles</b>        | 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”.

<sup>122</sup> 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.

<sup>123</sup> 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.

<sup>124</sup> 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

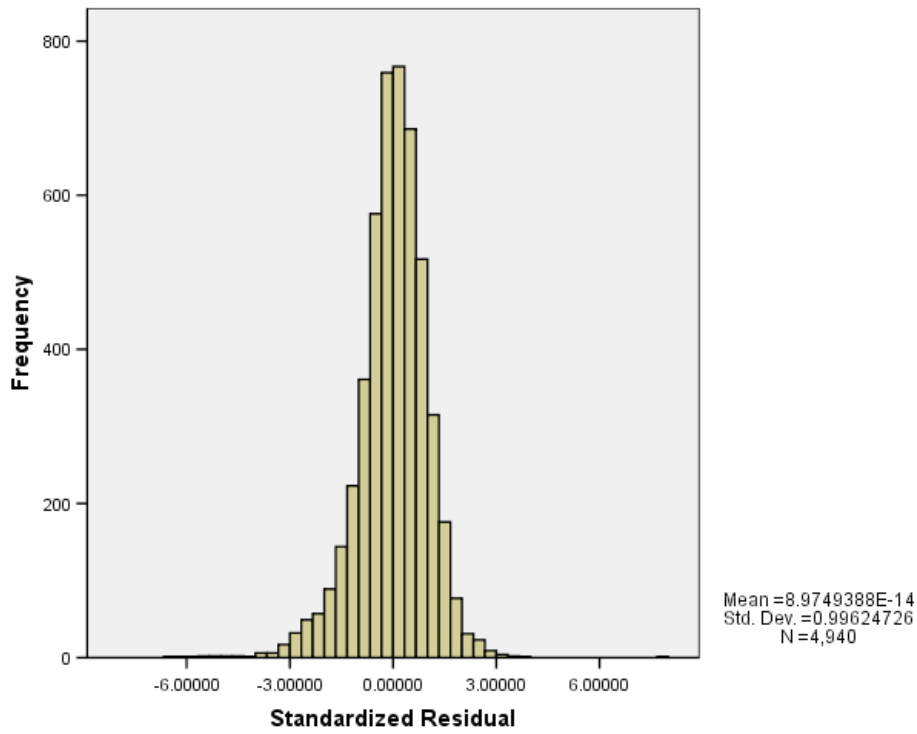
A number of criteria must be met to ensure that the Base Model and Alternative Hedonic Models produce unbiased coefficient estimates and standard errors: 1) appropriate controls for outliers and influencers; 2) homoskedasticity; 3) absence of serial or spatial autocorrelation; and 4) reasonably limited 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.<sup>125</sup> The histograms of these two sets of statistics from the two regressions are shown in Figure A - 15 through Figure A - 18.

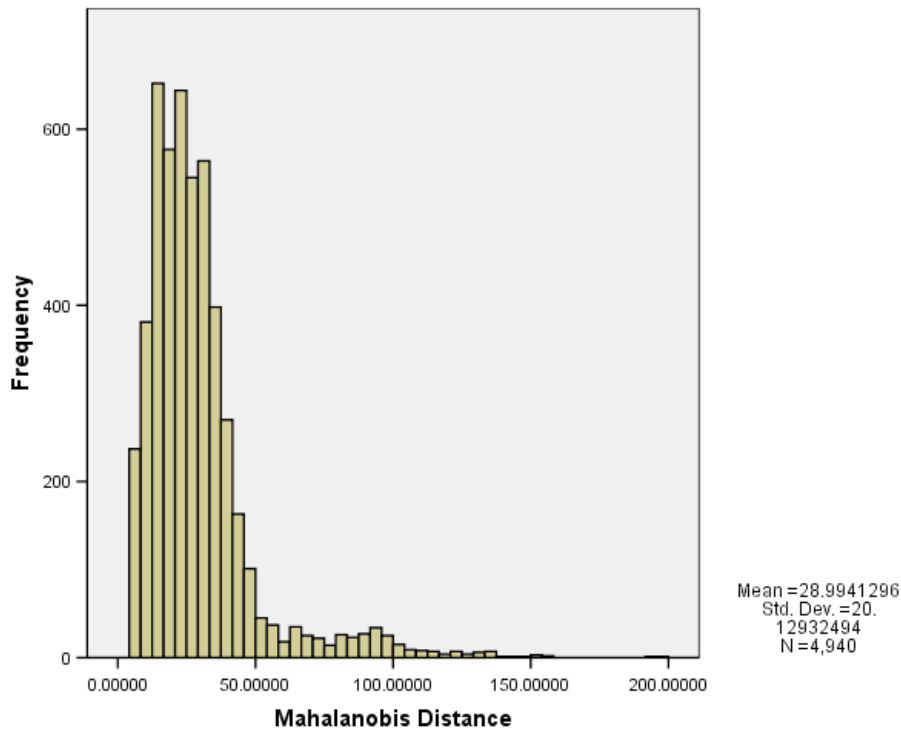
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<sup>125</sup> For the M Distance statistics all variables of interest were removed from the model. If they were left in the M-Distance statistics could be influenced by the small numbers of cases in the variables of interest. If these parameters were 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.

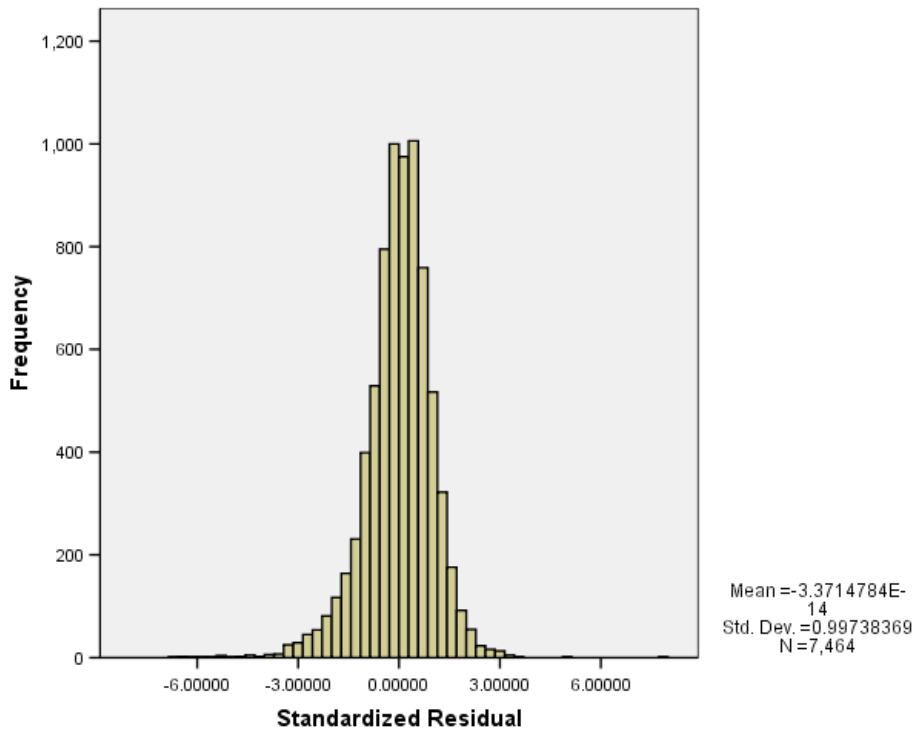
**Figure A - 15: Histogram of Standardized Residuals for Base Model**



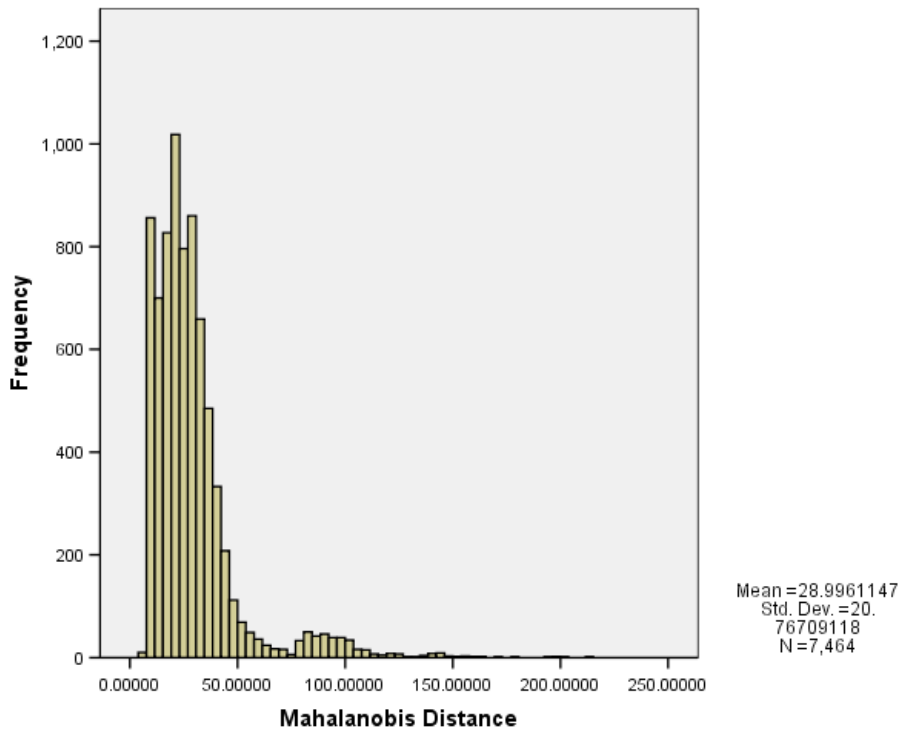
**Figure A - 16: Histogram of Mahalanobis Distance Statistics for Base Model**



**Figure A - 17: Histogram of Standardized Residuals for All Sales Model**



**Figure A - 18: Histogram of Mahalanobis Distance Statistics for All Sales Model**



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.<sup>126</sup> 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.<sup>127</sup> 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

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<sup>126</sup> 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).

<sup>127</sup> 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.<sup>128</sup>

- **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.<sup>129</sup> 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)

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<sup>128</sup> Put differently, the weight is the contribution of that home's inverse distance to the total sum of the five nearest neighbors' inverse distances.

<sup>129</sup> 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**

|                               | <b>Coef.</b> | <b>SE</b> | <b>Sig</b> | <b>n</b> |
|-------------------------------|--------------|-----------|------------|----------|
| <b>Intercept</b>              | 7.64         | 0.18      | 0.00       |          |
| <b>Nbr LN SalePrice96 hat</b> | 0.29         | 0.02      | 0.00       | 4,937    |
| <b>AgeatSale</b>              | -0.006       | 0.0004    | 0.00       | 4,937    |
| <b>AgeatSale Sqrd</b>         | 0.00002      | 0.000003  | 0.00       | 4,937    |
| <b>Sqft 1000</b>              | 0.28         | 0.01      | 0.00       | 4,937    |
| <b>Acres</b>                  | 0.02         | 0.00      | 0.00       | 4,937    |
| <b>Baths</b>                  | 0.09         | 0.01      | 0.00       | 4,937    |
| <b>ExtWalls Stone</b>         | 0.21         | 0.02      | 0.00       | 1,486    |
| <b>CentralAC</b>              | 0.09         | 0.01      | 0.00       | 2,575    |
| <b>Fireplace</b>              | 0.11         | 0.01      | 0.00       | 1,834    |
| <b>FinBsmt</b>                | 0.08         | 0.02      | 0.00       | 673      |
| <b>Cul De Sac</b>             | 0.10         | 0.01      | 0.00       | 992      |
| <b>Water Front</b>            | 0.34         | 0.04      | 0.00       | 87       |
| <b>Cnd Low</b>                | -0.45        | 0.05      | 0.00       | 69       |
| <b>Cnd BAvg</b>               | -0.24        | 0.02      | 0.00       | 350      |
| <b>Cnd Avg</b>                | Omitted      | Omitted   | Omitted    | 2,727    |
| <b>Cnd AAvg</b>               | 0.13         | 0.01      | 0.00       | 1,445    |
| <b>Cnd High</b>               | 0.23         | 0.02      | 0.00       | 337      |
| <b>Vista Poor</b>             | -0.21        | 0.02      | 0.00       | 310      |
| <b>Vista BAvg</b>             | -0.08        | 0.01      | 0.00       | 2,857    |
| <b>Vista Avg</b>              | Omitted      | Omitted   | Omitted    | 1,247    |
| <b>Vista AAvg</b>             | 0.10         | 0.02      | 0.00       | 448      |
| <b>Vista Prem</b>             | 0.13         | 0.04      | 0.00       | 75       |
| <b>WAOR</b>                   | Omitted      | Omitted   | Omitted    | 519      |
| <b>TXHC</b>                   | -0.75        | 0.02      | 0.00       | 1,071    |
| <b>OKCC</b>                   | -0.45        | 0.02      | 0.00       | 476      |
| <b>IABV</b>                   | -0.25        | 0.02      | 0.00       | 605      |
| <b>ILLC</b>                   | -0.09        | 0.03      | 0.00       | 213      |
| <b>WIKCDC</b>                 | -0.14        | 0.02      | 0.00       | 725      |
| <b>PASC</b>                   | -0.31        | 0.03      | 0.00       | 291      |
| <b>PAWC</b>                   | -0.08        | 0.03      | 0.00       | 222      |
| <b>NYMCOC</b>                 | -0.20        | 0.03      | 0.00       | 346      |
| <b>NYMC</b>                   | -0.15        | 0.02      | 0.00       | 469      |
| <b>Post Con NoView</b>        | Omitted      | Omitted   | Omitted    | 4,207    |
| <b>View Minor</b>             | -0.02        | 0.01      | 0.25       | 561      |
| <b>View Mod</b>               | 0.00         | 0.03      | 0.90       | 106      |
| <b>View Sub</b>               | -0.04        | 0.06      | 0.56       | 35       |
| <b>View Extrm</b>             | -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**

|                                 |                       |
|---------------------------------|-----------------------|
| <b>Model Equation Number</b>    | <b>3</b>              |
| <b>Model Name</b>               | <b>View Stability</b> |
| <b>Dependent Variable</b>       | <b>LN_SalePrice96</b> |
| <b>Number of Cases</b>          | <b>4937</b>           |
| <b>Number of Predictors (k)</b> | <b>33</b>             |
| <b>F Statistic</b>              | <b>495.9</b>          |
| <b>Adjusted R Squared</b>       | <b>0.77</b>           |

**Table A - 8: Full Results for the Continuous Distance Model**

|                               | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|-------------------------------|--------------|-----------|----------------|----------|
| <b>Intercept</b>              | 7.64         | 0.18      | 0.00           |          |
| <b>Nbr LN SalePrice96 hat</b> | 0.29         | 0.02      | 0.00           | 4,937    |
| <b>AgeatSale</b>              | -0.006       | 0.0004    | 0.00           | 4,937    |
| <b>AgeatSale Sqrd</b>         | 0.00002      | 0.000003  | 0.00           | 4,937    |
| <b>Sqft 1000</b>              | 0.28         | 0.01      | 0.00           | 4,937    |
| <b>Acres</b>                  | 0.02         | 0.00      | 0.00           | 4,937    |
| <b>Baths</b>                  | 0.09         | 0.01      | 0.00           | 4,937    |
| <b>ExtWalls Stone</b>         | 0.21         | 0.02      | 0.00           | 1,486    |
| <b>CentralAC</b>              | 0.09         | 0.01      | 0.00           | 2,575    |
| <b>Fireplace</b>              | 0.11         | 0.01      | 0.00           | 1,834    |
| <b>FinBsmt</b>                | 0.08         | 0.02      | 0.00           | 673      |
| <b>Cul De Sac</b>             | 0.10         | 0.01      | 0.00           | 992      |
| <b>Water Front</b>            | 0.34         | 0.04      | 0.00           | 87       |
| <b>Cnd Low</b>                | -0.45        | 0.05      | 0.00           | 69       |
| <b>Cnd BAvg</b>               | -0.24        | 0.02      | 0.00           | 350      |
| <b>Cnd Avg</b>                | Omitted      | Omitted   | Omitted        | 2,727    |
| <b>Cnd AAvg</b>               | 0.13         | 0.01      | 0.00           | 1,445    |
| <b>Cnd High</b>               | 0.23         | 0.02      | 0.00           | 337      |
| <b>Vista Poor</b>             | -0.21        | 0.02      | 0.00           | 310      |
| <b>Vista BAvg</b>             | -0.08        | 0.01      | 0.00           | 2,857    |
| <b>Vista Avg</b>              | Omitted      | Omitted   | Omitted        | 1,247    |
| <b>Vista AAvg</b>             | 0.10         | 0.02      | 0.00           | 448      |
| <b>Vista Prem</b>             | 0.13         | 0.04      | 0.00           | 75       |
| <b>WAOR</b>                   | Omitted      | Omitted   | Omitted        | 519      |
| <b>TXHC</b>                   | -0.75        | 0.02      | 0.00           | 1,071    |
| <b>OKCC</b>                   | -0.44        | 0.02      | 0.00           | 476      |
| <b>IABV</b>                   | -0.25        | 0.02      | 0.00           | 605      |
| <b>ILLC</b>                   | -0.09        | 0.03      | 0.00           | 213      |
| <b>WIKCDC</b>                 | -0.14        | 0.02      | 0.00           | 725      |
| <b>PASC</b>                   | -0.31        | 0.03      | 0.00           | 291      |
| <b>PAWC</b>                   | -0.07        | 0.03      | 0.00           | 222      |
| <b>NYMCOC</b>                 | -0.20        | 0.03      | 0.00           | 346      |
| <b>NYMC</b>                   | -0.15        | 0.02      | 0.00           | 469      |
| <b>No View</b>                | Omitted      | Omitted   | Omitted        | 4,207    |
| <b>Minor View</b>             | -0.01        | 0.01      | 0.33           | 561      |
| <b>Moderate View</b>          | 0.01         | 0.03      | 0.77           | 106      |
| <b>Substantial View</b>       | -0.02        | 0.07      | 0.72           | 35       |
| <b>Extreme View</b>           | 0.01         | 0.10      | 0.88           | 28       |
| <b>InvDISTANCE</b>            | -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**

|                                 |                                  |
|---------------------------------|----------------------------------|
| <b>Model Equation Number</b>    | <b>5</b>                         |
| <b>Model Name</b>               | <b>Continuous Distance Model</b> |
| <b>Dependent Variable</b>       | <b>LN_SalePrice96</b>            |
| <b>Number of Cases</b>          | <b>4937</b>                      |
| <b>Number of Predictors (k)</b> | <b>34</b>                        |
| <b>F Statistic</b>              | <b>481.3</b>                     |
| <b>Adjusted R Squared</b>       | <b>0.77</b>                      |

**Table A - 9: Full Results for the All Sales Model**

|                                     | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|-------------------------------------|--------------|-----------|----------------|----------|
| <b>Intercept</b>                    | 9.08         | 0.14      | 0.00           |          |
| <b>Nbr LN SP96 hat All OI</b>       | 0.16         | 0.01      | 0.00           | 7,459    |
| <b>AgeatSale</b>                    | -0.007       | 0.0003    | 0.00           | 7,459    |
| <b>AgeatSale Sqrd</b>               | 0.00003      | 0.000002  | 0.00           | 7,459    |
| <b>Sqft 1000</b>                    | 0.28         | 0.01      | 0.00           | 7,459    |
| <b>Acres</b>                        | 0.02         | 0.00      | 0.00           | 7,459    |
| <b>Baths</b>                        | 0.08         | 0.01      | 0.00           | 7,459    |
| <b>ExtWalls Stone</b>               | 0.21         | 0.01      | 0.00           | 2,287    |
| <b>CentralAC</b>                    | 0.12         | 0.01      | 0.00           | 3,785    |
| <b>Fireplace</b>                    | 0.11         | 0.01      | 0.00           | 2,708    |
| <b>FinBsmnt</b>                     | 0.09         | 0.01      | 0.00           | 990      |
| <b>Cul De Sac</b>                   | 0.09         | 0.01      | 0.00           | 1,472    |
| <b>Water Front</b>                  | 0.35         | 0.03      | 0.00           | 107      |
| <b>Cnd Low</b>                      | -0.43        | 0.04      | 0.00           | 101      |
| <b>Cnd BAvg</b>                     | -0.21        | 0.02      | 0.00           | 519      |
| <b>Cnd Avg</b>                      | Omitted      | Omitted   | Omitted        | 4,357    |
| <b>Cnd AAvg</b>                     | 0.13         | 0.01      | 0.00           | 2,042    |
| <b>Cnd High</b>                     | 0.22         | 0.02      | 0.00           | 440      |
| <b>Vista Poor</b>                   | -0.25        | 0.02      | 0.00           | 470      |
| <b>Vista BAvg</b>                   | -0.09        | 0.01      | 0.00           | 4,301    |
| <b>Vista Avg</b>                    | Omitted      | Omitted   | Omitted        | 1,912    |
| <b>Vista AAvg</b>                   | 0.10         | 0.01      | 0.00           | 659      |
| <b>Vista Prem</b>                   | 0.09         | 0.03      | 0.00           | 117      |
| <b>WAOR</b>                         | Omitted      | Omitted   | Omitted        | 790      |
| <b>TXHC</b>                         | -0.82        | 0.02      | 0.00           | 1,311    |
| <b>OKCC</b>                         | -0.53        | 0.02      | 0.00           | 1,113    |
| <b>IABV</b>                         | -0.31        | 0.02      | 0.00           | 822      |
| <b>ILLC</b>                         | -0.05        | 0.02      | 0.02           | 412      |
| <b>WIKCDC</b>                       | -0.17        | 0.01      | 0.00           | 810      |
| <b>PASC</b>                         | -0.37        | 0.03      | 0.00           | 494      |
| <b>PAWC</b>                         | -0.15        | 0.02      | 0.00           | 551      |
| <b>NYMCOC</b>                       | -0.25        | 0.02      | 0.00           | 463      |
| <b>NYMC</b>                         | -0.15        | 0.02      | 0.00           | 693      |
| <b>Pre-Construction Sales</b>       | Omitted      | Omitted   | Omitted        | 2,522    |
| <b>No View</b>                      | 0.02         | 0.01      | 0.06           | 4,207    |
| <b>Minor View</b>                   | 0.00         | 0.02      | 0.76           | 561      |
| <b>Moderate View</b>                | 0.03         | 0.03      | 0.38           | 106      |
| <b>Substantial View</b>             | 0.03         | 0.07      | 0.63           | 35       |
| <b>Extreme View</b>                 | 0.06         | 0.08      | 0.43           | 28       |
| <b>Inside 3000 Feet</b>             | -0.06        | 0.05      | 0.23           | 80       |
| <b>Between 3000 Feet and 1 Mile</b> | -0.08        | 0.05      | 0.08           | 65       |
| <b>Between 1 and 3 Miles</b>        | 0.00         | 0.01      | 0.79           | 2,359    |
| <b>Between 3 and 5 Miles</b>        | 0.01         | 0.01      | 0.58           | 2,200    |
| <b>Outside 5 Miles</b>              | 0.00         | 0.02      | 0.76           | 1,000    |
| <b>Pre-Announcement Sales</b>       | Omitted      | Omitted   | Omitted        | 1,755    |

"Omitted" = reference category for fixed effects variables

"n" indicates number of cases in category when category = "1"

**Model Information**

|                                 |                        |
|---------------------------------|------------------------|
| <b>Model Equation Number</b>    | <b>6</b>               |
| <b>Model Name</b>               | <b>All Sales Model</b> |
| <b>Dependent Variable</b>       | <b>LN_SalePrice96</b>  |
| <b>Number of Cases</b>          | <b>7459</b>            |
| <b>Number of Predictors (k)</b> | <b>39</b>              |
| <b>F Statistic</b>              | <b>579.9</b>           |
| <b>Adjusted R Squared</b>       | <b>0.75</b>            |

**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 |
| FinBsmnt               | 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   |
| NYMCOG                 | -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

|                           | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|---------------------------|--------------|-----------|----------------|----------|
| 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**

|                                     | <b>Coef.</b> | <b>SE</b> | <b>p Value</b> | <b>n</b> |
|-------------------------------------|--------------|-----------|----------------|----------|
| <b>Intercept</b>                    | 7.62         | 0.18      | 0.00           |          |
| <b>Nbr LN SalePrice96 hat</b>       | 0.29         | 0.02      | 0.00           | 4,937    |
| <b>AgeatSale</b>                    | -0.006       | 0.0004    | 0.00           | 4,937    |
| <b>AgeatSale Sqrd</b>               | 0.00002      | 0.000003  | 0.00           | 4,937    |
| <b>Sqft 1000</b>                    | 0.28         | 0.01      | 0.00           | 4,937    |
| <b>Acres</b>                        | 0.02         | 0.00      | 0.00           | 4,937    |
| <b>Baths</b>                        | 0.09         | 0.01      | 0.00           | 4,937    |
| <b>ExtWalls Stone</b>               | 0.21         | 0.02      | 0.00           | 1,486    |
| <b>CentralAC</b>                    | 0.09         | 0.01      | 0.00           | 2,575    |
| <b>Fireplace</b>                    | 0.11         | 0.01      | 0.00           | 1,834    |
| <b>FinBsmt</b>                      | 0.08         | 0.02      | 0.00           | 673      |
| <b>Cul De Sac</b>                   | 0.10         | 0.01      | 0.00           | 992      |
| <b>Water Front</b>                  | 0.33         | 0.04      | 0.00           | 87       |
| <b>Cnd Low</b>                      | -0.44        | 0.05      | 0.00           | 69       |
| <b>Cnd BAvg</b>                     | -0.24        | 0.02      | 0.00           | 350      |
| <b>Cnd Avg</b>                      | Omitted      | Omitted   | Omitted        | 2,727    |
| <b>Cnd AAvg</b>                     | 0.13         | 0.01      | 0.00           | 1,445    |
| <b>Cnd High</b>                     | 0.24         | 0.02      | 0.00           | 337      |
| <b>Vista Poor</b>                   | -0.21        | 0.02      | 0.00           | 310      |
| <b>Vista BAvg</b>                   | -0.08        | 0.01      | 0.00           | 2,857    |
| <b>Vista Avg</b>                    | Omitted      | Omitted   | Omitted        | 1,247    |
| <b>Vista AAvg</b>                   | 0.10         | 0.02      | 0.00           | 448      |
| <b>Vista Prem</b>                   | 0.13         | 0.04      | 0.00           | 75       |
| <b>WAOR</b>                         | Omitted      | Omitted   | Omitted        | 519      |
| <b>TXHC</b>                         | -0.75        | 0.03      | 0.00           | 1,071    |
| <b>OKCC</b>                         | -0.44        | 0.02      | 0.00           | 476      |
| <b>IABV</b>                         | -0.24        | 0.02      | 0.00           | 605      |
| <b>ILLC</b>                         | -0.08        | 0.03      | 0.00           | 213      |
| <b>WIKCDC</b>                       | -0.14        | 0.02      | 0.00           | 725      |
| <b>PASC</b>                         | -0.31        | 0.03      | 0.00           | 291      |
| <b>PAWC</b>                         | -0.07        | 0.03      | 0.01           | 222      |
| <b>NYMCOC</b>                       | -0.20        | 0.03      | 0.00           | 346      |
| <b>NYMC</b>                         | -0.15        | 0.02      | 0.00           | 469      |
| <b>No View</b>                      | Omitted      | Omitted   | Omitted        | 4,207    |
| <b>Minor View</b>                   | -0.01        | 0.06      | 0.92           | 561      |
| <b>Moderate View</b>                | 0.00         | 0.06      | 0.97           | 106      |
| <b>Substantial View</b>             | -0.01        | 0.09      | 0.87           | 35       |
| <b>Extreme View</b>                 | 0.02         | 0.17      | 0.89           | 28       |
| <b>Inside 3000 Feet</b>             | -0.04        | 0.07      | 0.55           | 67       |
| <b>Between 3000 Feet and 1 Mile</b> | -0.05        | 0.05      | 0.37           | 58       |
| <b>Between 1 and 3 Miles</b>        | 0.00         | 0.02      | 0.83           | 2,019    |
| <b>Between 3 and 5 Miles</b>        | 0.02         | 0.01      | 0.22           | 1,923    |
| <b>Outside 5 Miles</b>              | Omitted      | Omitted   | Omitted        | 870      |
| <b>Front Orientation</b>            | -0.01        | 0.06      | 0.82           | 294      |
| <b>Back Orientation</b>             | 0.03         | 0.06      | 0.55           | 280      |
| <b>Side Orientation</b>             | -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**

|                                 |                          |
|---------------------------------|--------------------------|
| <b>Model Equation Number</b>    | <b>8</b>                 |
| <b>Model Name</b>               | <b>Orientation Model</b> |
| <b>Dependent Variable</b>       | <b>LN_SalePrice96</b>    |
| <b>Number of Cases</b>          | <b>4937</b>              |
| <b>Number of Predictors (k)</b> | <b>40</b>                |
| <b>F Statistic</b>              | <b>410.0</b>             |
| <b>Adjusted R Squared</b>       | <b>0.77</b>              |

**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 |
| FinBsmnt                     | 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           |

**Impacts of Windmill Visibility on Property Values in  
Madison County, New York.**

Project Report Submitted to the Faculty of the  
Bard Center for Environmental Policy

By Ben Hoen

In partial fulfillment of the requirements for the degree of  
Master of Science in Environmental Policy

Bard College

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April 30, 2006

1. The first part of the document is a list of names.

2. The second part is a list of dates.

3. The third part is a list of locations.

4. The fourth part is a list of events.

5. The fifth part is a list of people.

6. The sixth part is a list of organizations.

7. The seventh part is a list of activities.

8. The eighth part is a list of places.

9. The ninth part is a list of things.

10. The tenth part is a list of people.

11. The eleventh part is a list of organizations.

12. The twelfth part is a list of places.

13. The thirteenth part is a list of things.

14. The fourteenth part is a list of people.

## Table of Contents

|          |   |            |
|----------|---|------------|
| <b>1</b> | <b>EXECUTIVE SUMMARY .....</b>  | <b>III</b> |
| <b>2</b> | <b>INTRODUCTION .....</b>   | <b>1</b>   |
| <b>3</b> | <b>OVERVIEW OF PREVIOUS STUDIES .....</b>   | <b>6</b>   |
| 3.1      | SURVEY BASED STUDIES .....  | 6          |
| 3.1.1    | <i>Conclusions drawn from survey studies .....</i>                                | <i>11</i>  |
| 3.2      | TRANSACTION BASED STUDIES OF ANALOGOUS HVTL STRUCTURES.....                       | 11         |
| 3.2.1    | <i>Are HVTL structures and windmills viewed similarly? .....</i>                  | <i>12</i>  |
| 3.2.2    | <i>Are spatial property value effects of HVTL similar to windfarms? .....</i>     | <i>13</i>  |
| 3.2.3    | <i>Are temporal property value effects of HVTL similar to windfarms? .....</i>    | <i>15</i>  |
| 3.2.4    | <i>Conclusions drawn from analogous HVTL studies .....</i>                        | <i>15</i>  |
| 3.3      | TRANSACTION BASED STUDIES OF WINDMILLS.....                                       | 16         |
| 3.3.1    | <i>Conclusions drawn from transaction studies .....</i>                           | <i>18</i>  |
| <b>4</b> | <b>STUDY AREA .....</b>   | <b>19</b>  |
| <b>5</b> | <b>METHODOLOGY .....</b>  | <b>20</b>  |
| 5.1      | THE NON-LINEAR HEDONIC MODEL .....  | 21         |
| 5.2      | VARIABLE SELECTION.....   | 21         |
| 5.3      | DATA COLLECTION .....   | 22         |
| 5.4      | CONSTRUCTION OF VIEWSHED VARIABLES .....  | 25         |
| 5.5      | DISCUSSION OF DESCRIPTIVE STATISTICS.....   | 27         |
| 5.6      | TESTING FOR VIOLATIONS OF OLS ASSUMPTIONS.....                                    | 27         |
| 5.6.1    | <i>Multicollinearity.....</i>   | <i>27</i>  |
| 5.6.2    | <i>Independence of Error Term and Independent Variables .....</i>                 | <i>28</i>  |
| 5.6.3    | <i>Homoskedasticity .....</i>   | <i>28</i>  |
| 5.6.4    | <i>Temporal Autocorrelation.....</i>  | <i>29</i>  |
| <b>6</b> | <b>ANALYSIS.....</b>  | <b>30</b>  |
| <b>7</b> | <b>CONCLUSIONS.....</b>   | <b>34</b>  |
| <b>8</b> | <b>POLICY IMPLICATIONS AND RECOMMENDATIONS .....</b>                              | <b>38</b>  |
| 8.1      | FUTURE RESEARCH CONSIDERATIONS .....  | 40         |
|          | <b>APPENDIX A: DEFINITIONS AND DESCRIPTIONS OF VARIABLES .....</b>                | <b>44</b>  |
|          | <b>APPENDIX B: MAP OF STUDY AREA.....</b>   | <b>47</b>  |
|          | <b>APPENDIX C: TECHNIQUE FOR CREATING GIS VIEWSHED PREDICTION ALGORITHM .....</b> | <b>48</b>  |
|          | <b>APPENDIX D: RESULTS OF GIS VIEWSHED PREDICTION ALGORITHM.....</b>              | <b>52</b>  |
|          | <b>APPENDIX E: LANDSCAPE CONSTRUCTIONS FOR VIEWSHED PREDICTION.....</b>           | <b>54</b>  |
|          | <b>APPENDIX F: MODEL RESULTS .....</b>  | <b>56</b>  |
|          | <b>APPENDIX G: HISTOGRAMS .....</b>   | <b>58</b>  |
|          | <b>BIBLIOGRAPHY .....</b>   | <b>59</b>  |

## List of Figures and Tables

|  |    |
|--|----|
| Figure I: Turbine Visibility Scoring Method .....                                    | vi |
| Figure II: Property Value Effects of HVTL and Distance .....                         | 14 |
| Figure III: Fenner Turbines & Parcels .....  | 19 |
| Figure IV: Turbine Visibility Scoring Method.....                                    | 25 |
| Figure V: Four Sets of Predicted Views versus the Actual Readings .....              | 53 |
| Figure VI: Depiction of the Study Area without Ground Cover .....                    | 54 |
| Figure VII: Depiction of the Study Area with Ground Cover.....                       | 54 |
| Figure VIII: 3D Rendering of Study Area.....   | 55 |
| Figure IX: Histogram of VIEW >0 .....  | 58 |
| Figure X: Histogram of VIEW .....  | 58 |
| Figure XI: Histogram of SALE_PRICE_95.....   | 58 |
| Figure XII: Histogram of LogSALE_PRICE_95 .....                                      | 58 |
| Figure XIII: Histogram of DIS_TO_MILLS.....  | 58 |
| Figure XIV: Histogram of TOWNSHIP .....  | 58 |
| Table I: Sixteen Most Significant Hedonic Variables in Housing Studies .....         | 22 |
| Table II: Twelve Most Influential Characteristics Recommended by Local Experts ..... | 23 |
| Table III: Description of Viewshed Variables .....                                   | 26 |
| Table IV: Testing for the Influence of Township on Home Value .....                  | 32 |
| Table V: Testing for Significance of View among 3 Price Levels.....                  | 33 |
| Table VI: Definitions of Non-Viewshed Variables.....                                 | 44 |
| Table VII: Definitions of Viewshed Variables.....                                    | 45 |
| Table VIII: Description of Viewshed Variables.....                                   | 45 |
| Table IX: Description of Binary Variables .....                                      | 46 |
| Table X: Description of Continuous Variables .....                                   | 46 |
| Table XI: Description of Heights for Ground Cover Raster Files (in feet).....        | 48 |
| Table XII: Description of Heights for Ground Cover Raster Files (in feet).....       | 52 |
| Table XIII: Results of Viewshed Predictions for 4 Sets of Ground Cover Heights.....  | 52 |
| Table XIV: Results - Models 1-3 .....  | 56 |
| Table XV: Results - Models 4 - 6 .....   | 56 |



## **Abstract**

Potentially adverse effects of windfarm visibility on property values can represent real costs to communities, yet few studies exist on the subject. The studies that are available are contradictory, and suffer from statistical flaws. A clearer understanding of actual effects of existing wind facilities will inform future decisions. To explore this subject this report analyzes 280 arms-length single-family residential sales using a hedonic regression model. The sales took place from 1996 to 2005 and are within 5 miles of a 20 turbines - 30 megawatt (MW) windfarm in Madison County, New York. The report differentiates itself from previous studies by visiting all homes ("ground truthing") in the sample to ascertain the actual level of turbine visibility. The analysis finds an absence of measurable effects of windfarm visibility on property transaction values. This result holds even when concentrating on homes within a mile of the facility and those that sold immediately following the announcement and construction of the windfarm in 2001. These results dispel the proposition that effects, either positive or negative, are universal. The report concludes by making recommendations to stakeholders and outlining possible considerations for further research.

## **Key Words**

Viewshed, view, vista, wind energy, windfarm, turbines, property values, transactions, hedonic, regression, review, GIS, ground cover

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## 1 Executive Summary

With federal renewable energy tax credits and a number of state incentive packages in place (AWEA, 2005b), U.S. states are increasingly relying on wind energy to mitigate risks related to resource scarcity, increasing costs of fossil fuel extraction, greenhouse gas emissions and other environmental hazards (CRS, 2005). This shift has caused wind energy development to grow at an unprecedented rate. In 2005 new capacity totaling 2,400 megawatts (MW) was installed in the U.S., an increase of 35% over 2004 U.S. capacity (AWEA, 2006).<sup>1</sup> At the same time windmill sizes have become increasingly large in order to capture greater efficiencies per turbine, and the numbers of turbines installed per windfarm has increased to capture economies of scale (AWEA, 2005c). Litigious conflicts between community members and facility developers have occurred (Adams, 2005) and are likely to increase if the industry trends of increasing size and number continue. Community attitudes regarding wind energy are often promoted by small groups of organized opponents or proponents, therefore the sentiments of the entire community on average may be missed. One way to measure the community's disposition is to use property transaction prices (transaction values) as a proxy. If the visibility of a windfarm is believed by the members of the community to adversely affect the view from the home, the transaction value, with all else being equal, will be lower as compared to other homes without a view. Alternatively, if residents find the view acceptable, no change in property values will be discernable.

Many opinions exist on the effects of wind development on surrounding property values. For example, the two largest studies completed in the U.S. reach contradictory

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<sup>1</sup> The American Wind Energy Association (AWEA) estimates that 2,400 MW of wind energy will supply energy for 600,000 homes (AWEA, 2006)



results. Houghton (2004) predicts sizable negative effects from windfarm development on property values in Cape Cod, Massachusetts while Sterzinger (2003) concludes from his analysis of 10 communities around the U.S. there are strong positive effects. Despite these contradictory results no studies to date have rigorously analyzed the subject by using a large sample of arms-length home transaction values combined with a verification to what degree each home in the sample can see the wind farm or not. Instead, with each new wind development interested parties are forced to rely on poorly constructed or inconclusive studies (Jordal-Jorgensen, 1996; Grover, 2002; Sterzinger *et al.*, 2003; Poletti, 2005), or comparisons to inappropriately analogous research (Zarem, 2005a). For instance in 2004, the Public Service Commission (PSC) of Wisconsin heard opposing conclusions of studies conducted by experienced economists (Poletti, 2005; Zarem, 2005b). Both cited, in their testimony, their frustration with the lack of available evidence in this subject area.

Compounding the lack of data problem, changes in property values are not likely to be taken into consideration by the developer and the community. These “hidden costs” or “externalities” are not weighed against the benefits of a project. Without proper analysis of these potential costs or externalities and a thorough understanding of when and how they affect property values, facilities may be either needlessly delayed or inappropriately approved. This report studies property values and windfarms with the hope of shedding light on these issues.

First the report reviews the existing literature on property values and windfarms finding in most cases a lack of rigor and insufficient detail to capture the complex relationship between home transaction prices and views, such as those found in research of high voltage transmission lines (HVTL) and property values (e.g. Des-Rosiers, 2002). Then

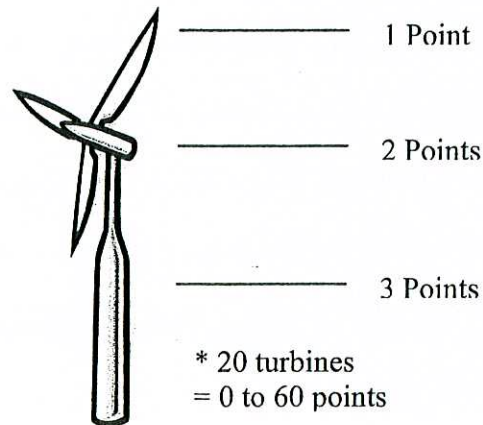
using data from a Madison County, New York community surrounding a 20 turbine windfarm, the report analyses home transaction values in an effort to ascertain if effects exist and to create a potential blueprint for future analysis of other communities. The data contains 280 arms-length single-family residential home sales which took place between 1996 and 2005; 140 occurred after facility construction began in 2001. None of the home sales were on properties that contained turbines, or received compensation from the operation of the turbines. Two methods of measuring the degree to which each home can see the turbines are developed, a simulated method and one involving field visits. Ultimately, as is discussed below, the method involving field visits was used for the regression model. The simulated method uses a geographical information system (GIS) model to predict visibility. Ten meter digital elevation model (DEM)<sup>2</sup> data provided by the United States Geological Survey (USGS) is combined with 10 meter ground-cover data by estimating heights of ground cover types and adding these heights to the surface elevations. The ESRI 3-D analyst viewshed algorithm, which is included in the Arc Map product, is used to analyze visibility. Then, GIS predictions are compared to field collected data. Although it incorporates techniques not previously used and reaches an accuracy rate of 85%, which is higher than the 50% accuracy rate found in the literature (Dean, 1997; Maloy and Dean, 2001), it is deemed an unsatisfactory level of accuracy for this report's hedonic analysis which requires greater than 95% accuracy. Therefore, the second, field visit method is used.

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<sup>2</sup> The DEM is a digital representation of the elevation of locations on the land surface. A DEM is often used in reference to a set of elevation values representing the elevations at points in a rectangular grid on the earth's surface.

For this method, each home in the sample is visited and the degree to which each of these homes can see the windfarm is quantified using a scoring method which attempts to minimize bias. From each home each of the twenty turbines is given a 0 (no view) to 3 (full view) score, which are then totaled resulting in a 0 to 60 score specific to that property.<sup>3</sup>

**Figure I: Turbine Visibility Scoring Method**



As well, a GIS is used to quantify the exact distance from each home to the nearest turbine. These two characteristics, view of and distance from turbines, are combined with a number of house and neighborhood characteristics. The combination of characteristics is then used in a hedonic regression model to investigate the marginal effect that the view of and distance from turbines has on home sale prices. The hedonic pricing model is well established in its usefulness in investigating the effects environmental characteristics have on home values (e.g. Dale *et al.*, 1999).

The report finds that the model significantly predicts home values (f-value 49-56, p-value 0.000,  $R^2$  0.792), and on average that there are no measurable effects on property values based on the view of and distance from turbine characteristics (p-value 0.410 and

<sup>3</sup> The actual range of scores for the sample set used in this report is 0 to 43.



0.679 respectively). This finding holds both temporally and spatially. In other words, homes which sold in the year the project was announced and constructed (2001), and had a clear view of the turbines, are not affected uniquely (p-value 0.742); and no measurable effect is found for homes located within a mile of the facility (p-value 0.656)<sup>4</sup>.

Additional tests are run to see if the township of Fenner in which the turbines are located, and to which payments are made by the facility owner, is accordingly perceived to have a positive value in the eyes of home purchasers as compared to the other townships. If the payment to the township is considered to be a distinct advantage by home purchasers, by adding needed dollars to the town budget, for example, it might be found the homes in Fenner are priced at a premium to other townships, all else being equal. In our analysis no measurable premium is found (p-value 0.689).

These results are important to policy makers and other stakeholders because they dispel the supposition that windfarm development has universally negative effects on home values. They support the results previously collected via surveys which find that a majority of residents in communities surrounding other wind facilities not only perceive the turbines to be “acceptable” (Warren *et al.*, 2005), but also “relatively nonexistent,” by rarely (< 3.0%) spontaneously mentioning them in descriptions of their surroundings (Braunholtz and MORI-Scotland, 2003).

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<sup>4</sup> A p-value is a measure of statistical significance, which can be reported in a number of ways in studies (e.g. margin of error, probability, or significance). They all report the same thing, the degree of confidence that the results were not reached by simple chance. As sample sizes grow, and variation among them becomes more predictable, more confidence can be had that “statistically significant” results from the analysis of the sample set can be transferred to the entire population. Conversely, if sample sizes are small, and variation among them is less predictable, results can not be validated against an average, and therefore present difficulties in being extrapolated to the population. In these cases results should be taken anecdotally or should not be transferred outside of the sample set.

With a paucity of research on the subject of effects of wind facilities on property values and a great deal of speculation regarding the actual effects, policy makers are forced to rely on poorly constructed studies and opinions. This report attempts to move the discussion toward the facts. Its research finds that in this community of 280 homes no effect is found. To the degree that these results are corroborated by further analytical research in other communities, the issue of negative impacts of windfarms on property values might take a lower priority in the decision making process. This report makes policy recommendations to stakeholders based on the results of this study and outlines possible areas for consideration which should be explored in future research.

## 2 Introduction

With federal renewable energy tax credits and a number of state incentive packages in place (AWEA, 2005b), the States are increasingly relying on wind energy to mitigate risks related to resource scarcity, increasing costs of fossil fuel extraction, green house gas emissions and other environmental hazards (CRS, 2005). Because wind energy, "is one of the lowest-priced renewable energy technologies available today" (USDOE, 2005, p. 1) and its resources are well distributed around the country, it has enjoyed an average annual growth of almost 20% over the last decade (GWEC, 2005) and is expected to continue its growth into the future (EIA, 2006). In the United States, twenty-one states have implemented a Renewable Portfolio Standard (RPS) which requires a percentage of retail sales to be from renewable sources (AWEA, 2005b). The American Wind Energy Association (AWEA) forecasts a 7-fold increase in the use of wind energy in the U.S. by 2020 (AWEA, 2005e). In 2005 alone roughly 2,400 MW (or 1666 turbines<sup>5</sup> in 140 "windfarms"<sup>6</sup>) have come online in the U.S. (AWEA, 2006).

Not only have the amount of windfarms been increasing but the number of turbines in each development has increased to capitalize on economies of scale. Additionally the sizes of the structures over the last 20 years have changed dramatically in order to increase turbine efficiency. As the height and rotor diameter of turbines increase, the power generated from the turbines grows exponentially (AWEA, 2005c). In 1980 when the Altamont Pass wind facility was erected outside of San Francisco in California (CA),

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<sup>5</sup> Estimated by using an average turbine size of 1.5 MW and farm size of 100 MW. Using this same estimate, if New York State is to meet its RPS goals of 25% by 2013 (NYS DPS, 2004) 30 new windfarms will have to be sited.

<sup>6</sup> These wind energy production facilities usually contain groupings of 10 or more turbines referred to as a "windfarm," because they are laid out, "as a farmer might approach...a field" (Gipe, 2002).



turbines averaged 30 meters in height (Pasqualetti, 2002). Now land based turbines sit on towers as high as 90 meters, and have blade lengths of 45 meters (AWEA, 2005c) totaling 135 meters (442 feet) from base to tip.<sup>7</sup> While increasing efficiency, this difference in heights makes them considerably more visible from long distances.

With the high number of windfarm installations expected to occur in the U.S. to meet RPS goals over the next decade and the ever increasing size of the facilities and the turbines themselves, it is inevitable that there will increasingly be conflicts between developers and members of the communities in which the windfarms are sited. Often these clashes revolve around environmental “aesthetics,” or how well the turbines fit into the surrounding environment in the eyes of community members. Findings suggest that respondents prefer smaller turbines over larger ones (e.g. Wolsink, 1989; SEI, 2003) and fewer structures rather than more in each group (e.g. Devine-Wright, 2004). Accordingly, homeowners have often claimed a proposed wind facility will ruin or “mar their view” (e.g. AP, 2006).

How can this claim be tested? When property owners say windmills will “ruin” their view, they are claiming both that there is some intrinsic value of “vista” (or view)<sup>8</sup> from their home, and that if the proposed windmills can be seen from the home this value will be diminished. It follows that if you can analyze home sales that have visual contact with the windmills in comparison with ones that do not, all other things being equal, an average effect can be verified. In other words, community attitudes of a wind development

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<sup>7</sup> Offshore turbines can be even bigger ranging up to 165 meters from base to tip.

<sup>8</sup> For this report, a distinction is made between “vista” and view or viewshed. “Vista” will always refer to the value of a home that is derived from a “good view” from the property. “View” or “Viewshed” will refer to the degree to which a property can see the windmills. In other words, “A property not only had a beautiful vista, but had a view of the windmills too.”

can be translated into home values, just as, for instance, the perceptions of a safe neighborhood or good quality public schools are translated into sale prices. This correlation of community attitude and property values has been confirmed in studies of other environmental attributes such as open space (e.g. Irwin, 2002), high voltage transmission lines (HVTL) (e.g. Des-Rosiers, 2002) and environmental stigmas (e.g. Dale *et al.*, 1999).

What are the ramifications to the community or society of such potential connections? If the effect of visibility of wind facilities on property values is universally highly negative, these costs might be very high. Haughton (2004), in his study of the proposed Cape Cod windfarm forecasts depreciation of property values in the billions! Yet, often changes in home values are outside the normal transactions of a developer and a community and are thus “hidden costs” or “externalities” of a project. These externalities are often grouped together and termed “environmental impacts” (EMC, 2005). Windfarm developers are often required, depending on the state or local laws, to investigate the nature and magnitude of these externalities by preparing an environmental impact statement (EIS) or something similar<sup>9</sup> often modeled after the Federal requirements as directed by the National Environmental Policy Act (NEPA)<sup>10</sup> regulations. An EIS is a report describing the investigations conducted by the developer of potential effects the facility will have on the surrounding environment. The report has a number of functions. First, it allows interested parties and stakeholders an opportunity to peel back, investigate and in some cases challenge the development’s declared environmental impacts. Secondly, it provides a record that can be later challenged if assertions are found to be incorrect. Lastly, it provides

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<sup>9</sup> More often than not, local laws will permit development to take place without a full environmental review (GAO, 2005), but often some type of impact assessment is required.

<sup>10</sup> National Environmental Policy Act (42 U.S.C. & 4321)



a schedule of expected environmental costs that can be compared against the proposed benefits any project will provide. In order for a project to proceed, “it must be demonstrated that the need for the proposal outweighs all adverse impacts” (EMC, 2005, p. 10).

Because of the importance of understanding actual effects on property values as costs to be weighed against benefits, it may be expected that this issue has been widely studied. However, this is not the case. Some studies exist using actual real estate transaction prices, but have made critical errors which weaken the results (e.g. Sterzinger *et al.*, 2003; Poletti, 2005), as explained in section 3. In the absence of actual prices, studies have used surveys of real estate professionals and homeowners as a proxy (e.g. Jordal-Jorgensen, 1996; Grover, 2002; Haughton *et al.*, 2004). Yet none of these studies reported their results accompanied by levels of significance.<sup>11</sup> Accordingly decision makers are forced to make educated guesses as to the predicted effects of a proposed windfarm. One controversy was played out in Wisconsin as two experts argued over the potential effects of the proposed Forward Wind Facility (Zarem, 2005b) and (Poletti, 2005) with each reaching distinctly different conclusions. Without well-designed studies with solid conclusions to work with, planners, developers, and potentially impacted communities will continue to needlessly delay or inappropriately rule on projects that might otherwise be decided differently.

This report examines whether property values were affected by a windfarm installed in Madison County in 2001. 280 home sales, which took place between three quarters and

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<sup>11</sup> Refer to discussion of “significance” in footnote 4 on page vii.

five miles of a 20 turbine windfarm, are analyzed using a hedonic pricing model<sup>12</sup> to establish the degree of impact that a view of windmills might have had on the transaction values of these homes. The report first outlines previous studies on the subject. Next the report presents methodology and results. Lastly the report discusses conclusions and makes policy recommendations to interested parties and research recommendations concerning decisions on siting wind facilities.

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<sup>12</sup> A hedonic pricing model, as discussed in section 5.1, is a statistical device which allows market goods to be broken into their component characteristics. It is often used to value individual characteristics of cars, such as the value of a sunroof, and homes, such as the value of a pool.

### 3 Overview of Previous Studies

The literature on wind energy facilities and surrounding property values can be grouped into three categories of increasing order of relevance for our research: survey-based studies (Jordal-Jorgensen, 1996; Grover, 2002; Haughton *et al.*, 2004; Khatri, 2004), transaction-based studies of analogous high voltage transmission lines (HVTL) structures (e.g. Delaney and Timmons, 1992; Hamilton and Schwann, 1995; Des-Rosiers, 2002), and transaction-based studies of windfarms (Sterzinger *et al.*, 2003; Poletti, 2005).

#### 3.1 Survey based studies

When transaction data are not available either because a windfarm has only been proposed or data are not recorded or available for public use,<sup>13</sup> surveys can be used to estimate values of viewshed impacts. Surveys specifically asking questions regarding values can be directed at assessors and real estate agents who have professional knowledge of how values can be impacted by a change in the surrounding environment (Grover, 2002; Haughton *et al.*, 2004; Khatri, 2004) or to residents who can offer their value judgments (Jordal-Jorgensen, 1996; Haughton *et al.*, 2004). Both of these methods can suffer from inflated and unrealistic values (Kroll and Priestley, 1991), and therefore it would be inappropriate to use these values as a replacement for actual economic impacts, as is discussed below. In the absence of other data, and if the surveys are taken using random and unbiased methods, they can be illustrative of community attitudes and indicate areas for further study.

Jordal-Jorgenson (1997) conducts two types of surveys using contingent evaluation methods. Contingent evaluation methods attempt to establish in monetary terms “non-

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<sup>13</sup> In the U.K., for example, residential transactional values are not public information.



market” environmental values by asking people how much they are willing to pay for an environmental amenity or to have an environmental nuisance removed.<sup>14</sup> Jordal-Jorgenson surveys 342 homeowners living “near” windmills in Denmark, inquiring if they find the turbines a nuisance and, if so, what they would be willing to pay to have them removed. 13% of the homeowners find them a nuisance and are willing to pay \$140 per household per year on average to have them removed.<sup>15</sup> Additionally, Jordal-Jorgensen asks respondents what they would be willing to pay to not live near the windmills. The study finds that people are willing to pay between \$2,314 and \$13,429 dollars to not live “near” a single or a group of turbines respectively.<sup>16</sup> The term “near” is not defined. The study points out that because the result is an average, a wide variety of impacts could be found among the homes, with individual homes experiencing potentially large impacts. Additionally, the author admits that the small number of houses, 26 out of 342, available for analysis near the turbines did not provide a statistically significant result, and that therefore the results could be “due to coincidental factors” (p. 2).<sup>17</sup> This is a problem, as well, with a number of other studies outlined below. Without a reported level of confidence in the results, readers are recommended to use the findings anecdotally.

Similarly, Grover’s (2002) survey results of 13 county tax assessors around Kittitas County, Oregon should also be used anecdotally because he both uses a very small sample size, and implies causality where only correlation has been found. Of the 13 county assessors that are interviewed, 6 state that their county’s residential properties have views of

<sup>14</sup> Surveyors use various techniques to improve the predictive power of this method. For further reading on this subject, Bateman (2002) is a good resource.

<sup>15</sup> Converted from Dutch Kroners (DKK) using 1996 exchange rates.

<sup>16</sup> Converted from Dutch Kroners (DKK) using 1996 exchange rates.

<sup>17</sup> Refer to footnote 4, on page vii, for a brief discussion on statistical significance, and how results which are reported without measures of significance should be used anecdotally and not empirically.

turbines, and 5 out of 6 report no complaints from residents. The report declares, "There is no evidence indicating that views of wind turbines decreased property values." (p. 4).

Technically this is true, but with only 6 assessors reporting it is not possible to have a great deal of confidence in the results. Additionally, the fact that residents did not complain (correlation) does not mean conclusively that property values are not affected (causation). It is possible other reasons intervened, such as either ignorance of residents that a reduction in assessed values could be requested, that the process would be futile, or perceptions that evidence warranting a decrease would be difficult to collect on their own.<sup>18</sup>

Although previous studies leave much room for criticism, the work by Haughton *et al.* (2004) is more solid because it largely uses accepted rigorous techniques of sampling and survey construction. Yet, predicting actual effects on property values based on these results would be risky because the results are descriptive,<sup>19</sup> not analytic, no significance values are reported, and survey responses might be influenced by other variables. Despite these limitations the results are illustrative of a community searching for solid answers to questions of property value impacts. As part of an economic analysis of the proposed offshore windfarm in Nantucket Sound, Haughton *et al.* (2004) conducts a survey of 546 real estate agents ( $n=45$ ) and residents ( $n=501$ ). It is the first large scale survey concerning wind energy in the U.S. since the late 1980s (Pasqualetti and Butler, 1987; Thayer and Freeman, 1987; Thayer and Hansen, 1988). The report concludes that there is an adverse expectation about the proposed windfarm on property values from both residents (21%) and realtors (49%). Homeowners believe that average values will decrease by 4.0% with losses

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<sup>18</sup> Grover (2002, p.5) states that in Lincoln WI, the assessor asked a complaining resident to show that nearby properties had diminished in value. This most likely is outside the abilities of the average homeowner.

<sup>19</sup> Descriptive results describe the distribution of variables without regard for causal or other hypothesis. Analytic studies are designed to examine these associations. (Last, 1995)



of 10.9% expected for waterfront properties. Realtors expect losses to total 4.6% on average. To extrapolate from these results is risky though. In a comparison of survey and hedonic approaches Brookshire *et al.* (1982) caution that, "biases due to lack of experience must be considered" (p. 176). The responder's estimates for anticipated impacts might be higher than those actually experienced. For example, the results of a survey in Scotland of 1,810 adults living near 10 windfarms with 9 or more turbines (Braunholtz and MORI-Scotland, 2003, p. 10) found that:

"Of those that lived in their homes prior to the construction, concerns about specific problems that might arise as a result of the windfarm do not seem to have materialized in many cases...Furthermore, while around half (54%) anticipated no problems over a range of issues associated with the windfarm development, as many as eight in ten (82%) say that there actually have been no problems."

This is corroborated by Warren (2005), in a study of residents surrounding windfarms in South-West Ireland who stated, "73% of residents across all [spatial] zones feel that their fears have not been realized" (p. 864). Finally, the predicted amount of value degradation as reported by Haughton *et al.* could be confounded by other variables, such as whether the respondent's home has a view of the sound, if they believe wind energy to be necessary, to what degree they believe it might contribute to positive environmental change, or if they had seen an actual windfarm. Yet Haughton does not report these interactions between these variables.

Despite these weaknesses, their results are important in other ways. They illuminate a belief that the brunt of the effects will be felt by residents on the water in full view of the sound. Haughton found that 69% of realtor respondents believed the effects of the windfarm would be felt to a greater extent on ocean front houses, with only 2% expecting the effects to be distributed evenly (29% no opinion). The reasoning for this follows the

logic that the “vista” of the sound provide value to the houses (e.g. Rodriguez and Sirmans, 1994; Seiler *et al.*, 2001). Incorporated with the belief that the addition of windmills will decrease the beauty of that “vista,” it follows that the values of these homes will be diminished. Further, it might be the case that *ceteris paribus*, home values more dependent on “vista” will experience an effect where others will not. There might be some threshold where an effect begins such as that found with HVTL in Des-Rosiers (2002) study where he found effects (positive and negative!) completely disappear outside of 500 feet from the transmission line. All told, it would be difficult to entirely dismiss the results of Haughton *et al.* as the musings of the inexperienced or the hysterias of those in fear. The proposed windfarm will consist of 130 turbines, and as mentioned above, people have a preference for smaller windfarms over larger ones (Wolsink, 1989; SEI, 2003). It seems likely that house values in that region will react in concert to some degree with resident dislike; the question will be in what amount.

The results of Khatri’s (2004) survey, for reasons similar to Haughton (2004) are illustrative of perceptions rather than actual values. Khatri mailed 1,942 surveys to licensed surveyors in Great Britain (U.K.); 405 voluntarily responded, and roughly 80 were surveyors who had experience with residential transactions near windfarms. The report finds that a majority (60%) of surveyors reported that property values will be adversely affected, though closer inspection finds dilutions to the results in three ways. The experienced respondents were concentrated in Wales and Scotland, where 43% of U.K. wind projects are located,<sup>20</sup> yet the percentage of Welsh (45%) and Scottish (55%)

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<sup>20</sup> from [www.bwea.org](http://www.bwea.org) as cited by Khatri (2004)



respondents reporting decreased values is below the survey's national average (60%).<sup>21</sup> This implies that the national average is not appropriate to use as a final result. Secondly, because responses were voluntary, there might be a selection bias as the sample was unlikely to represent the population (Heckman, 1979).<sup>22</sup> Lastly the actual survey is not provided so it is difficult to assess the quality of the research, for example the nature of the questions.<sup>23</sup>

### 3.1.1 Conclusions drawn from survey studies

The survey studies do not give a clear indication as to whether there is an actual decrease in value. Even Haughton's (2002) study suffers from the likelihood that without actually experiencing what windmills look like in Nantucket Sound, respondents will overestimate the impacts. Haughton does elucidate, though, the possibility of thresholds of sensitivity for price devaluation. The results of these studies reinforce the need for more research and lead us into the next category of studies that are often used as a proxy for windfarm property value analysis: transaction-based studies of analogous HVTL structures.

### 3.2 *Transaction based studies of analogous HVTL structures*

With little to go on from existing research of wind energy and property values, interested parties have turned to property value studies of high voltage transmission lines (HVTL) in an attempt to make a benefits transfer from these structures to windfarms. It has been found that HVTL structures are perceived negatively and often adversely affect property values

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<sup>21</sup> A decrease in experienced effects is more recently corroborated by Warren (2005, p.853) "inverse NIMBYism"

<sup>22</sup> It is possible that only those that were bothered by the wind farms responded because they cared the most. If that is the case, than the results are skewed and in actuality less assessors feel there will be a decrease in property values.

<sup>23</sup> The report results "60% agreeing" imply that a leading question was used such as, "Do you agree the windfarms hurt property values?"



(e.g. Kroll and Priestley, 1991; Des-Rosiers, 2002). Because newer windmills are larger, and often more noticeable because of moving parts than HVTL, the temptation is there to assume turbines will have an equal or greater effect on property values (e.g. Zarem, 2005a).

### 3.2.1 Are HVTL structures and windmills viewed similarly?

Research conducted in 2003 in Ireland, based on a survey of 1,200 people indicated that windfarms were preferred over HVTL towers (as well as cellular towers and fossil fuel stations) (SEI, 2003). Why is this? Thayer and Hansen (1988) found that perceptions of windfarms were based on symbolic aspects in addition to aesthetic ones. Devine-Wright (2004) concurs, stating that symbolic aspects “could include the degree to which turbines are associated with wider environmental concerns such as climate change and feelings of personal responsibility to address such problems” (p. 129). This more complicated view of turbines is echoed in Warren (2005). When respondents living around windfarms were asked to rank the most positive and most negative aspects of the turbines, their presence in the landscape topped both categories (34% and 44% respectively). People either love them or loathe them.<sup>24</sup> It follows that if the U.S. effort in building windfarms is increasingly perceived as a reduction of risks, and therefore a solution to problems of energy scarcity and security, reaction to them will improve. Conversely, it is unlikely that HVTL would ever be perceived as offering a greater good. In fact, however unfounded,<sup>25</sup> electromagnetic radiation from HVTL is still a concern for individuals.<sup>26</sup> Because of these differences in

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<sup>24</sup> This turn of phrase has been used often to describe public sentiment (e.g. Bishop and Proctor, 1994; Freris, 1998).

<sup>25</sup> Goeters (1997) reports that no study has provided scientific evidence of a relationship between cancer and HVTL proximity.

<sup>26</sup> Delaney (1992) reports that, “Even appraisers who had not appraised such property [near HVTL] believe that power lines contribute negatively to property values [for health reasons].” (p. 315).

perception between windmills and HVTL it would be imprudent to make a one for one comparison between the two.

### 3.2.2 Are spatial property value effects of HVTL similar to windfarms?

Des-Rosiers (2002) found that effects from HVTL and their accompanying easements<sup>27</sup> disappeared outside of 500 ft. Additionally his results show a very sensitive interplay between proximity to the tower structure and proximity to the easement. Des-Rosiers (2002) found both an unambiguous negative effect due to towers and an unambiguous positive effect due to easement of HVTL on house values. In his review of the HVTL literature Des Rosier's (2002) finds that most studies conclude that, "Other physical as well as neighborhood attributes prevail [over proximity to HVTL] in the price determination process." (p. 277). This conclusion is also borne out in his findings that the negative effects of a view of a tower from a house immediately adjacent to it are overwhelmed by the positive effects of living near a HVTL easement just a few doors away (Figure I).

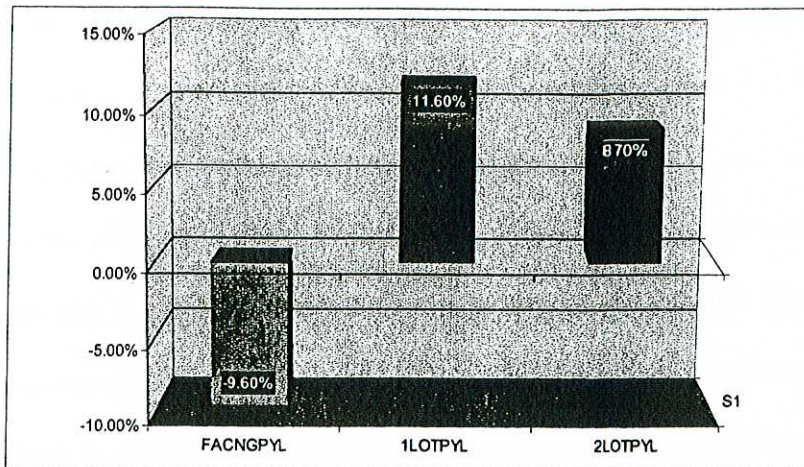
If HVTL and windmills exhibit similar effects on values, can it be assumed that property value effects of windmills will entirely disappear outside of 500 ft? Perhaps they will disappear, but at what point; one tenth of one mile, a half of one mile, or some other distance? Additionally, what effect will some overriding positive attribute, such as "vista" of sunsets, a bucolic field, or a mountain range, have on the potentially adverse effects of a view of windmills in close proximity?

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<sup>27</sup> In the case of HVTL easements are clearings through which transmission lines pass. They have benefits, for example, in that ensure a development free zone and can provide access to green space.



**Figure II: Property Value Effects of HVTL and Distance**



*Source: (Des-Rosiers, 2002, p.293) Effects on houses adjacent to towers (FACNGPYL), are negative (-9.60%). Those on lots 1 or 2 away (1LOTPYL & 2LOTPYL) are positive (11.60% and 8.70 % respectively).*

Lastly, it is interesting to consider Warren's (2005) theory "inverse-NIMBYism" that there is an increased appreciation for wind turbines as you move closer to them, and the findings of Brauhnoltz (2003) which show largely ambivalent and positive reactions of residents to nearby turbines. Brauhnoltz finds that of the people living within 5 km (3 miles) of turbines 45% had largely positive views (with 6% having negative views and 49% ambivalent/no opinion), which differed significantly from those residents living outside of 10 km (6 miles) of which 17% had positive views (with 6% negative and 77% ambivalent/no opinion). The logical extension of inverse-NIMBYism on property values would have values increasing as distance from turbines decreases! Despite this possibility the report assumes the conventional stance that windmills will either decrease values or not change them at all.

### 3.2.3 Are temporal property value effects of HVTL similar to windfarms?

Kroll (1991) finds that where newly installed HVTL have effects on property values, they tend to fade away entirely over four to ten years. This is similar to results of some studies conducted near wind energy facilities. Exeter-Enterprises-Ltd (1993) found via its longitudinal study of facilities in the U.K. that negative perceptions diminish over time. "The results show that any change of attitude...is toward thinking that wind power is better." (p. 53) On the other hand, Devine-Wright (2004) believes the opposite. His re-analysis of Krohn's (1999) results show that negative perceptions of development can increase over time. Is this because older turbines are often decommissioned yet are not removed? Thayer (1988) believes so, finding that community sentiment is correlated with the number of turbines in operation, and if turbines are standing idle, negative perceptions increase. Given these contradictory results, a generalization of the similarities of HVTL and windfarm's temporal effects is not appropriate.

### 3.2.4 Conclusions drawn from analogous HVTL studies

The comparisons of HVTL effects on property values and those of windmills seem unclear. HVTL structures are not viewed the same as windmills, and windmills can even take on positive connotations. Moreover the interplay between HVTL and property values is both tenuous and very sensitive to distance and other neighborhood characteristics. There are spatial and temporal thresholds for HVTL property value effects which also could exist for windmills. As with the survey study analysis above, a careful look at HVTL studies reinforce the need for more research. Possibly other structures, for instance offshore drilling platforms, could be used as a more appropriate proxy as will be discussed further in the recommendations section. The studies conducted using actual property transaction



values surrounding wind facilities offer more empirical data, but are also inconclusive as to the effects of windfarms on these values.

### 3.3 *Transaction based studies of windmills*

To date only two studies have been conducted using actual transaction values of homes surrounding wind facilities. The results of these are varied. Sterzinger *et al.*, (2003) conclude that property values rise in the area of windfarms, and Poletti (2005) comes to the conclusion that no effect exists.

Sterzinger *et al.*, (2003) analyses roughly 24,000 transactions near 11 windfarms in the U.S., and compared average transaction values for houses in a control area outside the viewshed of the windfarm with transactions occurring within the viewshed (a 5-mile radius). The study comes to the conclusion that, "There is no support for the claim that wind development will harm property values." (p. 9), and even declares, "For the great majority of projects [windfarms] the property values rose more quickly in the viewshed than they did in the comparable community." (p. 2). Although this study is often quoted,<sup>28</sup> its methods have been criticized (e.g. ECW, 2004) for four reasons. First, the authors attempt to calculate a value for the variable "view of windmills," without properly controlling for it. There is no attempt to discern which properties within the ten different 5-mile viewsheds can see the windfarm or not. In effect, the study makes the erroneous assumption that all properties in the 5-mile radii can see the windfarm, when many houses' views in fact are obstructed by geological features, trees, and other houses (RBA, 1998a; Poletti, 2005).<sup>29</sup>

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<sup>28</sup> A "Google" internet search using all of the following words, "REPP", "wind" and "property" generates 18,600 results. [tested 2-20-06]

<sup>29</sup> Sterzinger *et al* analyze the community surrounding the Madison County windfarm, which is the subject of this report. We found 66% of the homes sampled in the 5 mile radius could not see the windfarm at all.

Secondly, the analysis does not control for distance to the turbines, thereby making the assumption that the “viewshed” effect is the same, on average, for homes five miles from the windfarm and those in immediate proximity to the turbines. Third, there are problems with how the study validates its results. The report provides readers with only  $R^2$  (or goodness-of-fit) values for its outcomes, and this is problematic, since, by itself, the  $R^2$  statistic is a poor indicator of explanatory power (Halcoussis, 2005). Compounding this problem, the report gives  $R^2$  values which are very low, for instance 0.02 for some models, which is saying in essence the model describes only 2% of the actual movement of property values. Despite this somewhat flagrant disregard for rigor it treats these models as it does models where the statistic is high, for example 0.85. This inconsistency is not addressed by the report. The last reason this research is often criticized is that no attempt is made to sort out inappropriate transactions. Sales that are not arms-length (divorce, sales between family members, estate sales etc.) are included. By doing so the report includes transactions that do not represent the agreement between a willing buyer and a willing seller, a requirement for accurate analysis. Combined, these four omissions in rigor render the results of the report extremely weak, if not entirely misleading.

The analysis by Poletti (2005) improves on that of Sterzinger *et al.* (2003) by culling out transactions that were not arms-length. As well, it excludes sales of homes built before 1960, in an effort to control for house-specific characteristics such as construction quality, amenities and condition. Poletti looks at roughly 300 sales that occurred in and around two windfarms in Wisconsin and Illinois. He comes to the conclusion that there is not sufficient evidence in the data to warrant rejection of the claim that windfarms have an effect on property values. Poletti compares average values of properties surrounding the windfarms,



which he entitles “target area” with those in a “control area,” which is outside the view of the windfarm. However, Poletti does not attempt to measure to what degree, if any, homes can see the windfarm. The author describes the area surrounding the windfarms as rolling with potentially obscuring features, so the implication is that some of the properties have no view of the windfarm. Further, no effort is made to control for distance. Although statistically sound techniques were used to compare the control area to the target area, by not properly controlling for view and distance, the study results are inconclusive at predicting the effects of the windfarm on property values.

### 3.3.1 Conclusions drawn from transaction studies

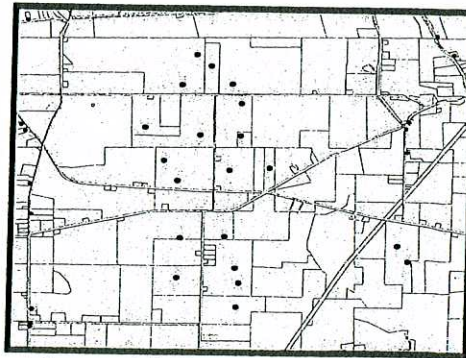
Taken together, the two studies using transaction values still leave open to conjecture the question as to the actual effects of windfarms on property values. By not appropriately sorting out misleading data, empirically establishing the degree to which houses could see the windfarm, and not factoring in distance, these studies most likely miss the potentially subtle interaction between view and value that has been found with other environmental stigmas (Des-Rosiers, 2002).

If results of studies of property values and windfarms can be confidently applied in windfarm siting decision making, the above analysis makes clear the importance of using large samples (>30), of measuring the actual visibility of and distance from turbines from each house, and of testing the results for significance. The following analysis attempts to do this. First there will be a brief discussion of the study area, then methodology, results, conclusions and recommendations.

#### 4 Study Area

The Fenner windfarm was announced near the end of 2000; construction commenced in the spring of 2001 and was completed in the fall of 2001 (Moore, 2005). The 30 megawatt (MW) installation consists of 20 turbines, each 218 feet tall, with a rotor radius of 110 feet, making the top of the turbine blade's sweep roughly 328 feet above the ground. The windfarm sits atop 14 different parcels over 2,000 rolling acres. The Fenner Township receives \$150,000 as a payment in lieu of taxes (PILOT) from the project owner which goes to increased road maintenance and schools (Cary, 2005). As is required under the New York State Environmental Quality Review Act (SEQRA) an Environmental Assessment Form (EAF) was prepared and submitted to the lead agency which was the Town of Fenner Board. It issued a Negative Declaration on the project based on the EAF, citing adverse impacts as insignificant. The public was given a number of opportunities to participate in the decision making process at town board and planning board meetings, which were characterized as both numerous and without much opposition (Moore, 2005). Larger maps of the study area are included in Appendix B.

**Figure III: Fenner Turbines & Parcels**



*Source: Madison County Tax Office*

*(Large dots are windmills, rectangles are parcels, parallel lines are HVTL, and the dark lines are roads.)*



## 5 Methodology

The general purpose of this case study is to test if the view of the Fenner windfarm from homes inside of 5 miles from the windfarm has any significant effect on transaction values. "View" is defined using a continuous variable from 0 (no view) to 60 (a full view of all 20 turbines). The study additionally investigates how this effect varies with distance (spatially), time (temporally) and house value. Lastly, the effect and degree of the PILOT payment to Fenner Township is investigated.

The hedonic pricing model is well suited to dissect these issues revolving around windfarm acceptance. The rigor of the instrument in measuring the marginal contribution housing and neighborhood characteristics have on home transaction values is well supported in the literature for assessment purposes (Brookshire *et al.*, 1982; Malpezzi, 2002; Sirmans, G.S. *et al.*, 2005a; Sirmans, G. Stacy *et al.*, 2005b), in establishing effects of HVTL (Kroll and Priestley, 1991; Delaney and Timmons, 1992; Hamilton and Schwann, 1995; Des-Rosiers, 2002), in valuing the contribution "vista" has to value (Rodriguez and Sirmans, 1994; Benson *et al.*, 2000; Seiler *et al.*, 2001; Bond *et al.*, 2002), and in determining the effect of open space (Irwin, 2002) and environmental stigmas (Dale *et al.*, 1999). The model, given enough data, is sensitive enough to allow sales to be grouped temporally (e.g. by year), spatially (e.g. by distance from an amenity such as a body of water), and economically (by the value of the home). Once these divisions are made, variables of interest (e.g. the marginal contribution of fireplaces to homes values) from one group can be compared to other groups, both in terms of significance and the level of contribution.

### 5.1 *The non-linear hedonic model*

The non-linear hedonic pricing model in its present form is often attributed to Sherwin Rosen (1974) for his contribution to its utility in deciphering housing prices. A number of reviews (Malpezzi, 2002; Sirmans, G. Stacy *et al.*, 2005b) validate his construction in its ability to rigorously predict changes in residential transaction values based upon characteristics of the homes.

The model takes the form:

$$\text{Log (Sale\_Price)} = f(\text{Physical Characteristics, Other Factors}).$$

“Physical Characteristics” often used include square footage of the home, lot size, number of bathrooms, number of bedrooms, type of construction, etc. “Other Factors” often include proximity to amenities, school district, local tax rates, and in this case study, “view” of and distance from turbines.

### 5.2 *Variable selection*

Although inclusion of the most commonly significant variables as taken from the literature (e.g. Sirmans, G. Stacy *et al.*, 2005b) is important and necessary, often local conditions can direct the proper construction of the model more than convention. Local assessors, realtors, and residents often have considerable insight into how prices are affected by changes in characteristics and other factors. Therefore in constructing the model used for this report Sirman’s (2005b) recommendations for variables were included as well as those cited by a survey of two local assessors and two real estate agents. The results of the two inquiries are listed in Table I and Table II.

Sirman's list included all of the variables on the local expert list except School District, the distinction between distance to I90 and distance to State Route 20, local tax rates and building styles. All of the available variables from both the Sirman list and the local expert list were included.

**Table I: Sixteen Most Significant Hedonic Variables in Housing Studies**

| Variable             | Appearances | # Times Positive | # Times Negative | % Time Significant |
|----------------------|-------------|------------------|------------------|--------------------|
| Square Feet (SFLA)   | 69          | 62               | 4                | 96%                |
| Central Air          | 37          | 34               | 1                | 95%                |
| Age at Time of Sale  | 78          | 7                | 63               | 90%                |
| Pool                 | 31          | 27               | 0                | 87%                |
| Acres                | 52          | 45               | 0                | 87%                |
| # of Full Baths      | 37          | 31               | 1                | 86%                |
| # of Stories         | 13          | 4                | 7                | 85%                |
| Deck                 | 12          | 10               | 0                | 83%                |
| # of Fireplaces      | 57          | 43               | 3                | 81%                |
| # of Garage Spaces   | 61          | 48               | 0                | 79%                |
| # Rooms              | 14          | 10               | 1                | 79%                |
| Basement Type        | 21          | 15               | 1                | 76%                |
| # of Bedrooms        | 40          | 21               | 9                | 75%                |
| Brick or Stone Extr. | 13          | 9                | 0                | 69%                |
| Distance             | 15          | 5                | 5                | 67%                |
| Time On Market       | 18          | 1                | 8                | 50%                |

*Source: (Sirmans, G. Stacy et al., 2005b)*

### 5.3 Data collection

The data concerning transaction values and assessor information is collected from Madison County Real Property Tax Office. From January 1, 1996 through June 1, 2005, 452 sales took place that were coded "arms-length" transactions by county assessors, and were within 5 miles of the windfarm. Of these, 152 were removed as land-only sales<sup>30</sup>, and upon closer inspection 20 sales (15 land-only and 5 non arms-length) were found to have been coded incorrectly and were removed. For the remaining 280 sales, assessor records from the

<sup>30</sup> "Land Only" sales refer to sales of parcels that did not contain a house at the time of sale.



closest preceding inspection were collected providing information about structural characteristics and location.

Although most of the recommended variables were included in the Madison County records, there were many gaps in the records for the following variables which made them unusable: Pool, deck, number of stories, number of rooms, and garage spaces.<sup>31</sup> Data for time on the market was not available, and therefore was not included.<sup>32</sup>

**Table II: Twelve Most Influential Characteristics Recommended by Local Experts**

| Variable                   | Percent of the 4 Local Experts Recommending this Variable |
|----------------------------|---|
| # of Full Baths            | 100%  |
| # of Bedrooms              | 100%  |
| Overall Condition          | 100%  |
| Basement Type              | 75%   |
| # of Fireplace             | 75%   |
| Acres                      | 75%   |
| Square Feet (SFLA)         | 75%   |
| Age at Time of Sale        | 75%   |
| Building Style             | 50%   |
| Distance to I90            | 50%   |
| School District & Taxes    | 50%   |
| Distance to State Route 20 | 50%   |

*Source: Joel Arsenault, Century 21 Real Estate; Jenny Chapin, Don Kinsley Real Estate; Priscilla Suits, Assessor Fenner & Nelson Townships, Madison County; Tanya Pifer, Assessor Lincoln Township, Madison County*

Sale price was adjusted to 1995 dollars by using the Department of Labor's CPI for Rural New York (SALE\_PRICE\_95) and then converted to its natural log

<sup>31</sup> During field analysis decks and pools were rarely present, and the number of rooms and stories was expected to be highly correlated with the square feet, so their exclusion was not expected to compromise the results. The County is conducting a reassessment of every house in its records, which should be completed in 2006, which is expected to fill in the gaps of these characteristics.

<sup>32</sup> Although time on the market generally has the effect of lowering the price it has in some cases produced higher prices. It is assumed that this is because buyers can wait for the price that they want, or that the market slowly appreciates up to their asking price (Sirmans, G. Stacy *et al.*, 2005b).

(LNSALE\_PRICE\_95).<sup>33</sup> The thoroughness of this adjustment was tested by including a continuous variable (DEED\_YEAR) to account for a potential linear escalation in market price which exceeded the CPI inflation rate. Four binary variables (WINTER\_SALE, SPRING\_SALE, SUMMER\_SALE, and FALL\_SALE) were included in the model to account for seasonality in the housing market. Descriptive statistics for all non-viewshed variables are given in Appendix A: Tables IX and X.

A geographic information system (GIS) was used to calculate distance from the houses to the nearest turbine (DIS\_TO\_MILLS). Elevation and spatial location layers were populated using the 10 meter digital elevation model (DEM) provided by the United States Geological Survey (USGS), ortho-imagery was provided by New York's Department of Environmental Conservation (NYDEC), and roads, windmill locations and parcels were provided by the Madison County Planning Department. Parcel shapefiles did not contain actual house location, so a housepoint file was constructed using the ortho images overlaid with the parcel map, for each parcel that sold during the study period.

All layers were projected using the NAD 1983 Coordinate System and the New York State Plane Central projection. Where possible, shapefiles were corroborated with ortho-images, as was the case with the windmills, to ensure locational accuracy. Distances to major roadways (Route 20: DIS\_TO\_RT20 and U.S. Route 90: DIS\_TO\_I90) were calculated using linear distance. Although this is not a measurement of actual driving time

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<sup>33</sup> To account for the "bubble" in the housing market binary variables for all years were tested but were found to be insignificant, so the CPI 1995 adjusted prices were used without these variables.

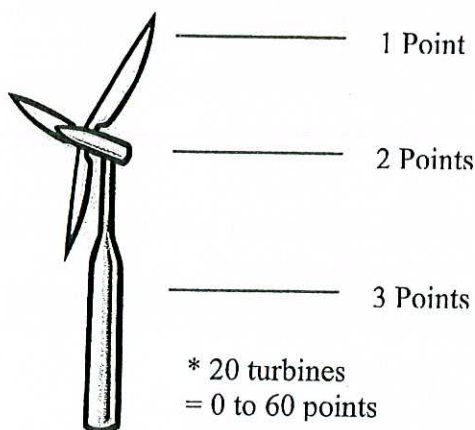
to these arteries, field experience indicated that the high density of roads in this area allowed residents a fairly direct route to the arteries at roughly the same speed.<sup>34</sup>

#### 5.4 Construction of viewshed variables

To populate the variables for windfarm viewshed (VIEW) two methods were developed: a GIS simulated method and one involving field visits, and one method was ultimately used: the field visit method. The GIS method, as discussed in Appendix C, achieved an accuracy rate of 85% which improved on previous studies (Dean, 1997; Maloy and Dean, 2001) but did not meet accuracy requirements for this report's analysis of greater than 95%.

Therefore the second method involving field analysis was used to ensure complete accuracy of the "view" variables. Visits were made to each of the 280 homes which sold after Jan 1, 2001 and were within 5 miles of the windfarm (138 homes visited) to assess the degree to which the home could see the windfarm. By standing at or near the house a rating of 1 to 60 was established for each home. This rating was based on the degree to which viewers could see each of the 20 windmills in the Fenner windfarm (Figure III).

**Figure IV: Turbine Visibility Scoring Method**



<sup>34</sup> A more accurate measurement would be a shortest elapsed time traveled incorporating speed limits of roads, and distance traveled on them. This is similar to the algorithms used by, for instance, Mapquest.



If the viewer could see only the top 1/3 of the turbine blades one point was given for that turbine, visibility of the nacelle (or hub) was a second point and visibility below the sweep of the turbine blades a third. Therefore a total of 3 points per turbine were possible, with a total of 60 points for the 20 turbines. No distinction was made for the direction the house faced because it was assumed purchasers were likely to walk around the house and inspect all views. If the turbines were clearly in view from the property surrounding the house, and the purchasers had a strong reaction to their visibility, it was assumed they were not likely to make a distinction between front, back and side windows at the time of purchase. Inspections were done on October 30 and 31, 2005 when deciduous trees had partially dropped their leaves. A slight distinction between winter (leaves off) or summer (leaves on) sale dates could be made from some properties; therefore visibility was calculated using the appropriate condition. Finally photographs of the house and of the predominant view were taken to corroborate results at a later time if needed.

**Table III: Description of Viewshed Variables**

|                     |   |
|---------------------|---|
| <b>DIS TO MILLS</b> | The distance from the home to the nearest turbine as calculated by the GIS.   |
| <b>VIEW</b>         | The view of the turbines as recorded from the field analysis with possible range from 0 to 60. If house sold before Jan 1, 2001 the value is 0. |
| <b>VIEW1MILE</b>    | The VIEW of the home if $0 > \text{DIS TO MILLS} \leq 1$ , otherwise 0  |
| <b>VIEW2MILE</b>    | The VIEW of the home if $1 > \text{DIS TO MILLS} \leq 2$ , otherwise 0  |
| <b>VIEW3MILE</b>    | The VIEW of the home if $2 > \text{DIS TO MILLS} \leq 3$ , otherwise 0  |
| <b>VIEW4MILE</b>    | The VIEW of the home if $3 > \text{DIS TO MILLS} \leq 4$ , otherwise 0  |
| <b>VIEW5MILE</b>    | The VIEW of the home if $4 > \text{DIS TO MILLS} \leq 5$ , otherwise 0  |
| <b>VIEW2001</b>     | The VIEW of the home if the year of sale was 2001, otherwise 0  |
| <b>VIEW2002</b>     | The VIEW of the home if the year of sale was 2002, otherwise 0  |
| <b>VIEW2003</b>     | The VIEW of the home if the year of sale was 2003, otherwise 0  |
| <b>VIEW2004</b>     | The VIEW of the home if the year of sale was 2004, otherwise 0  |
| <b>VIEW2005</b>     | The VIEW of the home if the year of sale was 2005, otherwise 0  |



### 5.5 *Discussion of Descriptive Statistics*

Of the 280 properties in the sample, the mean value of homes was \$102,384, the mean number of acres was 8.8 and the mean age of the home at the time of sale was 42 years old. Approximately 28% of all the houses in the sample could see the windfarm; of the 149 sales that took place after January 1, 2001, 43 were from homes which could see the windfarm. A full description of all the variables is included in Appendix A.

### 5.6 *Testing for violations of OLS assumptions*

After the model had been constructed the data were tested in accordance with the ordinary least squares (OLS) assumptions which govern hedonic regression models. These assumptions include: multicollinearity, the independence of the error term and the independent variables, homoskedasticity and temporal autocorrelation.<sup>35</sup>

#### 5.6.1 Multicollinearity

The assumption of multicollinearity posits that the independent variables are in fact independent and not highly correlated with each other. If one variable is highly dependent on one or a combination of variables, the  $p$ -values will be inappropriately increased. This assumption can be tested for by regressing each independent variable on the others and then looking at the unadjusted  $R^2$  values. Convention holds that  $R^2$  values less than 0.75 indicate a multicollinearity low enough to allow results to be largely undisturbed (Halcoussis,

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<sup>35</sup> A fifth assumption which is commonly considered in OLS models, but rarely in hedonic literature is simultaneity, when the dependent variable affects the independent variables. This was not directly tested for, but its effect on coefficient significance is to increase it. In the case of this report, this does not alter our results.

2005).<sup>36</sup> In our case all  $R^2$  values were under this threshold, and most (80%) were considerably under it (in the .5 to .2 range).

During initial analysis of the variables, a correlation matrix was generated. It was found that the number of bedrooms (NBR\_BEDROOMS) was highly correlated (0.746) with square feet (SFLA), but the number of bathrooms (NBR\_BATHROOMS) (0.474) and the number of half baths (NBR\_HALF\_BATHS) (0.361) were acceptably correlated with square feet and each other (0.044), so bedrooms was dropped from the model and half baths was added. Additionally it was found that distance to I90 (DIS\_TO\_I90) was highly negatively correlated to distance to Route 20 (DIS\_TO\_RT20) (-0.977) because they run roughly parallel to each other. Therefore, I90 was dropped from the model.

#### 5.6.2 Independence of Error Term and Independent Variables

Independence of the error term and the independent variables is important in assuring that the variables are the best predictor of the dependent variable. To test this assumption, the residuals were regressed on the independent variables. None of the independent variables were significant ( $p$ -value range from 0.138 – 0.913) and the model itself is non-significant ( $f$ -value 0.258,  $p$ -value 0.999, adjusted  $R^2$  -0.059).

#### 5.6.3 Homoskedasticity

Homoskedasticity of the variables assumes that the error terms of any range of values of a continuous variable are similar. The values of the variables are ordered in ascending or descending order and divided into thirds. The Levine test statistic compares the variances

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<sup>36</sup> Actually the measure used is the Variance Influence Factor (VIF) which is calculated as follows:  $1/(1-R^2)$ . A VIF of 4 or below is appropriate to reject the claim of a high degree of Multicollinearity. An  $R^2$  more than 0.75 will result in a VIF more than 4.

of the thirds. If that statistic falls outside the acceptable range ( $p$ -value  $> 0.05$ ) the assumption holds. In our case all continuous variables returned values exceeding 0.05 therefore the OLS assumption of homoskedasticity was met.

#### 5.6.4 Temporal Autocorrelation

The existence of temporal autocorrelation violates the OLS requirement that the residuals are independent of each other. If temporal autocorrelation exists, the values of the dependent variable, and therefore their residuals, are affected by the value in the previous temporal term. By arraying the residuals in chronological order and testing the correlation of any residual against its preceding residual their autocorrelation can be determined. The Durbin Watson test statistic ranges from 0 to 4. Within a range of 1.5 to 2.5 there is considered to be no autocorrelation. A statistic either more or less than that range is considered to have either a positive or a negative autocorrelation respectively. All of the models had a Durbin Watson test statistic between 1.798 and 2.047, therefore no autocorrelation was detected.<sup>37</sup>

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<sup>37</sup> Spatial autocorrelation was not tested for, yet it is possible that it would exist within the data, following the logic that a neighbor's transaction value affects the surrounding transactional values both on the sellers and buyers side of the transaction.



## 6 Analysis

Results of the six models that were run are reported in Appendix F. Initially, the model was run with all potentially significant variables (Model #1), as recommended by the literature (Table I) and the local experts (Table II). Many building styles and school districts did not meet initial significance criteria ( $p$ -value  $< 0.75$ ). As well, the variable for air conditioning (CENTRAL\_AIR) was found to be insignificant. These variables were removed. As expected these changes improved the model's overall significance (Model #2). Model #3 is further refined with all non-significant ( $p$ -value  $> 0.1$ ) variables removed except those for seasonality (e.g. FALL\_SALE). This model (Model #3) had an F-value (63.764) considerably higher than that of Model #2 (39.185) indicating the removed variables created undue "noise" in the model. All variables had the expected sign except for the Fenner Township binary variable, which is discussed below. Model #3 was then used to test the significance of the viewshed variables.

Initially the variables for distance to the windmills (DIS\_TO\_MILLS) and view of the windmills (VIEW) were added to the model (Model #4). The coefficients for these variables were both positive yet non-significant at both the 95% or 90% levels of confidence (0.679 and 0.410 respectively). Models #5 and #6 explore the potential micro-spatial and temporal effects of view in 1 mile bands (VIEW1MILE thru VIEW5MILE) and subsequent years (VIEW2001 thru VIEW2005) respectively. Although both models are significant in general, all 10 variables did not meet the significance criteria ( $p$ -value  $< 0.10$ ), therefore interpretation of the coefficient value or sign is not appropriate.

As mentioned above the sign (coeff. -0.083) and significance ( $p$ -value 0.018) of the binary variable for the Fenner Township (FENNER) is surprising. This variable measures

the marginal change in value for homes in Fenner Township as compared to all other townships. We included this variable to explore if the payment the township receives in lieu of taxes from windfarm operations (PILOT) has had an effect on the values of homes in the township all else being equal. The assumption is that if the payments, which largely go to the school system in the township, are considered to have significantly improved conditions in the township in the eyes of home purchasers, this variable would be both positive and significant. But, in our model the coefficient was negative and quite large (the coefficient -0.083 corresponds roughly to a decrease of 8%). Therefore, to further explore we added binary variables for all townships including Fenner (Smithfield was the omitted township). The results of this test indicated that none of the townships had a significant influence on price when taken together. This indicated that the influence of Fenner was being spread among the townships. Therefore, finally we omitted the Fenner variable and included all of the other township variables and found both Cazenovia (coeff. 0.106,  $p$ -value 0.095) and Nelson (coeff. 0.105,  $p$ -value 0.081) were significant and positive. Results for these variables are in Table IV. The positive sign implies that in relation to Fenner *ceteris paribus* the placement of the house in Cazenovia and Nelson adds value. We explored whether this had to do with the wind energy facility by adding view variables to the model. Because distance to turbines can be largely explained by the township variables<sup>38</sup> we only included the variable VIEW [of turbines]. We found that neither the magnitude nor the significance for the township variables changed when we took view into account. This implies that the decreased value of homes in Fenner is not related to the wind facility. To investigate the effects of township further we contacted a local realtor (Arsenault, 2006).

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<sup>38</sup> Regressing distance on the township variables produced adj.  $R^2$  of 0.579 and a  $p$ -value of 0.000.



He believed there was a correlation between the township (Fenner) and the value of homes, in that homes of higher values were not being built in the Township. He attributed this to the windmills, and believed that there was a correlation between values of home and the

**Table IV: Testing for the Influence of Township on Home Value**

|                            | Coeff. | p-vlu | Coeff. | p-vlu | Coeff. | p-vlu. | Coeff. | p-vlu | Coeff. | p-vlu |
|----------------------------|--------|-------|--------|-------|--------|--------|--------|-------|--------|-------|
| <b>CAZENOVIA</b>           | 0.077  | 0.301 | 0.106  | 0.095 | 0.117  | 0.141  | 0.113  | 0.077 | 0.118  | 0.076 |
| <b>LINCOLN</b>             | 0.009  | 0.880 | 0.056  | 0.505 | 0.073  | 0.404  | 0.072  | 0.405 | 0.067  | 0.456 |
| <b>NELSON</b>              | 0.095  | 0.115 | 0.105  | 0.081 | 0.109  | 0.147  | 0.105  | 0.079 | 0.109  | 0.071 |
| <b>SULLIVAN</b>            | 0.038  | 0.564 | 0.079  | 0.290 | 0.100  | 0.244  | 0.097  | 0.215 | 0.092  | 0.250 |
| <b>SMITHFIELD</b>          |        |       | 0.029  | 0.628 | 0.036  | 0.567  | 0.035  | 0.566 | 0.032  | 0.616 |
| <b>FENNER</b>              | -0.023 | 0.689 |        |       |        |        |        |       |        |       |
| <b>DIS TO MILLS</b>        |        |       |        |       | -0.002 | 0.930  |        |       |        |       |
| <b>VIEW</b>                |        |       |        |       | 0.001  | 0.428  | 0.001  | 0.411 |        |       |
| <b>VIEW1MILE</b>           |        |       |        |       |        |        |        |       | 0.001  | 0.716 |
| <b>VIEW2MILE</b>           |        |       |        |       |        |        |        |       | 0.000  | 0.913 |
| <b>VIEW3MILE</b>           |        |       |        |       |        |        |        |       | 0.006  | 0.113 |
| <b>VIEW4MILE</b>           |        |       |        |       |        |        |        |       | 0.002  | 0.676 |
| <b>VIEW5MILE</b>           |        |       |        |       |        |        |        |       | -0.002 | 0.711 |
|                            |        |       |        |       |        |        |        |       |        |       |
| <b>Model R<sup>2</sup></b> |        | 0.791 |        | 0.806 |        | 0.790  |        | 0.790 |        | 0.789 |
| <b>F/Significance</b>      | 53.921 | 0.000 | 51.184 | 0.000 | 46.524 | 0.000  | 48.827 | 0.000 | 41.132 | 0.000 |

*Note: Non viewshed variables were included in the model but were not shown above. Coefficients roughly correspond to percentages (e.g. 0.100 ≈ 10% increase), and p-values correspond to the likelihood that this result was reached by chance (e.g. 0.100 ≈ 10%).*

affect “view of the turbines” had on them. He said, “Higher priced homes were not being built in the Fenner area because of the view of the turbines.” To analyze this claim we broke sample set of home sales into thirds and investigated whether the variable for view was affected. In so doing we tested the claim that homeowners of higher priced homes care more about the view than those of lower value. Table V contains the results. We found that view did not have a significant effect at any price range. We also found that although splitting the groups did not affect the significance of the overall model, it did dramatically decrease the R<sup>2</sup> statistic as compared to previous models (roughly 0.80 to 0.23). A portion of this decrease can be explained by the decrease in the number of cases in each group ( $n$ ),

Table V: Testing for Significance of View among 3 Price Levels

| Price Level                       | Lower 3rd |         | Middle 3rd |         | Upper 3rd |         |
|-----------------------------------|-----------|---------|------------|---------|-----------|---------|
|                                   | Coeff.    | p-value | Coeff.     | p-value | Coeff.    | p-value |
| DIS TO MILLS                      | -0.009    | 0.773   | 0.023      | 0.132   | -0.022    | 0.285   |
| VIEW                              | 0.003     | 0.313   | 0.002      | 0.361   | 0.000     | 0.918   |
|                                   |           |         |            |         |           |         |
| <i>n</i> /Adjusted R <sup>2</sup> | 92        | 0.472   | 93         | 0.226   | 92        | 0.627   |
| F/Significance                    | 6.13      | 0.000   | 2.507      | 0.003   | 9.605     | 0.000   |

*Note: All non-viewshed variables were included in the model but are not shown above. Coefficients roughly correspond to percentages (e.g. 0.100  $\approx$  10% increase), and p-values correspond to the likelihood that this result was reached by chance (e.g. 0.100  $\approx$  10%).*

but not all. It could reflect the variance between the income levels, and indicates a need for further research into how each income level makes home buying decisions, based on the non-viewshed variables that were included in the model (i.e. number of bathrooms, square feet, and number of acres).



## 7 Conclusions

Our analysis of 280 home sales within 5 miles of the Fenner windfarm, in Madison County, New York failed to uncover any statistically significant relationship between either proximity to or visibility of the windfarm and the sale price of homes. Additionally, the analysis in this report failed to uncover a relationship even when concentrating on homes within a mile or that sold immediately following the announcement and construction of the windfarm. Therefore it is safe to conclude, in this community, a view of the windfarm does not produce either a universal or localized effect, adverse or not. To the degree that other communities emulate the Fenner rural farming community, these results should be transferable. But, to be safe in these conclusions, let us first consider the possibility that: 1) effects exists, but the instruments which were used in this study were not effective in measuring them, and 2) effects exists but because those effects are situated outside the sample area our analysis did not discover them.

First we investigate the possibility: whether the instruments were not effective in measuring an effect. The instruments in question are 1) the hedonic pricing model and 2) the methods used to calculate turbine visibility. The hedonic model is appropriate as it has been well tested in various applications including, but not limited to, assessments, in valuing nearby open spaces and in valuing the effects of HVTL and environmental stigmas. It is particularly effective at discerning universal influences, and the question of effects on property values is not whether one or two houses are affected but rather if groups of houses are affected in a predictable universal way. The construction of the model, used in this report, follows the convention described as “test, test, test” (Kennedy, 2003), which refers to a model construction method that, “discovers which models of the economy are tenable,

and to test rival views.” (p. 83) By carefully testing the assumptions behind the model, as were described in section 5.8, the model that was ultimately chosen can be considered to be, “the best estimated regression line” (Halcoussis, 2005).

In regards to the tests of “visibility” from each of the homes, the method chosen was intended to reduce bias and allow for a robust set of measurements (0 to 60). View was measured not in a subjective way, but rather by counting the numbers of points seen from the house. The distance was measured by linear calculations produced by a GIS. Because the range of the two measurements is relatively large, a small miscalculation of “view” (0-60 scale) or distance (0.00 to 5.99 miles) will not adversely affect the ability of the model to explain variations in sale price. It is therefore safe to say that the instruments this report used are both appropriate.

The second possibility of error concerns whether effects exist outside the sample area and therefore were not measured by our analysis. In other words, is it possible that a house inside of 0.76 miles, outside of 5 miles or that will sell after June 2005 will be affected differently than what our sample describes? The possibility should be investigated in other studies, but in the case of Fenner it is unlikely unless the situation on the ground changes.<sup>39</sup> Our sample set includes *all* arms-length transactions of single family homes which occurred from January, 1996 to June, 2005 within 5 miles of (and as close to 0.76 miles from) the windfarm. If one is to attempt to address the question of whether effects exist, a sample set containing all transactions cannot be improved upon.<sup>40</sup> If houses were

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<sup>39</sup> For example, if the turbines are taken out of operation yet are not decommissioned or removed. Thayer (1987) found a strong negative reaction to just such a situation in California in the 1980s.

<sup>40</sup> The sample data is normally distributed as would be expected of 280 transactions. See Appendix F.



measurably affected outside the sample set, it seems unlikely that concurrently no effect, weak or strong, would be found inside the sample set.

If the potential inadequacy of the instruments has largely been ruled out, and we are confident that the study area represents an adequate sample we can conclude no effect exists for this community, or, if they do, the effects are random and therefore, by definition, unpredictable. The result of “no effect” has been corroborated by peer-reviewed large sample survey studies. Warren (2005) found, on average, windfarms were of little concern to residents stating, “The data reveal a clear pattern of public attitudes becoming significantly more positive following personal experience of operational windfarms” (p. 866). Further, Brauholtz (2003) finds,

“It is extremely rare for people to spontaneously mention their local windfarm as either a positive [ $<3.0\%$  of sample] or negative [ $0.3\%$  of sample] aspect of their area. This fact that suggests that, for most at least, [the windfarm] is not foremost in their minds when thinking of, and describing, the area” (p. 5).

A rural setting with a history of farming, these townships might accept harvesting wind energy as an extension of the use of their land. The wind farm does not seem to have been in contest with the sense of place that is mentioned in Devine-Wright’s (2004) discussion. Possibly the non-linear layout is desirable. It is rather undulating as is the landscape itself. There are many opportunities for hide and reveal<sup>41</sup> in this landscape, which might allow viewers to keep an emotional distance from the turbines if they are in opposition to them, or to look at them more affectionately if they are in favor of them.

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<sup>41</sup> “Hide and reveal” or “miegakure” (jap.) is a phrase used in landscaping where even in small spaces portions screening of features (the “hide”) encourages viewers to see what lies just around that bend (the “reveal”).

Thayer (1987) found that public sentiment was strongly tied to the bureaucracy behind the decision to erect the windfarm (local officials, developer). This is echoed by Wolsink (1989) and Krohn (1999), who states "decision making over the heads of local people is the direct route to protest" (p.959). In the case of Fenner the developer was required to prepare and submit for public review an EAF. And the Town of Fenner was the lead agency overseeing the approval of permits. Therefore, to the degree that the EAF process effectively addressed and corrected negative concerns, the community might not have retained much negative sentiment toward the project going into construction. Possibly the research of Devine-Wright (2004) offers an explanation. He states, "the opinions of significant others such as friends and family living in the local area are important in determining public perceptions of wind farms" (p.130). In Fenner, one civically involved couple who leased their land to the developer is not only a proponent of wind energy, but also talks with great pride of the Fenner Township and surrounding area. They host tours and offer t-shirts and hats for wind farm visitors. They might have influenced the community positively. In fact an imminent windfarm expansion in Fenner from 20 to 29 turbines has been met with no opposition. This matches with Warren's (2005) results. He samples residents both with and without experience living near windfarms and found those with experience are much more likely to favor expansion of them.

To the degree that other similar communities exist in the US, in that they have similar land uses, median home prices, and homeowner profiles, these results should be transferable. Extrapolation of these results to communities which do not fit this description, without careful consideration, is not recommended until more research is conducted. Specific recommendations for further research are outlined below.



## 8 Policy Implications and Recommendations

Contrary to the notion that adverse effects are universal, this report did not produce any significant relationship between distance from, or visibility of the windfarm and the sale prices of homes. These results fit with those reported in other empirical studies that surveyed public attitudes, which found that people living near turbines find them “acceptable” and, in fact, rarely spontaneously mention them (Braunholtz and MORI-Scotland, 2003). Together these studies suggest that in communities similar to the one surrounding the Fenner windfarm, the question of property value effects should be lessened in importance in the decision making process. Further, if these results are substantiated in further research as discussed below, the implications for stakeholders are significant.

Specific recommendations for many of the stakeholders in the windfarm planning process are as follows:

- **Town Officials/Planners:** Town planners should realize that the methods for facility approval can greatly contribute to placating community concerns. A transparent process which allows residents to address siting concerns such as the size of the project, the placement of the turbines as it relates to dwellings, and the provisions for dealing with maintenance and decommissioning are very important. If steps such as these are followed, local decision makers should be able to enjoy favorable community sentiment and avoid property devaluation.
- **Community Members:** This research should provide some confidence to community members that a windfarm siting does not guarantee a devaluation of property values, and that assertions to that effect should be thoroughly investigated. In fact, if more studies corroborate these findings devaluation might be considered unlikely. If residents

believe their community is similar to Fenner's, factors other than property devaluation should be concentrated on. These could include the level of payments in lieu of taxes (PILOT), the quality of decommissioning assurances and the level of transparency in the planning process. Based on the findings of this study these factors could play a more important role than potential property devaluation in a community's proposed windfarm evaluation process. Additionally, urging local, state and federal policy makers to promote continuing research into public attitudes surrounding other wind energy facilities will allow for greater understanding of upcoming development proposals, and a larger area of transferability of results.

- State lawmakers: This report's findings of "no effect" might indicate that the planning process used for the Fenner windfarm should be used as a model. Currently some state laws allow the review process to be entirely avoided (GAO, 2005), yet an environmental review and subsequent community involvement can help ensure that appropriate decisions are made and development is accepted by the community going forward. State regulations should require all wind developments to participate in the EIS process, to ensure that the planning process is transparent, and that community involvement is encouraged. Additionally, through an intense effort to research and disseminate findings, such as reactions of other communities to wind development in the U.S., lawmakers can give local officials the tools needed to weigh real costs and benefits. In so doing, decision makers can avoid having to rely on insufficient information and speculation.
- Wind industry representatives: Although these findings seem to show that property devaluation did not occur in the community surrounding the Fenner windfarm, it should

be clear that property value effects are strongly tied to public attitudes, a cooperative planning process, and might be influenced by characteristics not present in the Fenner community. These are discussed below and include the number of second homes, the proximity to the wind turbines, and the percentage of “vista” included in the home value. Accordingly, encouraging further empirical research of public attitudes and property transaction values surrounding wind developments might provide decision makers with the information needed to make appropriate decisions regarding development proposals going forward.

### *8.1 Future research considerations*

For communities, especially ones that are not similar to Fenner, there is an intense need for more research. With this, policy makers and other stakeholders will have better answers to this contentious issue. More information is needed regarding the following categories:

- Other windfarm communities: Roughly 90 sites in the U.S. are larger than the Fenner site (AWEA, 2005d), and many of them would be appropriate for study. Sites should be chosen with a variety of socio-economic characteristics, windfarm sizes, and population densities. Studies should analyze homes closer than 4000 feet, and include variables for “vista,”<sup>42</sup> level of community cooperation in approval process, degree that farming matches sense of place (such as the percentage of large tract vs. small), and whether homes are the primary or secondary residences.
  - Distance: This study contains homes only as close as 0.75 miles or 4000 feet to the turbines. HVTL studies have found effects exist only inside 500 feet

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<sup>42</sup> As discussed in footnote 8 on page 2



(Des-Rosiers, 2002). Future studies should find communities with homes closer than 0.75 miles, and preferably as close as 500 feet if they exist.<sup>43</sup>

- Vista: This study does not include a separate measurement for “vista” (or good view) in its analysis. For example, Haughton (2004) finds that homes with a high percentage of “vista” represented in their value (such as might be found in homes on the coast) might be affected differently by wind development.
- Cooperative Process: The community studied in this report was at least partially involved in the planning process, in so far as they were invited to attend and submit comments at a number of meetings (Moore, 2005). The degree to which the project developer includes the community in the planning process of other communities might influence results (Warren *et al.*, 2005) and should be studied.
- Sense of Place: Anecdotal evidence implies that this community still largely embraces the farming nature of its past. How well wind energy “harvesting” fits with other community’s sense of appropriate land use might also alter outcomes (Devine-Wright, 2004). Using an average tract size for a sample might be a proxy for this variable.
- Size of Project: The Fenner windfarm is 20 turbines. Because there is evidence that community’s prefer smaller windfarms over larger ones

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<sup>43</sup> Homes within 500 feet of the turbines, in this study area, were situated on the same parcels that had turbines, and therefore the homeowners received income from the windfarm owners. This coincidence could present complications in analysis of sale prices. Additionally, none were sold during the study period.

(Wolsink, 1989; SEI, 2003) studies conducted using homes surrounding facilities larger than 20 might reach different results.

- Primary Residence: This study does not include a separate variable describing if homes are primary residences or not. It is possible that homeowners of non-primary residences might be more sensitive to changes in their viewshed. Future studies should include this variable.
- Other potentially analogous structures: Although the research from HVTL is helpful in establishing potential effects of windfarms on property values, research concerning other infrastructures might be more applicable. For instance, investigating transaction value effects on coastal homes having views of offshore drilling platforms could shed light on the property value effects when a high “vista” value is present.
- Comparisons of hedonic and survey results: Because survey results are often used as a proxy for actual effects, studies to determine the appropriateness of these methods as it applies to windfarms would be very fruitful for policy makers. If combined hedonic and survey studies were conducted in communities with existing windfarms, which started before announcement and continued well after construction, policy makers and stakeholders could determine the applicability of using surveys to determine present and future property value effects.
- GIS visibility determinations: By continuing research into this area, and using the most up to date data, such as that being newly collected by light detecting and ranging (LIDAR) radar techniques, policy makers and stakeholders may find a very inexpensive method for determining visibility and therefore conducting analysis on communities.

By conducting and disseminating further research, policy makers and other stakeholders can more fully understand the subtle interaction between a view of windfarms and property values. As a result, they will have more appropriate tools to make well informed decisions regarding wind energy siting proposals. For now, it is safe to say property value effects are not guaranteed, and in fact, in the case of Fenner, do not seem to exist at all.



## Appendix A: Definitions and Descriptions of Variables

Table VI: Definitions of Non-Viewshed Variables

|                 |  |
|-----------------|--|
| ACRES           | The number of acres in parcel  |
| AGE AT SALE     | The age of home at time of sale. Calculated by subtracting year built from Deed Year.      |
| BLDSTYL-AFRM    | Building style binary variable equal to 1 for A Frame houses and 0 otherwise               |
| BLDSTYL-CAPE    | Building style binary variable equal to 1 for Cape houses and 0 otherwise                  |
| BLDSTYL-CNTMP   | Building style binary variable equal to 1 for Contemporary houses and 0 otherwise          |
| BLDSTYL-COLNL   | Building style binary variable equal to 1 for Colonial houses and 0 otherwise              |
| BLDSTYL-CTTG    | Building style binary variable equal to 1 for Cottage houses and 0 otherwise               |
| BLDSTYL-LOG     | Building style binary variable equal to 1 for Log Cabin houses and 0 otherwise             |
| BLDSTYL-OLDSTYL | Building style binary variable equal to 1 for Old Style houses and 0 otherwise             |
| BLDSTYL-RANCH   | Building style binary variable equal to 1 for Ranch houses and 0 otherwise                 |
| BLDSTYL-RSRNCH  | Building style binary variable equal to 1 for Raised Ranch houses and 0 otherwise          |
| BLDSTYL-SPLIT   | Building style binary variable equal to 1 for Split Level houses and 0 otherwise           |
| CAZENOVIA       | Binary variable equal to 1 if township is Fenner, otherwise 0.                             |
| CENTRAL AIR     | House has central air conditioning   |
| DIS TO I90      | Distance from home to Interstate I 90 in miles   |
| DIS TO RT 20    | Distance from home to State Route 20 in miles  |
| DIS TO TOWN     | Distance from home to nearest town center in miles   |
| DEED YEAR       | Year of sale as recorded on the deed.  |
| DEED YEAR SQRD  | Year of sale as recorded on the deed - Squared   |
| FALL SALE       | Binary variable equal to 1 for transactions in quarter 4 and 0 otherwise                   |
| FENNER          | Binary variable equal to 1 if township is Fenner, otherwise 0.                             |
| LINCOLN         | Binary variable equal to 1 if township is Lincoln, otherwise 0.                            |
| LNSALE PRICE 95 | Natural Log of Sale Price in 1995 dollars  |
| NBR BEDROOMS    | Number of bedrooms house contains  |
| NBR FIREPLACES  | Number of fireplaces house contains  |
| NBR FULL BATHS  | Number of full bathrooms house contains  |
| NBR HALF BATHS  | Number of half bathrooms house contains  |
| NELSON          | Binary variable equal to 1 if township is Nelson, otherwise 0.                             |
| OVERALL COND    | Overall condition of home at time of last assessment                                       |
| RBSMNT TYP DUM  | Binary variable equal to 1 for full or finished basement and 0 otherwise                   |
| SALE PRICE 95   | Sale price converted to 1995 dollars   |
| SCHDIS-CAZ      | School district binary variable equal to 1 for Cazenovia school district and 0 otherwise   |
| SCHDIS-CHTNGO   | School district binary variable equal to 1 for Chittenango school district and 0 otherwise |
| SCHDIS-CNSTO    | School district binary variable equal to 1 for Canastota school district and 0 otherwise   |
| SCHDIS-MORS     | School district binary variable equal to 1 for Morrisville school district and 0 otherwise |
| SCHDIS-ONIEDA   | School district binary variable equal to 1 for Oneida school district and 0 otherwise      |
| SCHDIS-STKBRDG  | School district binary variable equal to 1 for Stockbridge school district and 0 otherwise |
| SFLA            | Number of square feet in the home  |
| SMITHFIELD      | Binary variable equal to 1 if township is Smithfield, otherwise 0.                         |
| SPRING SALE     | Binary variable equal to 1 for transactions in quarter 2 and 0 otherwise                   |
| STONE WALL MAT  | Binary variable equal to 1 for stone or brick exterior and 0 otherwise                     |
| SULLIVAN        | Binary variable equal to 1 if township is Sullivan, otherwise 0.                           |
| SUMMER SALE     | Binary variable equal to 1 for transactions in quarter 3 and 0 otherwise                   |
| WINTER SALE     | Binary variable equal to 1 for transactions in quarter 1 and 0 otherwise.                  |

Table VII: Definitions of Viewshed Variables

|                     |   |
|---------------------|---|
| <b>DIS TO MILLS</b> | The distance from the home to the nearest turbine as calculated by the GIS.   |
| <b>VIEW</b>         | The view of the turbines as recorded from the field analysis with possible range from 0 to 60. If house sold before Jan 1, 2001 the value is 0. |
| <b>VIEW1MILE</b>    | The VIEW of the home if $0 > \text{DIS TO MILLS} \leq 1$ , otherwise 0  |
| <b>VIEW2MILE</b>    | The VIEW of the home if $1 > \text{DIS TO MILLS} \leq 2$ , otherwise 0  |
| <b>VIEW3MILE</b>    | The VIEW of the home if $2 > \text{DIS TO MILLS} \leq 3$ , otherwise 0  |
| <b>VIEW4MILE</b>    | The VIEW of the home if $3 > \text{DIS TO MILLS} \leq 4$ , otherwise 0  |
| <b>VIEW5MILE</b>    | The VIEW of the home if $4 > \text{DIS TO MILLS} \leq 5$ , otherwise 0  |
| <b>VIEW2001</b>     | The VIEW of the home if the year of sale was 2001, otherwise 0  |
| <b>VIEW2002</b>     | The VIEW of the home if the year of sale was 2002, otherwise 0  |
| <b>VIEW2003</b>     | The VIEW of the home if the year of sale was 2003, otherwise 0  |
| <b>VIEW2004</b>     | The VIEW of the home if the year of sale was 2004, otherwise 0  |
| <b>VIEW2005</b>     | The VIEW of the home if the year of sale was 2005, otherwise 0  |

*Note: This table also appears in the main text*

Table VIII: Description of Viewshed Variables

| <b>VIEWSHED VARIABLES</b> | <b>Mean</b> | <b>Minimum</b> | <b>Maximum</b> | <b>Frequency</b> |
|---------------------------|-------------|----------------|----------------|------------------|
| <b>DIS TO WNDMILS</b>     | 3.50        | 0.76           | 5.98           | 280              |
| <b>VIEW</b>               | 3.09        | 0              | 46             | 43               |
| <b>VIEW1MILE</b>          | 0.60        | 0              | 40             | 5                |
| <b>VIEW2MILE</b>          | 0.81        | 0              | 46             | 15               |
| <b>VIEW3MILE</b>          | 0.46        | 0              | 46             | 6                |
| <b>VIEW4MILE</b>          | 0.84        | 0              | 32             | 11               |
| <b>VIEW5MILE</b>          | 0.38        | 0              | 38             | 6                |
| <b>VIEW2001</b>           | 0.60        | 0              | 39             | 11               |
| <b>VIEW2002</b>           | 0.55        | 0              | 40             | 9                |
| <b>VIEW2003</b>           | 0.79        | 0              | 46             | 8                |
| <b>VIEW2004</b>           | 1.03        | 0              | 46             | 12               |
| <b>VIEW2005</b>           | 0.11        | 0              | 17             | 3                |



Table IX: Description of Binary Variables

|                                | Median | Mean | Minimum | Maximum | Frequency |
|--------------------------------|--------|------|---------|---------|-----------|
| <i><b>BINARY VARIABLES</b></i> |        |      |         |         |           |
| BLDSTYL-CAPE                   | 0      | 0.07 | 0       | 1       | 20        |
| BLDSTYL-CNTMP                  | 0      | 0.11 | 0       | 1       | 30        |
| BLDSTYL-COLNL                  | 0      | 0.15 | 0       | 1       | 41        |
| BLDSTYL-CTTG                   | 0      | 0.01 | 0       | 1       | 2         |
| BLDSTYL-LOG                    | 0      | 0.04 | 0       | 1       | 10        |
| BLDSTYL-OLDSTYL                | 0      | 0.21 | 0       | 1       | 59        |
| BLDSTYL-RANCH                  | 0      | 0.34 | 0       | 1       | 96        |
| BLDSTYL-RSDRNCH                | 0      | 0.04 | 0       | 1       | 11        |
| BLDSTYL-SPLIT                  | 0      | 0.03 | 0       | 1       | 9         |
| CENTRAL AIR                    | 0      | 0.06 | 0       | 1       | 280       |
| FENNER DUM                     | 0      | 0.29 | 0       | 1       | 80        |
| RBSMNT TYP DUM                 | 1      | 0.80 | 0       | 1       | 224       |
| STONE WALL MAT                 | 0      | 0.01 | 0       | 1       | 2         |
| SCHDIS-CAZ                     | 0      | 0.47 | 0       | 1       | 131       |
| SCHDIS-CHTNGO                  | 0      | 0.14 | 0       | 1       | 39        |
| SCHDIS-CNSTO                   | 0      | 0.18 | 0       | 1       | 51        |
| SCHDIS-MORS                    | 0      | 0.15 | 0       | 1       | 43        |
| SCHDIS-ONIEDA                  | 0      | 0.03 | 0       | 1       | 8         |
| SCHDIS-STKBRDG                 | 0      | 0.03 | 0       | 1       | 8         |
| SPRING SALE                    | 0      | 0.28 | 0       | 1       | 78        |
| SUMMER SALE                    | 0      | 0.34 | 0       | 1       | 94        |
| FALL SALE                      | 0      | 0.24 | 0       | 1       | 67        |
| WINTER SALE                    | 0      | 0.15 | 0       | 1       | 41        |

Table X: Description of Continuous Variables

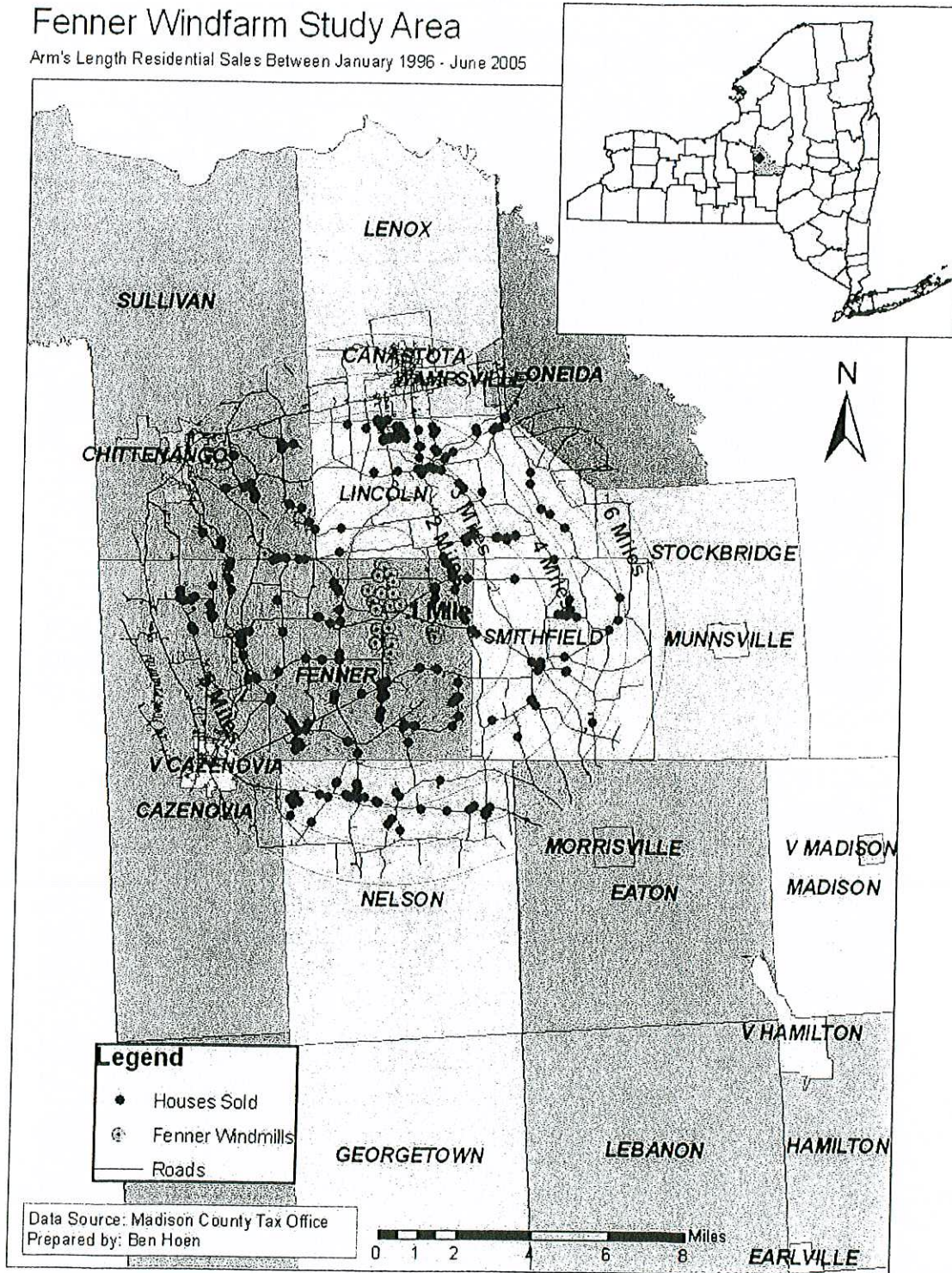
| <i><b>CONTINUOUS VARIABLES</b></i> | Median   | Mean      | Minimum  | Maximum   | Frequency |
|------------------------------------|----------|-----------|----------|-----------|-----------|
| SALE PRICE 95                      | \$91,293 | \$102,371 | \$10,049 | \$284,935 | 280       |
| LNSALE PRICE 95                    | 11.42    | 11.41     | 9.215    | 12.560    | 280       |
| ACRES                              | 2.26     | 8.61      | 0.13     | 237.26    | 280       |
| AGE AT SALE                        | 20.5     | 42.36     | 0        | 205       | 280       |
| DEED YEAR                          | 2001     | 2001      | 1995     | 2005      | 280       |
| DEED YEAR SQRD                     | 49       | 54.40     | 1        | 121       | 280       |
| DIS TO RT20                        | 4.66     | 4.69      | 0.01     | 10.17     | 280       |
| DIS TO TOWN                        | 3.68     | 3.78      | 1.51     | 6.87      | 280       |
| NBR FIREPLACES                     | 0        | 0.51      | 0        | 5         | 116       |
| NBR FULL BATHS                     | 2        | 1.63      | 0        | 4         | 278       |
| NBR HALF BATHS                     | 0        | 0.39      | 0        | 1         | 110       |
| OVERALL COND                       | 3        | 3.09      | 1        | 5         | 280       |
| SFLA                               | 1715     | 1804      | 420      | 5194      | 280       |



### Appendix B: Map of Study Area

## Fenner Windfarm Study Area

Arm's Length Residential Sales Between January 1996 - June 2005



### Appendix C: Technique for Creating GIS Viewshed Prediction Algorithm

A predicted view from each home was calculated using GIS techniques. The accuracy of the best performing predicted view was 85% as compared to actual view measurements. Since this did not meet confidence requirements, it was not used in the model.

To create a viewshed that effectively mimics the reality of a landscape the ground surface elevations as well the ground cover need to be simulated. In our case the 10 meter USGS DEM was used for surface elevations. The DEM was converted to a 3 dimensional ESRI raster file with the ARCGIS 9 "DEM to RASTER" algorithm using float and no z-value conversion. 10 meter data from the Multi-resolution Land Characterization (MRLC) Consortium<sup>44</sup> depicted the ground cover. Then by estimating heights for each ground cover type in our sample area, and reclassifying the raster fields to these heights, a raster addition was possible between the DEM and the MRLC. Four sets of heights for deciduous, conifer, and mixed forests, shrubs and grass (cultivated land) were tested (See Table IV). All other groundcover types were given a height of 0.

**Table XI: Description of Heights for Ground Cover Raster Files (in feet)**

| Set                | Conifer | Deciduous | Mixed | Grass & Shrubs |
|--------------------|---------|-----------|-------|----------------|
| <b>WINTER</b>      | 100     | 0         | 50    | 5              |
| <b>80 NO-GRASS</b> | 80      | 70        | 75    | 0              |
| <b>80</b>          | 80      | 70        | 75    | 5              |
| <b>100</b>         | 100     | 90        | 95    | 10             |

<sup>44</sup> Partners include the USGS (National Mapping, Biological Resources, and Water Resources divisions), USEPA, the U.S. Forest Service, and the National Oceanic and Atmospheric Administration



Road and turbine location shapefiles were provided by the Madison County Tax Office, and a river shapefile was provided by the USGS National Map. House locations were derived as described in section 5.3. Because MRLC raster cells often spanned roads and covered houses and turbine locations, buffer shapefiles were created around each. 10 foot buffers were created around roads and houses, and 30 foot buffers surrounded turbines. To improve viewshed algorithm performance each raster grid (both DEM alone and DEM/MRCL additions) was converted to a triangulated irregular network (TIN) (Dean, 1997; Reeves, 2004). Z coordinates were not provided for the road, river, turbine, house shapefiles and accompanying buffers so these were derived from the DEM TIN. Buffers were added to the DEM/MRLC TINs using hard replace, and rivers were added using hardline which effectively erased all ground cover in the buffer areas and along the lines of the rivers. A map depicting the landscape is provided in Appendix D.

To calculate the viewsheds that simulated the 3 point score used in field analysis, three values for OFFSETA<sup>45</sup> were used corresponding to the heights on the turbines. The top height was 430 ft, the middle height was 328 ft and the lowest height was 210 ft. Additionally a value for OFFSETB of 10 ft was used.<sup>46</sup> Then the viewshed algorithm was run for the 20 “observation” points of the

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<sup>45</sup> OFFSETA is the field name used by ESRI Arc viewshed algorithms of values of vertical distance in surface units that are added to the z-value of each cell as it is considered for visibility.

<sup>46</sup> OFFSETB is the field name used by ESRI Arc viewshed algorithms of values of vertical distance in surface units that are added to the z-value of the observation point.

turbines at each of the three heights (top, middle, lowest). This produced three 10 meter raster grids with values from 0 to 20 possible. All were added together to produce a grid with values from 0 to 60 possible. These raster values were extracted using the house point locations giving a discrete value (from 0 to 60) for each home in our sample set. Of the four sets of heights used to create the ground cover raster values originally (see Table IV) the 80 No-Grass set was best at neither over nor under predicting visibility (See results in Appendix C) but still did not meet confidence threshold of 95% that we had hoped for.

#### *Suggestions for improving GIS viewshed predictions*

The reasons we believe our estimates are off is because of inherent errors in the DEM which then transferred to our TIN surface. We test this theory by using 63 geodetic markers from the USGS which were within our study area. Roughly 15% (10/63) of the two elevations differ by more than 1%, which in some cases is more than 5 feet (max = 7 feet). The direction of the errors are 60/40 peaks to pits<sup>47</sup> ("peaks" = 37, "pits" = 26). Errors are smaller for the largest 26 peaks (mean = 1.51 feet) versus the largest 26 pits (mean = -2.76 feet). The errors in the viewshed calculations are well distributed between over predicting the homes' view of the turbines and under predicting it. Therefore, we conclude if the surface of the entire study area is similar in inaccuracies to the test points, predicted

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<sup>47</sup> "Peaks" refers to points on the TIN that are at a higher elevation than the geodetic markers, and "pits" refers to the opposite, where the TIN surface is at a lower elevation than the marker.

viewshed inaccuracies could be entirely based on pits and peaks in the DEM. A 5-foot peak in the TIN surface could obscure a large portion of the landscape a few miles away from predicted visibility. Concurrently an observer on a 5-foot peak could be predicted to see a great deal more than actually can be seen.

Methods for correcting or smoothing these errors were not investigated, and therefore additional research in this area would be important.

Another contributing factor for viewshed inaccuracies might be ground cover representation. It is observed in field analysis that canopy heights are not similar across all forests of the same type. For instance some deciduous forests have been planted in the last 15 years and have not grown to a mature height, while other forests are in late stage progression with mature heights. We use the same height for all forests of the same type. Further, square raster cells do not accurately depict non-uniform patterns of forest growth, and are particularly bad at depicting lines of trees that cross diagonally to the raster grid. Lastly the depiction of the top of the canopy is flat, but in reality the top is non-uniform. Field analysis proves it was possible to view turbines through the variation of the canopy. Combined these inaccuracies could add to the errors in our visibility prediction results. A smaller grid than 10 meters for the ground cover layer and access to ground cover data that includes z-values would greatly improve depiction and therefore viewshed analysis.



**Appendix D: Results of GIS Viewshed Prediction Algorithm**

**Table XII: Description of Heights for Ground Cover Raster Files (in feet)**

| Set         | Conifer | Deciduous | Mixed | Grass |
|-------------|---------|-----------|-------|-------|
| Winter      | 100     | 0         | 50    | 5     |
| 80 No-Grass | 80      | 70        | 75    | 0     |
| 80          | 80      | 70        | 75    | 5     |
| 100         | 100     | 90        | 95    | 10    |

**Table XIII: Results of Viewshed Predictions for 4 Sets of Ground Cover Heights**

| PREDICTED | Winter | OBSERVED |        |       | Correct |
|-----------|--------|----------|--------|-------|---------|
|           |        | See      | No See | Total |         |
|           | See    | 42       | 47     | 89    |         |
| No See    | 3      | 37       | 40     | 39%   |         |
| Total     | 45     | 84       | 129    |       |         |

| PREDICTED | 80 No-Grs | OBSERVED |        |       | Correct |
|-----------|-----------|----------|--------|-------|---------|
|           |           | See      | No See | Total |         |
|           | See       | 36       | 10     | 89    |         |
| No See    | 9         | 74       | 40     | 15%   |         |
| Total     | 45        | 84       | 129    |       |         |

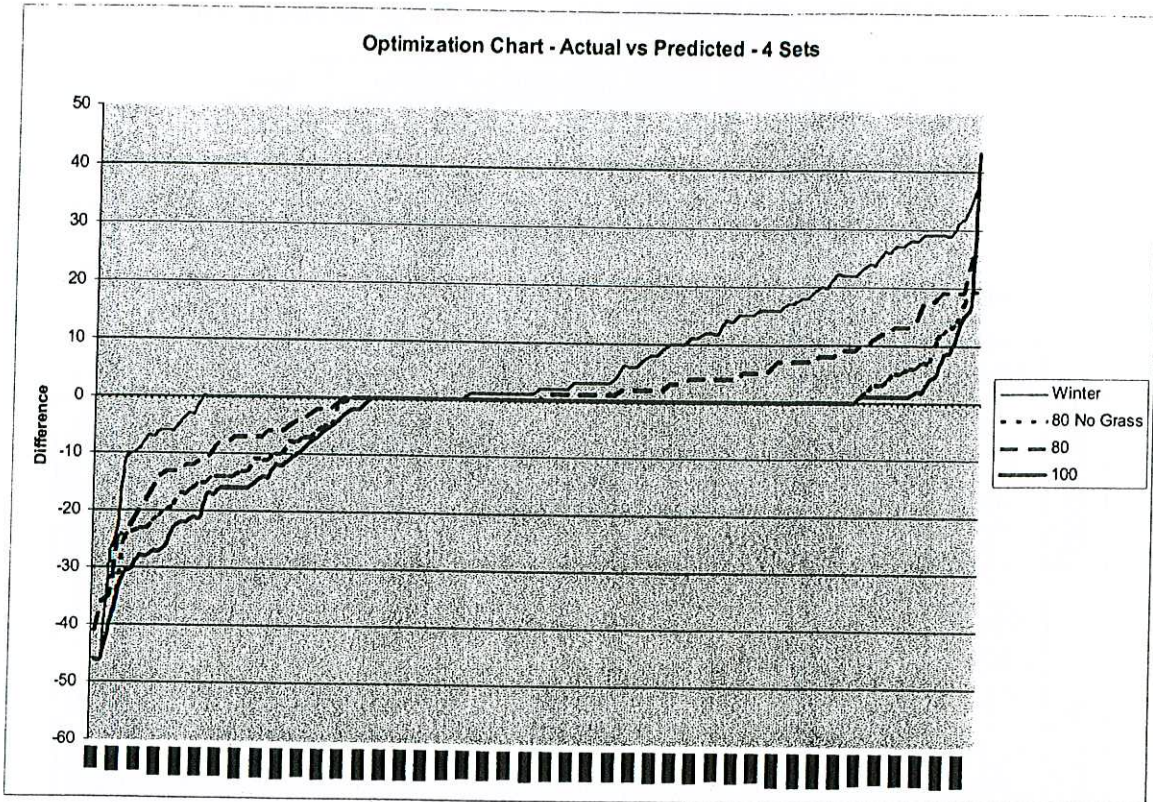
| PREDICTED | 100 | OBSERVED |        |       | Correct |
|-----------|-----|----------|--------|-------|---------|
|           |     | See      | No See | Total |         |
|           | See | 26       | 13     | 89    |         |
| No See    | 19  | 71       | 40     | 25%   |         |
| Total     | 45  | 84       | 129    |       |         |

| PREDICTED | 80  | OBSERVED |        |       | Correct |
|-----------|-----|----------|--------|-------|---------|
|           |     | See      | No See | Total |         |
|           | See | 42       | 55     | 89    |         |
| No See    | 3   | 29       | 40     | 45%   |         |
| Total     | 45  | 84       | 129    |       |         |

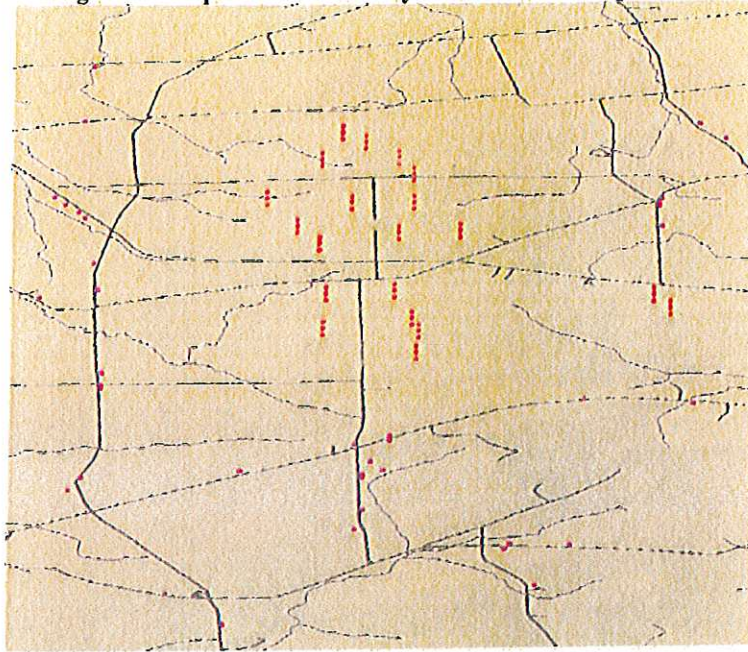
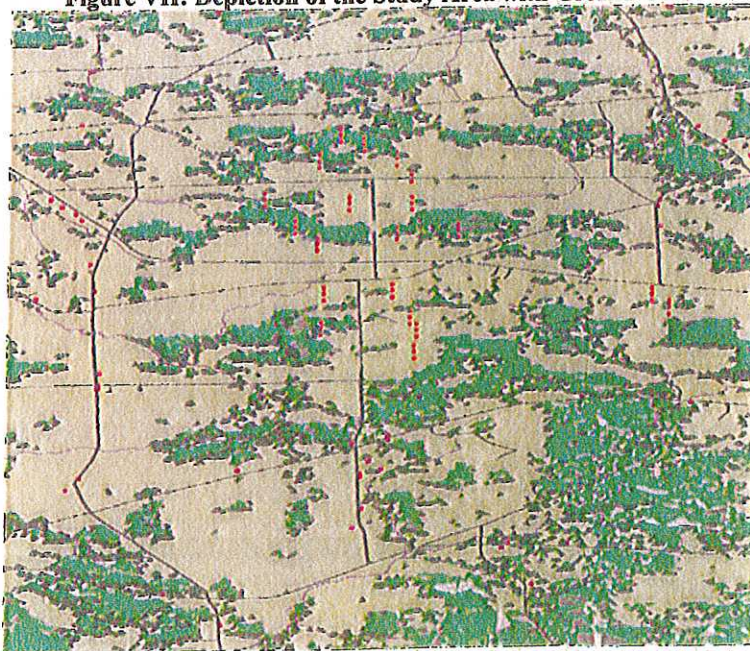


Figure V: Four Sets of Predicted Views versus the Actual Readings



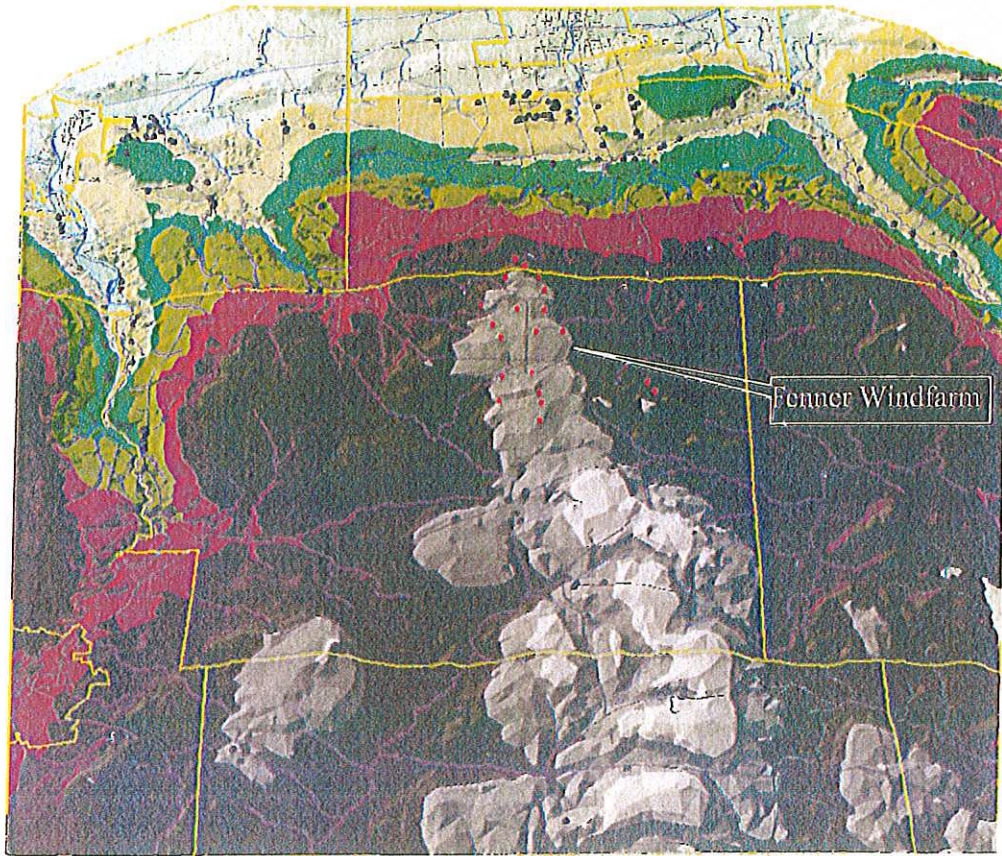
*Note: Results for each set are arrayed in ascending order without regard to house location. Therefore the amount of difference for one set for a particular house might not be similar for another set. Results are for 129 separate view readings. It is important to note the relatively even distribution of differences between positive and negative implying that the predicted viewshed models were most likely effected by forces outside the model such as random errors in the DEM*



**Appendix E: Landscape Constructions for Viewshed Prediction****Figure VI: Depiction of the Study Area without Ground Cover****Figure VII: Depiction of the Study Area with Ground Cover**

*Figure V and VI notes: Groups of three red dots are top, middle and low heights of turbines, randomly spaced purple dots are houses sold after 2001, heavy grey lines are roads, thin blue lines are rivers and raised green areas are depictions of ground cover*



**Figure VIII: 3D Rendering of Study Area**

*Note: Depiction has elevation exaggerated 10 times. Except for where indicated dots are houses which sold after 1996, and lines are township borders. If possible rendering should be viewed in color.*



## Appendix F: Model Results

Table XIV: Results - Models 1-3

|                                    | Model # 1 |         | Model # 2 |         | Model # 3 |         |
|------------------------------------|-----------|---------|-----------|---------|-----------|---------|
|                                    | Coeff.    | p-value | Coeff.    | p-value | Coeff.    | p-value |
| (CONSTANT)                         | -32.240   | 0.632   | -30.185   | 0.647   | 9.830     | 0.000   |
| <b><i>CONTINUOUS VARIABLES</i></b> |           |         |           |         |           |         |
| ACRES                              | 0.005     | 0.000   | 0.005     | 0.000   | 0.005     | 0.000   |
| AGE AT SALE                        | -0.001    | 0.053   | -0.001    | 0.003   | -0.002    | 0.000   |
| SALE YEAR                          | 0.021     | 0.532   | 0.049     | 0.456   |           |         |
| SALE YEAR SQR                      | -0.002    | 0.523   | 0.110     | 0.090   |           |         |
| DIS TO RT 20                       | -0.012    | 0.198   | -0.013    | 0.156   | -0.009    | 0.072   |
| DISTOTOWN-MILES                    | -0.021    | 0.198   | 0.090     | 0.093   |           |         |
| NBR FIREPLACES                     | 0.051     | 0.058   | 0.050     | 0.059   | 0.053     | 0.041   |
| NBR FULL BATHS                     | 0.151     | 0.000   | 0.152     | 0.000   | 0.153     | 0.000   |
| NBR HALF BATHS                     | 0.054     | 0.170   | 0.060     | 0.123   | 0.088     | 0.014   |
| OVERALL COND                       | 0.205     | 0.000   | 0.202     | 0.000   | 0.197     | 0.000   |
| SFLA (in 1000s)                    | 0.233     | 0.000   | 0.234     | 0.000   | 0.261     | 0.000   |
| <b><i>BINARY VARIABLES</i></b>     |           |         |           |         |           |         |
| BLDSTYL-CAPE                       | 0.101     | 0.703   | 0.022     | 0.688   |           |         |
| BLDSTYL-CNTMP                      | 0.187     | 0.476   | 0.199     | 0.001   | 0.158     | 0.003   |
| BLDSTYL-COLNL                      | 0.082     | 0.752   |           |         |           |         |
| BLDSTYL-CTTG                       | -0.003    | 0.992   | 0.004     | 0.984   |           |         |
| BLDSTYL-LOG                        | 0.287     | 0.287   | 0.297     | 0.000   | 0.287     | 0.000   |
| BLDSTYL-OLDSTYL                    | 0.003     | 0.991   | 0.052     | 0.461   |           |         |
| BLDSTYL-OTHR                       | -0.076    | 0.836   |           |         |           |         |
| BLDSTYL-RANCH                      | -0.009    | 0.972   | 0.020     | 0.542   |           |         |
| BLDSTYL-RSDRNCH                    | 0.052     | 0.846   | -0.001    | 0.542   |           |         |
| BLDSTYL-SPLIT                      | -0.089    | 0.743   | -0.020    | 0.206   |           |         |
| CENTRAL AIR                        | 0.008     | 0.915   |           |         |           |         |
| FENNER DUM                         | -0.060    | 0.129   | -0.058    | 0.142   | -0.083    | 0.018   |
| RBSMNT TYP DUM                     | 0.239     | 0.000   | 0.241     | 0.000   | 0.268     | 0.000   |
| STONE WALL MAT                     | 0.372     | 0.043   | 0.377     | 0.036   | 0.363     | 0.037   |
| SCHDIS-CHTNGO                      | 0.050     | 0.457   | -0.143    | 0.214   |           |         |
| SCHDIS-CNSTO                       | 0.048     | 0.508   | -0.068    | 0.790   |           |         |
| SCHDIS-MORS                        | 0.024     | 0.676   |           |         |           |         |
| SCHDIS-ONIEDA                      | -0.151    | 0.197   |           |         |           |         |
| SCHDIS-STKBRDG                     | -0.437    | 0.000   | -0.437    | 0.000   | -0.489    | 0.000   |
| SPRING SALE                        | 0.055     | 0.278   | 0.054     | 0.287   | 0.058     | 0.239   |
| SUMMER SALE                        | 0.027     | 0.596   | 0.026     | 0.597   | 0.026     | 0.587   |
| FALL SALE                          | 0.085     | 0.101   | 0.086     | 0.091   | 0.097     | 0.052   |
| ADJUSTED R2                        |           | 0.793   |           | 0.793   |           | 0.793   |
| F/SIGNIFICANCE                     | 32.857    | 0.000   | 39.185    | 0.000   | 63.764    | 0.000   |

Table XV: Results - Models 4 - 6

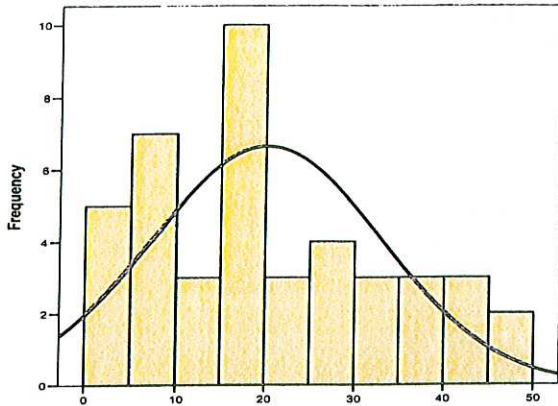


|                                    | Model # 4 |         | Model # 5 |         | Model # 6 |         |
|------------------------------------|-----------|---------|-----------|---------|-----------|---------|
|                                    | Coeff.    | p-value | Coeff.    | p-value | Coeff.    | p-value |
| (CONSTANT)                         | 9.803     | 0.000   | 9.826     | 0.000   | 9.840     | 0.000   |
| <b><i>CONTINUOUS VARIABLES</i></b> |           |         |           |         |           |         |
| ACRES                              | 0.005     | 0.000   | 0.005     | 0.000   | 0.005     | 0.000   |
| AGE AT SALE                        | -0.002    | 0.000   | -0.002    | 0.000   | -0.002    | 0.000   |
| DIS TO RT20                        | -0.009    | 0.082   | -0.009    | 0.066   | -0.010    | 0.046   |
| NBR FIREPLACES                     | 0.050     | 0.053   | 0.048     | 0.071   | 0.051     | 0.048   |
| NBR FULL BATHS                     | 0.153     | 0.000   | 0.157     | 0.000   | 0.152     | 0.000   |
| NBR HALF BATHS                     | 0.085     | 0.018   | 0.091     | 0.012   | 0.084     | 0.022   |
| OVERALL COND                       | 0.196     | 0.000   | 0.196     | 0.000   | 0.196     | 0.000   |
| SFLA (in 1000s)                    | 0.263     | 0.000   | 0.262     | 0.000   | 0.263     | 0.000   |
| <b><i>BINARY VARIABLES</i></b>     |           |         |           |         |           |         |
| BLDSTYL-CNTMP                      | 0.154     | 0.004   | 0.161     | 0.003   | 0.162     | 0.002   |
| BLDSTYL-LOG                        | 0.286     | 0.000   | 0.286     | 0.000   | 0.287     | 0.000   |
| FENNER DUM                         | -0.076    | 0.108   | -0.092    | 0.015   | -0.094    | 0.010   |
| RBSMNT TYP DUM                     | 0.271     | 0.000   | 0.273     | 0.000   | 0.268     | 0.000   |
| STONE WALL MAT                     | 0.359     | 0.041   | 0.366     | 0.037   | 0.367     | 0.035   |
| SCHDIS-STKBRDG                     | -0.491    | 0.000   | -0.485    | 0.000   | -0.482    | 0.000   |
| SPRING SALE                        | 0.056     | 0.260   | 0.058     | 0.243   | 0.055     | 0.270   |
| SUMMER SALE                        | 0.026     | 0.592   | 0.024     | 0.624   | 0.029     | 0.550   |
| FALL SALE                          | 0.094     | 0.060   | 0.093     | 0.063   | 0.095     | 0.061   |
| <b><i>VIEWSHED VARIABLES</i></b>   |           |         |           |         |           |         |
| DIS TO WNDMILLS                    | 0.007     | 0.679   |           |         |           |         |
| VIEW                               | 0.001     | 0.410   |           |         |           |         |
| VIEW1MILE                          |           |         | 0.001     | 0.656   |           |         |
| VIEW2MILE                          |           |         | 0.000     | 0.936   |           |         |
| VIEW3MILE                          |           |         | 0.006     | 0.115   |           |         |
| VIEW4MILE                          |           |         | 0.001     | 0.881   |           |         |
| VIEW5MILE                          |           |         | -0.001    | 0.764   |           |         |
| VIEW2001                           |           |         |           |         | -0.001    | 0.742   |
| VIEW2002                           |           |         |           |         | 0.006     | 0.175   |
| VIEW2003                           |           |         |           |         | -0.002    | 0.613   |
| VIEW2004                           |           |         |           |         | 0.003     | 0.224   |
| VIEW2005                           |           |         |           |         | 0.001     | 0.906   |
| ADJUSTED R2                        |           | 0.792   |           | 0.791   |           | 0.792   |
| F/SIGNIFICANCE                     | 56.822    | 0.000   | 48.990    | 0.000   | 49.210    | 0.000   |

(Coefficients roughly correspond to the percentage change of sale price for each unit of change of the underlying variable. For example, adding an additional full bathroom to a house (coeff. = 0.153) adds roughly 15% to the value of the home, for homes that are near the sample mean value of \$91,293.)

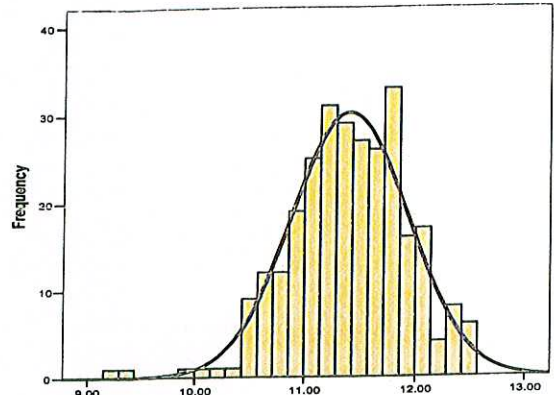
Appendix G: Histograms

Figure IX: Histogram of VIEW >0



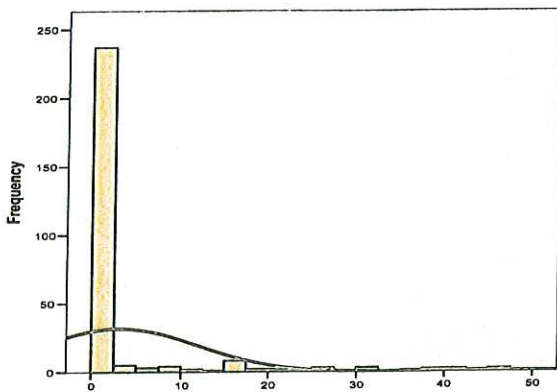
Notes: Line represents normal curve. n=43

Figure XII: Histogram of LogSALE\_PRICE\_95



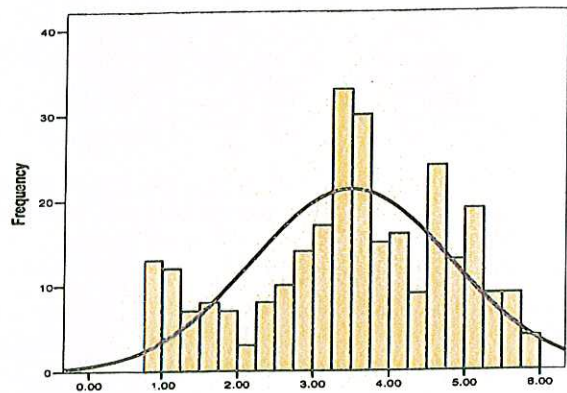
Notes: Line represents normal curve. n=280

Figure X: Histogram of VIEW



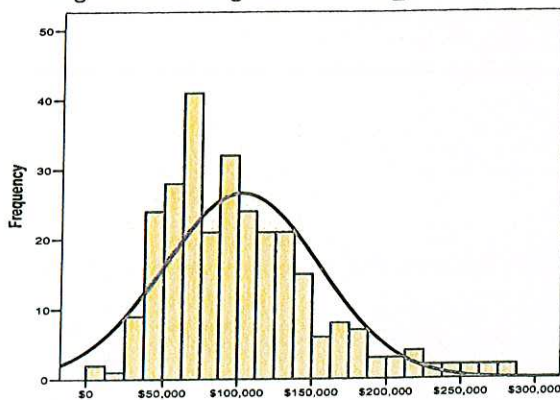
Notes: Line represents normal curve. n=280

Figure XIII: Histogram of DIS\_TO\_MILLS



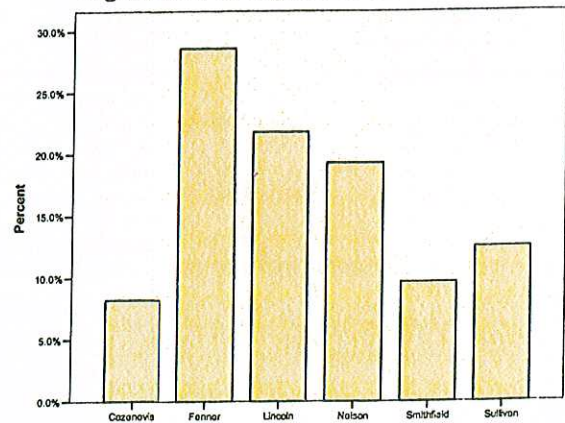
Notes: Line represents normal curve. n=280

Figure XI: Histogram of SALE\_PRICE\_95



Notes: Line represents normal curve. n=280

Figure XIV: Histogram of TOWNSHIP



Notes: n=280



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# THE EFFECT OF WIND DEVELOPMENT ON LOCAL PROPERTY VALUES

R E P P  
RENEWABLE ENERGY POLICY PROJECT

ANALYTICAL REPORT | MAY 2003

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## TABLE OF CONTENTS

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|   |           |
|---|-----------|
| <b>Chapter I. Project Overview</b>                    | <b>1</b>  |
| <b>Chapter II. Methodology</b>                        | <b>10</b> |
| <b>Chapter III. Site Reports</b>                      | <b>17</b> |
| Site Report 1.1: Riverside County, California         | 17        |
| Site Reports 2.1 and 2.2: Madison County, New York    | 24        |
| Site Report 3: Carson County, Texas                   | 32        |
| Site Report 4: Bennington County, Vermont             | 38        |
| Site Report 5: Kewaunee County, Wisconsin             | 43        |
| Site Report 6: Somerset County, Pennsylvania          | 49        |
| Site Report 7: Buena Vista County, Iowa               | 54        |
| Site Report 8: Kern County, California                | 62        |
| Site Report 9: Fayette County, Pennsylvania           | 67        |
| Site Report: Projects Excluded From Analyses          | 72        |
| <b>References</b>                                     | <b>76</b> |
| <b>Appendix 1. County Classification Descriptions</b> | <b>77</b> |

# CHAPTER I. PROJECT OVERVIEW

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## **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](http://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.

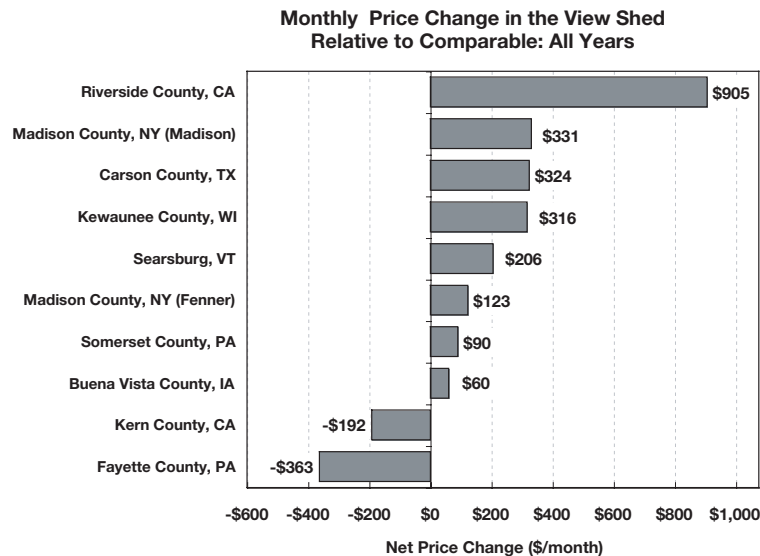


FIGURE I: MONTHLY PRICE CHANGE IN THE VIEW SHED  
RELATIVE TO COMPARABLE: ALL YEARS

### 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  | Jan 96 - Oct 02 | \$401.86                  | 0.67           | 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.                               |
|        | Comparable, all data | Jan 96 - Oct 02 | \$341.87                  | 0.72           |   |
| Case 2 | View shed, before    | Jan 96 - Apr 99 | \$370.52                  | 0.51           | 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.                        |
|        | View shed, after     | May 99 - Oct 02 | \$631.12                  | 0.53           |   |
| Case 3 | View shed, after     | May 99 - Oct 02 | \$631.12                  | 0.53           | 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. |
|        | Comparable, after    | May 99 - Oct 02 | \$234.84                  | 0.23           |   |



**Location: Carson County, TX**  
**Project: Llano Estacado**

| Model  | Dataset              | Dates           | Rate of Change (\$/ month) | Model Fit (R2) | Result  |
|--------|----------------------|-----------------|----------------------------|----------------|---|
| Case 1 | View shed, all data  | Jan 98 - Dec 02 | \$620.47                   | 0.49           | 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.                         |
|        | Comparable, all data | Jan 98 - Dec 02 | \$296.54                   | 0.33           |   |
| Case 2 | View shed, before    | Jan 98 - Oct 01 | \$553.92                   | 0.24           | 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.                  |
|        | View shed, after     | Nov 01 - Dec 02 | \$1,879.76                 | 0.83           |   |
| Case 3 | View shed, after     | Nov 01 - Dec 02 | \$1,879.76                 | 0.83           | 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. |
|        | Comparable, after    | Nov 01 - Dec 02 | -\$140.14                  | 0.02           |   |

**Location: Fayette County, PA**  
**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           |  |

**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  | 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           |  |

**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  | Jan 96 - Sep 02 | \$434.48                   | 0.26           | 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.        |
|        | Comparable, all data | Jan 96 - Sep 02 | \$118.18                   | 0.05           |  |
| Case 2 | View shed, before    | Jan 96 - May 99 | -\$238.67                  | 0.02           | 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. |
|        | View shed, after     | Jun 99 - Sep 02 | \$840.03                   | 0.32           |  |
| Case 3 | View shed, after     | Jun 99 - Sep 02 | \$840.03                   | 0.32           | 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. |
|        | Comparable, after    | Jun 99 - Sep 02 | -\$630.10                  | 0.37           |  |

**Location: Madison County, NY**  
**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           |  |

**Location: Madison County, NY**  
**Project: Fenner**

| Model  | Dataset              | Dates           | Rate of Change (\$/ month) | Model Fit (R2) | Result   |
|--------|----------------------|-----------------|----------------------------|----------------|--|
| Case 1 | View shed, all data  | Jan 97 - Jan 03 | \$368.47                   | 0.35           | 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.                          |
|        | Comparable, all data | Jan 97 - Jan 03 | \$245.51                   | 0.34           |  |
| Case 2 | View shed, before    | Jan 97 - Nov 01 | \$587.95                   | 0.50           | 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.     |
|        | View shed, after     | Dec 01 - Jan 03 | -\$418.98                  | 0.04           |  |
| Case 3 | View shed, after     | Dec 01 - Jan 03 | -\$418.98                  | 0.04           | 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. |
|        | Comparable, after    | Dec 01 - Jan 03 | -\$663.38                  | 0.63           |  |

**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  | Jan 96 - Nov 02 | \$1,719.65                 | 0.92           | 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.                   |
|        | Comparable, all data | Jan 96 - Nov 02 | \$814.17                   | 0.81           |   |
| Case 2 | View shed, before    | Jan 96 - Apr 99 | \$1,062.83                 | 0.68           | 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.                  |
|        | View shed, after     | May 99 - Nov 02 | \$1,978.88                 | 0.81           |   |
| Case 3 | View shed, after     | May 99 - Nov 02 | \$1,978.88                 | 0.81           | 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. |
|        | Comparable, after    | May 99 - Nov 02 | \$1,212.14                 | 0.74           |   |

**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  | Jan 94 - Oct 02 | \$536.41                   | 0.70           | 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.                         |
|        | Comparable, all data | Jan 94 - Oct 02 | \$330.81                   | 0.45           |   |
| Case 2 | View shed, before    | Jan 94 - Jan 97 | -\$301.52                  | 0.88           | 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.             |
|        | View shed, after     | Feb 97 - Oct 02 | \$771.06                   | 0.71           |   |
| Case 3 | View shed, after     | Feb 97 - Oct 02 | \$771.06                   | 0.71           | 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. |
|        | Comparable, after    | Feb 97 - Oct 02 | \$655.20                   | 0.78           |   |

**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  | Jan 97 - Oct 02 | \$190.07                   | 0.30           | 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.                              |
|        | Comparable, all data | Jan 97 - Oct 02 | \$100.06                   | 0.07           |  |
| Case 2 | View shed, before    | Jan 97 - Apr 00 | \$277.99                   | 0.37           | 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.                 |
|        | View shed, after     | May 00 - Oct 02 | \$969.59                   | 0.62           |  |
| Case 3 | View shed, after     | May 00 - Oct 02 | \$969.59                   | 0.62           | 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. |
|        | Comparable, after    | May 00 - Oct 02 | -\$418.73                  | 0.23           |  |

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           |
| <b>TOTAL</b>                    | <b>14,842</b>  | <b>9,504</b>     | <b>24,346</b> |

\*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

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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](http://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

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### SITE REPORT I: RIVERSIDE COUNTY, CALIFORNIA

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#### 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.



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FIGURE I.1 VIEW OF WIND FARMS AT SAN GORGONIO PASS, RIVERSIDE COUNTY, CA

PHOTO BY DAVID F. GALLAGHER, 2001 - [WWW.LIGHTNINGFIELD.COM](http://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 I.2 REGIONAL WIND PROJECT LOCATION  
(DOTS APPROXIMATE WIND FARM LOCATIONS)

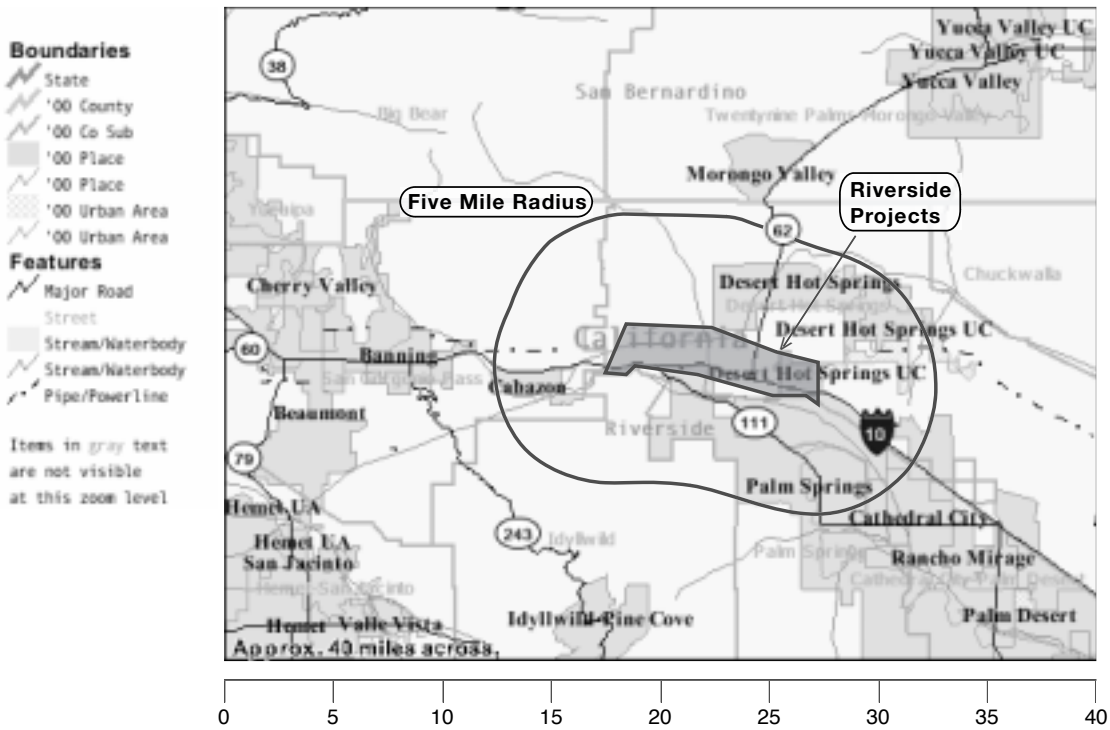


FIGURE I.3 SAN GORONIO, RIVERSIDE COUNTY, CALIFORNIA VIEW SHED  
(5 MILE RADIUS FROM PROJECT EDGE)  
MAP SOURCE: U.S. CENSUS BUREAU WEBSITE  
PROJECT LOCATION DETAILS: INTERVIEWS AND AERIAL PHOTOGRAPHS

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 I.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 I.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 I.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 (R <sup>2</sup> ) | Result  |
| Case 1  | View shed, all data  | Jan 96 - Nov 02 | \$1,719.65                | 0.92                        | 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.                   |
|   | Comparable, all data | Jan 96 - Nov 02 | \$814.17                  | 0.81                        |   |
| Case 2  | View shed, before    | Jan 96 - Apr 99 | \$1,062.83                | 0.68                        | 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.                  |
|   | View shed, after     | May 99 - Nov 02 | \$1,978.88                | 0.81                        |   |
| Case 3  | View shed, after     | May 99 - Nov 02 | \$1,978.88                | 0.81                        | 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. |
|   | Comparable, after    | May 99 - Nov 02 | \$1,212.14                | 0.74                        |   |

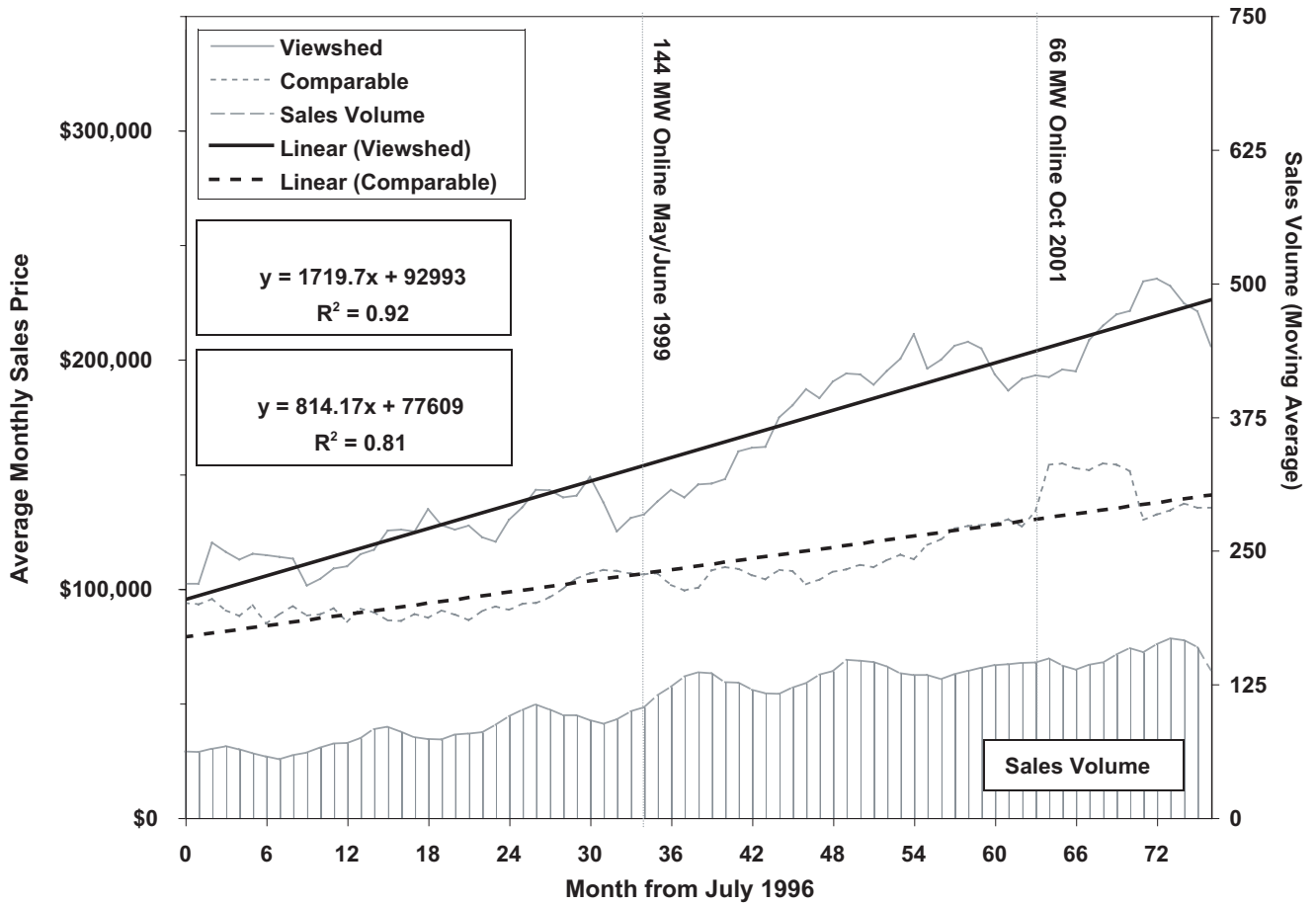


FIGURE I.4 AVERAGE RESIDENTIAL HOUSING SALES PRICE  
RIVERSIDE COUNTY, CALIFORNIA 1996-2002

**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

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## 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.



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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)

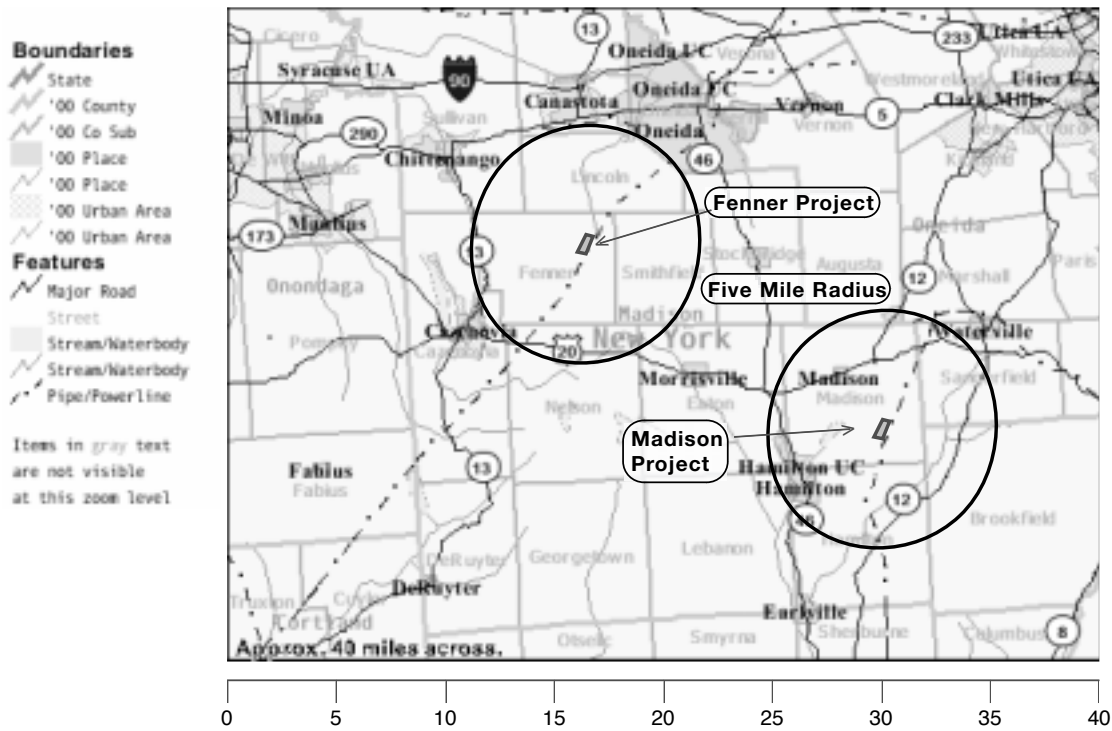


FIGURE 2.3. LOCATION OF WIND PROJECTS IN MADISON COUNTY  
SITE LOCATIONS SOURCE: MADISON ASSESSORS OFFICE  
BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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                                 |
| <b>FENNER DEMOGRAPHICS</b>     |           |                     | <b>4,416</b>  | <b>\$29,101</b>         | <b>11%</b>                       | <b>1,576</b>         | <b>\$63,267</b>                          |
| 1990                           | Y         | Madison town        | 2,774         | \$29,779                | 10%                              | 1,239                | \$65,200                                 |
| 1990                           | Y         | Madison village     | 316           | \$26,250                | 12%                              | 135                  | \$50,000                                 |
| <b>MADISON DEMOGRAPHICS</b>    |           |                     | <b>3,090</b>  | <b>\$28,015</b>         | <b>11%</b>                       | <b>1,374</b>         | <b>\$57,600</b>                          |
| 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                                 |
| <b>COMPARABLE DEMOGRAPHICS</b> |           |                     | <b>11,918</b> | <b>\$25,491</b>         | <b>13%</b>                       | <b>4,327</b>         | <b>\$55,283</b>                          |
| 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

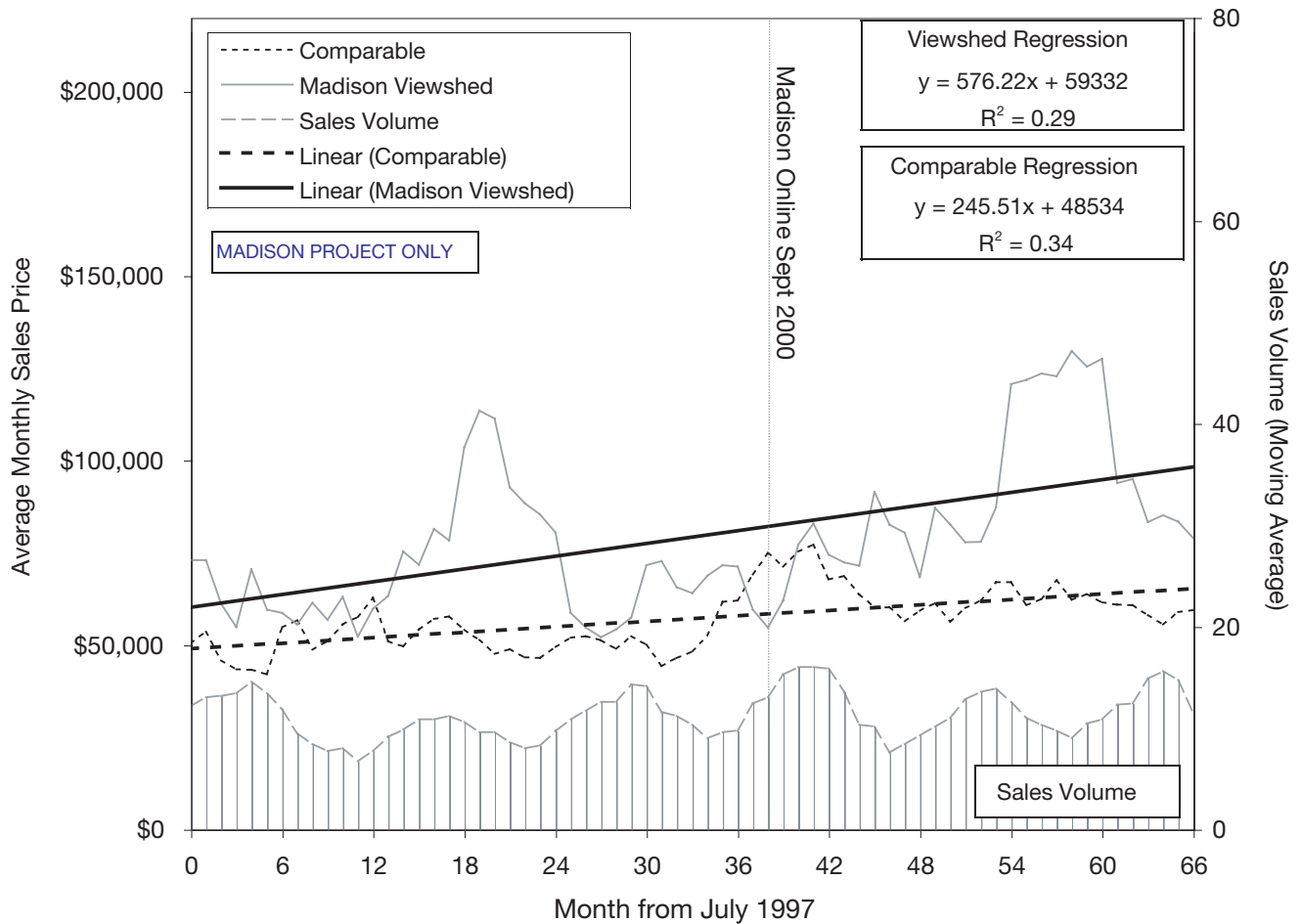
In five of the six regression models, monthly average sales prices grew faster or declined slower in the view shed than in the comparable area. However, in the case of the underperformance of the view shed, the explanatory power of the model is very poor. Thus, there is no significant evidence in these 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 (R <sup>2</sup> ) | 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

## 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 to 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  | Jan 97 - Jan 03 | \$368.47                  | 0.35           | 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.                          |
|        | Comparable, all data | Jan 97 - Jan 03 | \$245.51                  | 0.34           |  |
| Case 2 | View shed, before    | Jan 97 - Nov 01 | \$587.95                  | 0.50           | 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.     |
|        | View shed, after     | Dec 01 - Jan 03 | -\$418.98                 | 0.04           |  |
| Case 3 | View shed, after     | Dec 01 - Jan 03 | -\$418.98                 | 0.04           | 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. |
|        | Comparable, after    | Dec 01 - Jan 03 | -\$663.38                 | 0.63           |  |



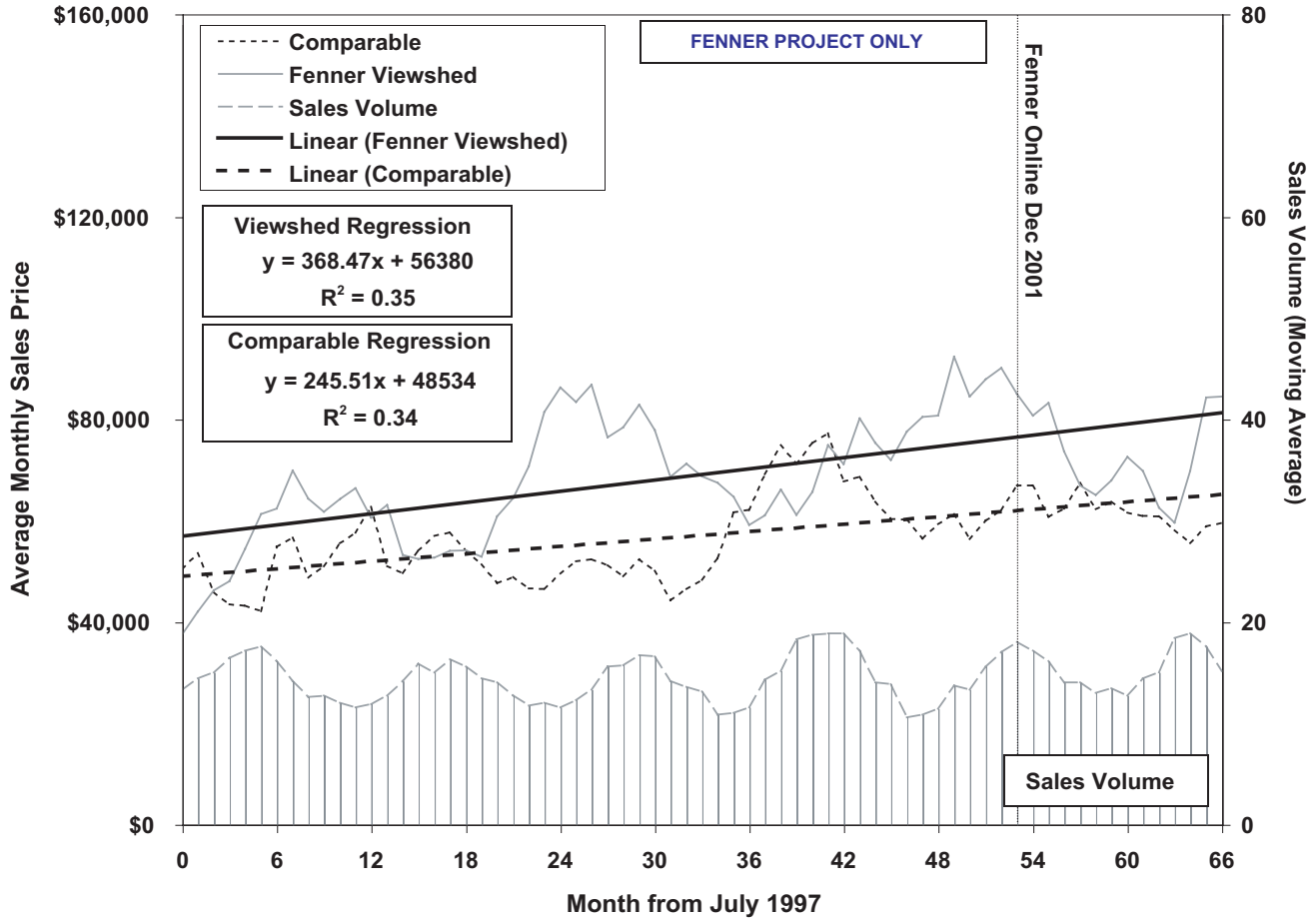


FIGURE 2.5 AVERAGE RESIDENTIAL HOUSING SALES PRICE FOR FENNER PROJECT  
MADISON COUNTY, NEW YORK 1997-2002

**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)

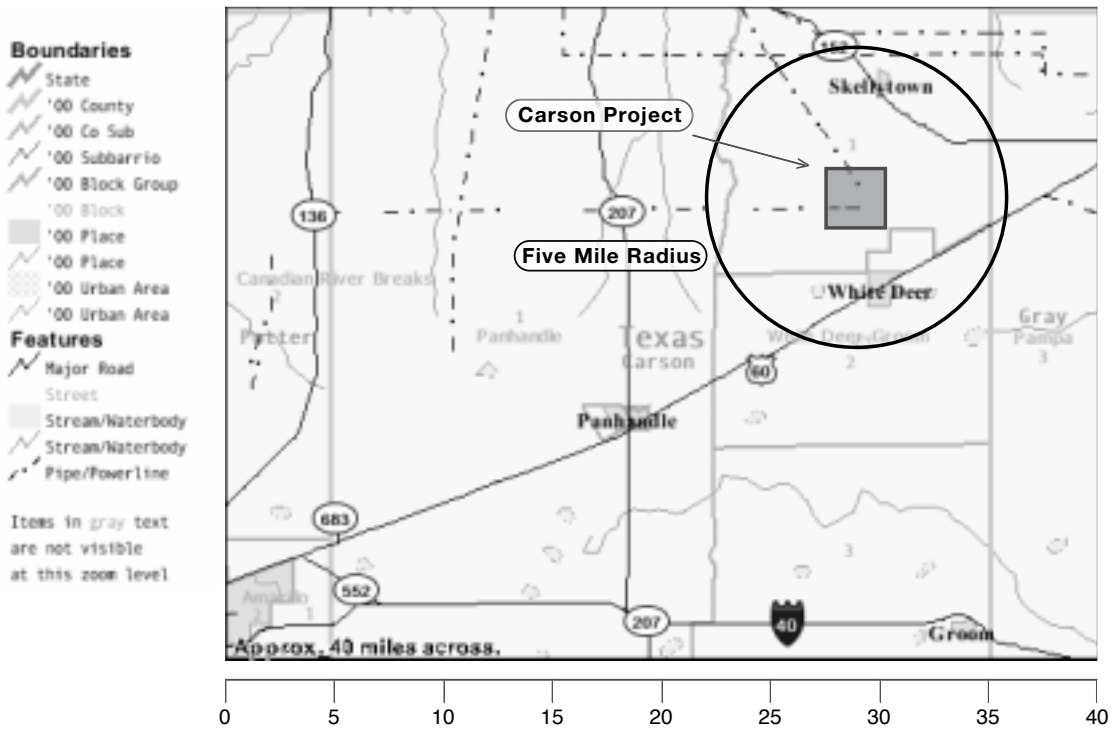


FIGURE 3.3. CARSON COUNTY, TEXAS VIEW SHED  
SITE LOCATION SOURCE: CARSON APPRAISAL DISTRICT  
BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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                                 |

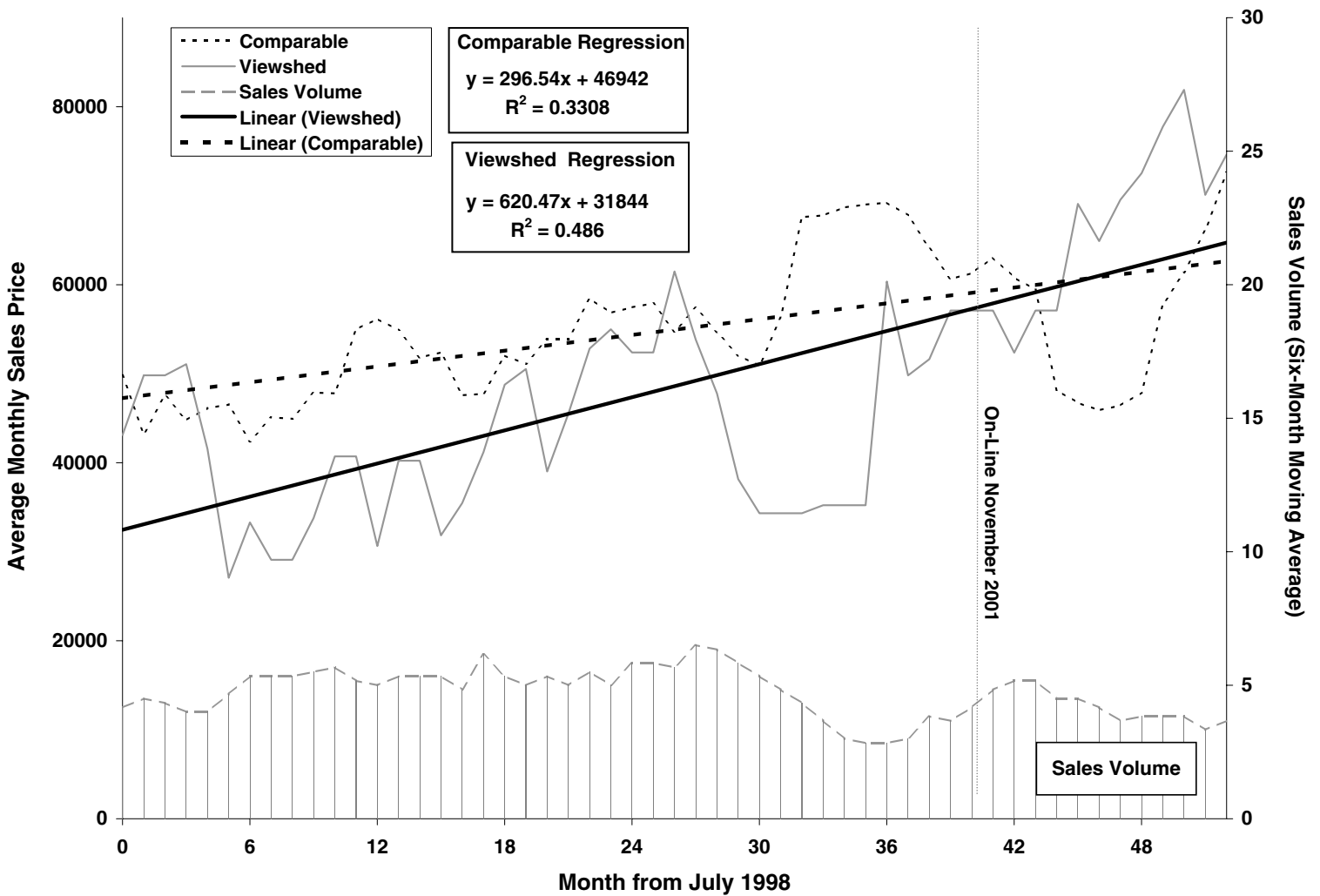
#### iv. Analytical Results and Discussion

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  | Jan 98 - Nov 02 | \$620.47                  | 0.49           | 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.                         |
|        | Comparable, all data | Jan 98 - Nov 02 | \$296.54                  | 0.33           |   |
| Case 2 | View shed, before    | Jan 98 - Oct 01 | \$553.92                  | 0.24           | 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.                  |
|        | View shed, after     | Nov 01 - Nov 02 | \$1,879.76                | 0.83           |   |
| Case 3 | View shed, after     | Nov 01 - Nov 02 | \$1,879.76                | 0.83           | 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. |
|        | Comparable, after    | Nov 01 - Nov 02 | -\$140.14                 | 0.02           |   |



**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](http://www.pantex.com) website.

## SITE REPORT 4: BENNINGTON COUNTY, VERMONT

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### 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.



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**FIGURE 4.1 SEARSBURG WIND PROJECT TURBINES**

PHOTO COURTESY VERMONT ENVIRONMENTAL RESEARCH ASSOCIATES, 2002. [WWW.NORTHEASTWIND.COM](http://WWW.NORTHEASTWIND.COM)



FIGURE 4.2 THE SEARSBURG WIND PROJECT IS LOCATED IN SOUTHERN VERMONT

BASE MAP IMAGE SOURCE: U.S. CENSUS BUREAU

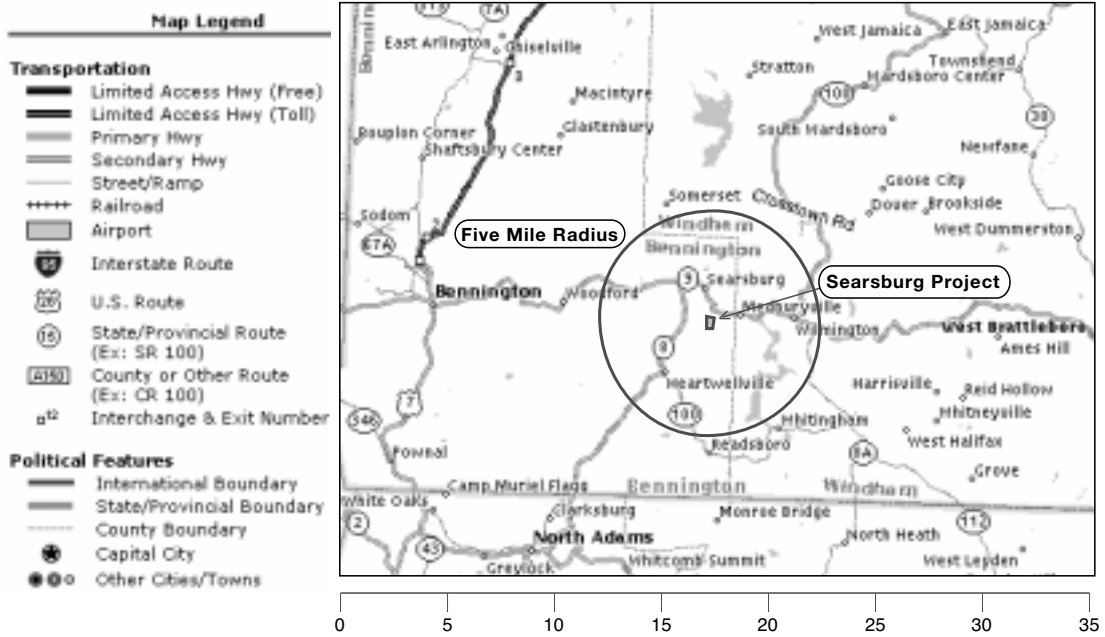


FIGURE 4.3. SEARSBURG, VERMONT AREA VIEW SHED

LOCATION SOURCE: VERMONT ENVIRONMENTAL ASSOCIATES

BASE MAP SOURCE: MAPQUEST.COM

## 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                                |

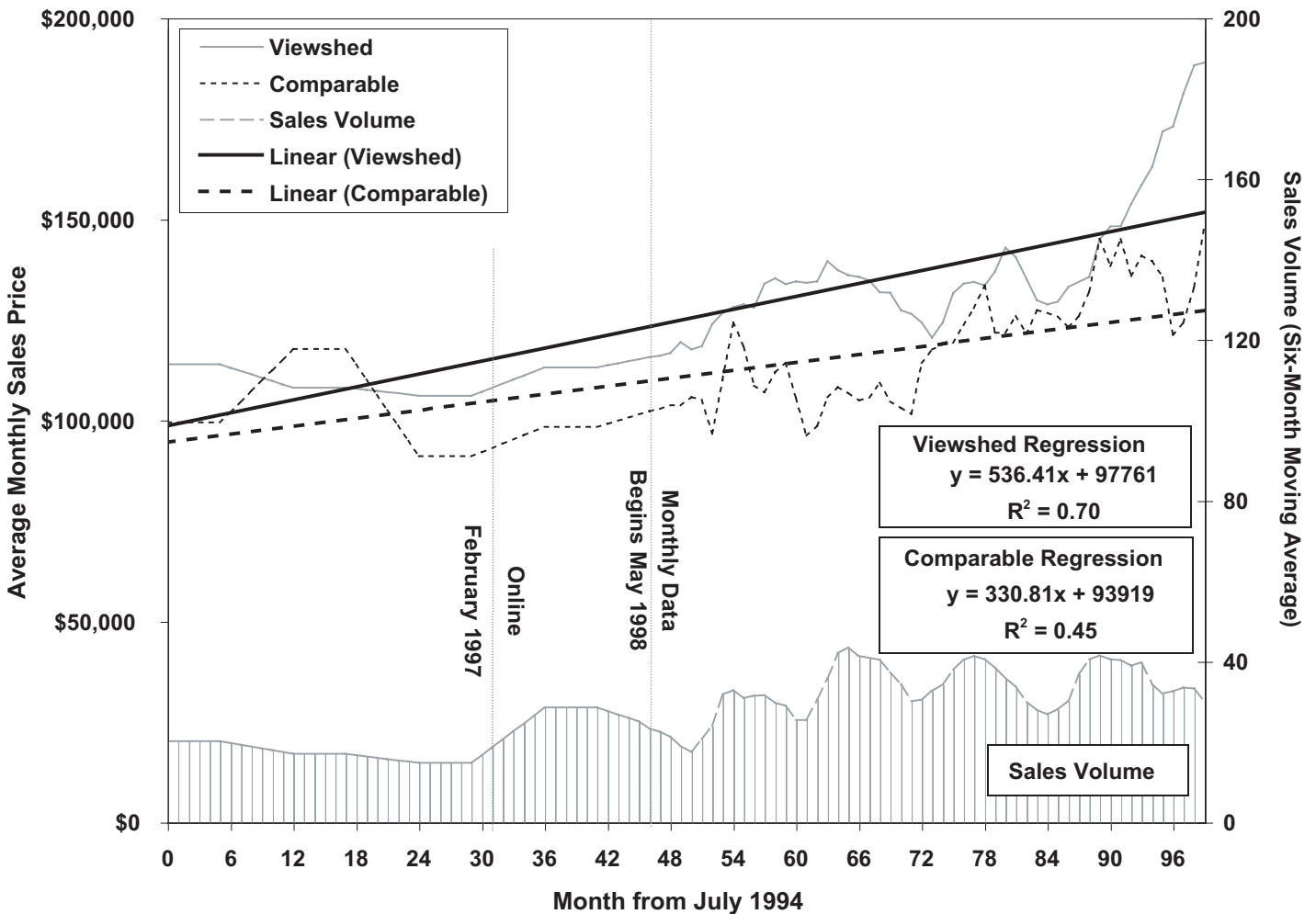
In Case I, the monthly sales price change in the view shed is 62 percent greater than the monthly sales price change of the comparable over the study period. The Case I model provides a reasonable fit to the view shed data, with 70 percent of the variance in the data for the view shed and 45 percent 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<sup>1</sup> 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  | Jan 94 - Oct 02 | \$536.41                  | 0.70           | 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.                         |
|        | Comparable, all data | Jan 94 - Oct 02 | \$330.81                  | 0.45           |   |
| Case 2 | View shed, before    | Jan 94 - Jan 97 | -\$301.52                 | 0.88           | 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.             |
|        | View shed, after     | Feb 97 - Oct 02 | \$771.06                  | 0.71           |   |
| Case 3 | View shed, after     | Feb 97 - Oct 02 | \$771.06                  | 0.71           | 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. |
|        | Comparable, after    | Feb 97 - Oct 02 | \$655.20                  | 0.78           |   |



**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

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### 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

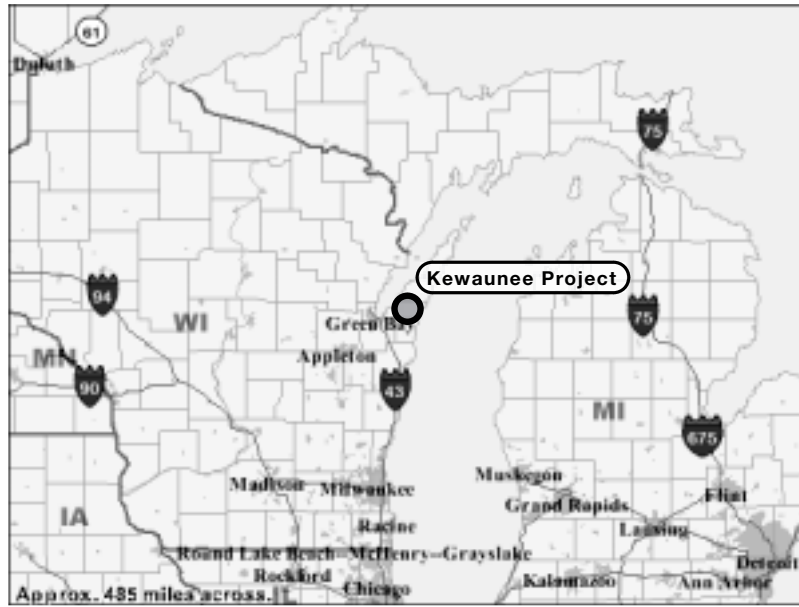


FIGURE 5.2 LOCATION OF KEWAUNEE COUNTY WIND PROJECTS

BASE MAP IMAGE SOURCE: U.S. CENSUS BUREAU

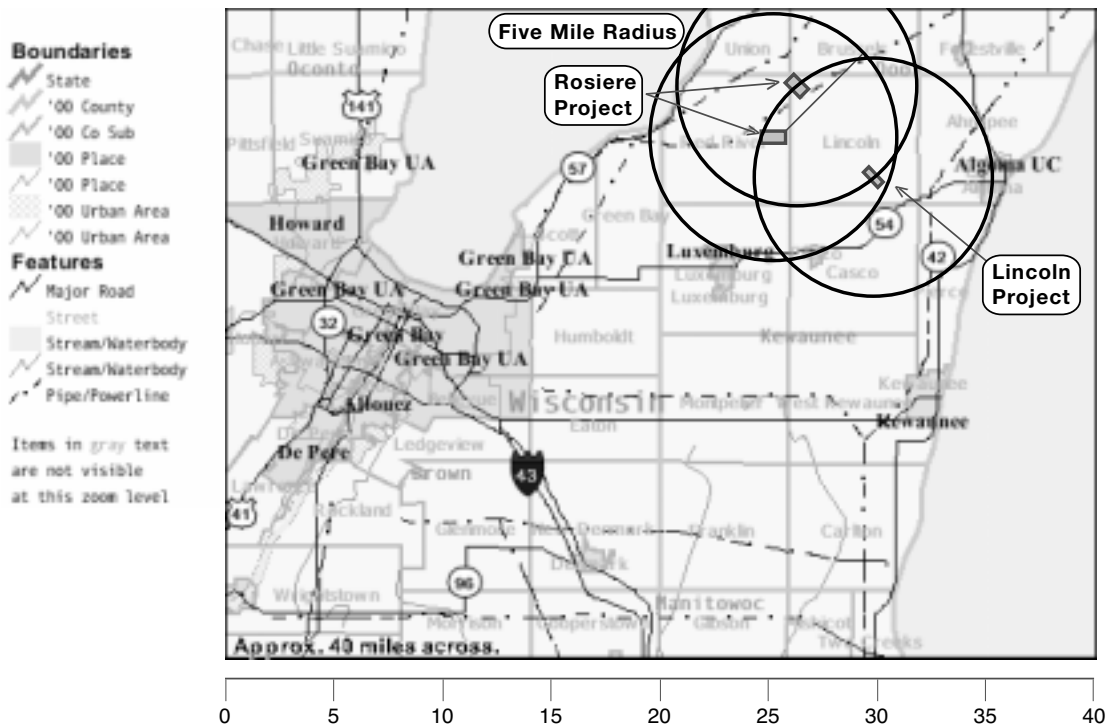


FIGURE 5.3. KEWAUNEE COUNTY VIEW SHED

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

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                                 |
| <b>VIEW SHED DEMOGRAPHICS</b>  |           |                    | <b>2,947</b> | <b>\$28,962</b>         | <b>6%</b>                        | <b>1,113</b>         | <b>\$53,200</b>                          |
| 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                                 |
| <b>COMPARABLE DEMOGRAPHICS</b> |           |                    | <b>3,625</b> | <b>\$31,026</b>         | <b>8%</b>                        | <b>1,291</b>         | <b>\$51,733</b>                          |
| 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                                |
| <b>VIEW SHED DEMOGRAPHICS</b>  |           |                    | <b>3,005</b> | <b>\$44,868</b>         | <b>6%</b>                        | <b>1,183</b>         | <b>\$102,200</b>                         |
| 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                                |
| <b>COMPARABLE DEMOGRAPHICS</b> |           |                    | <b>3,658</b> | <b>\$49,429</b>         | <b>4%</b>                        | <b>1,360</b>         | <b>\$104,067</b>                         |
| 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<br>Change (\$/<br>month) | Model<br>Fit<br>(R2) | Result   |
|--------|----------------------|-----------------|----------------------------------|----------------------|--|
| Case 1 | View shed, all data  | Jan 96 - Sep 02 | \$434.48                         | 0.26                 | 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.        |
|        | Comparable, all data | Jan 96 - Sep 02 | \$118.18                         | 0.05                 |  |
| Case 2 | View shed, before    | Jan 96 - May 99 | -\$238.67                        | 0.02                 | 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. |
|        | View shed, after     | Jun 99 - Sep 02 | \$840.03                         | 0.32                 |  |
| Case 3 | View shed, after     | Jun 99 - Sep 02 | \$840.03                         | 0.32                 | 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. |
|        | Comparable, after    | Jun 99 - Sep 02 | -\$630.10                        | 0.37                 |  |

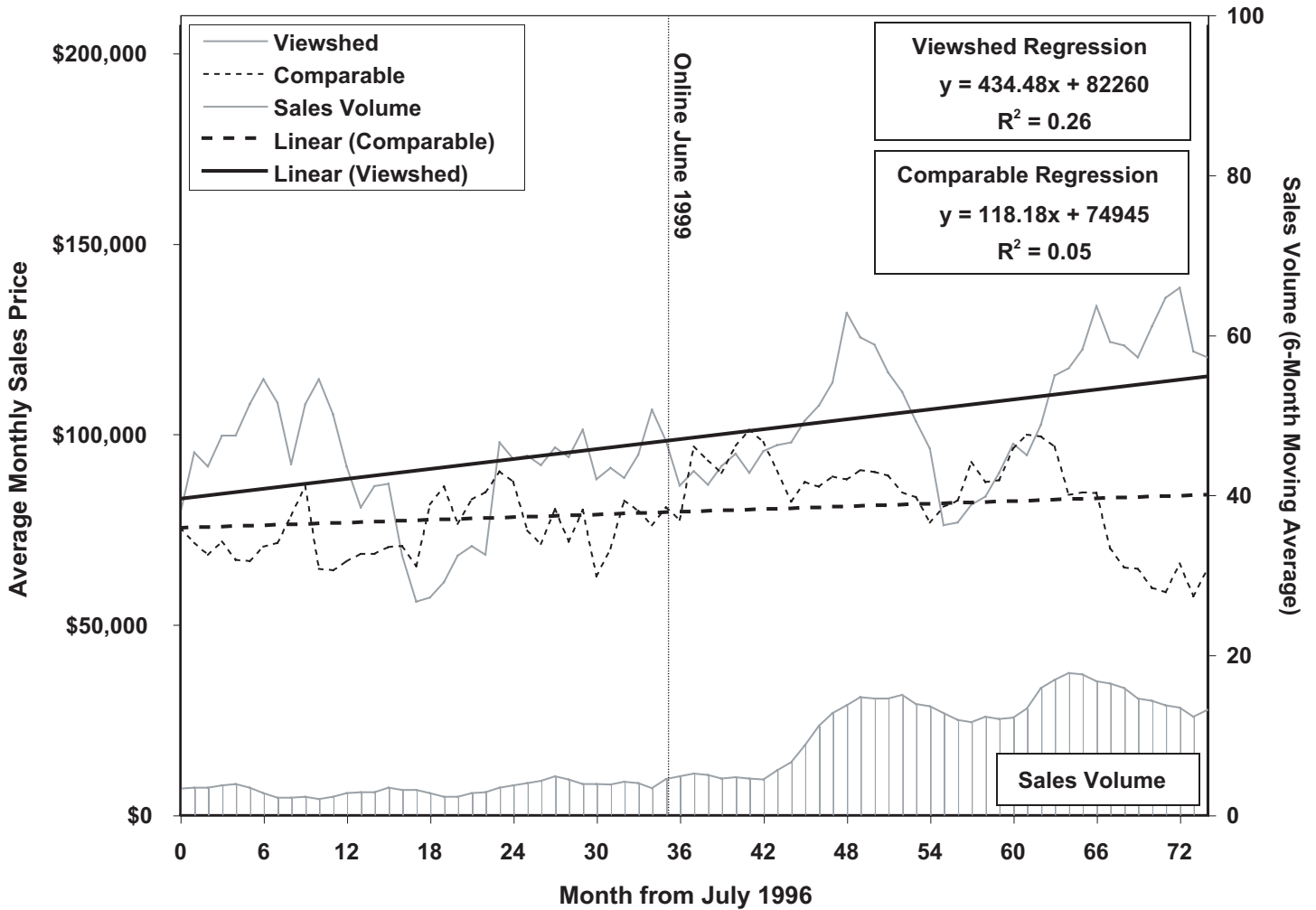


FIGURE 5.4 AVERAGE RESIDENTIAL HOUSING SALES PRICE  
KEWAUNEE COUNTY, WISCONSIN 1996-2002

**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

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### 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.



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FIGURE 6.1 SOMERSET WIND TOWER

PHOTO COURTESY GE WIND ENERGY © 2002

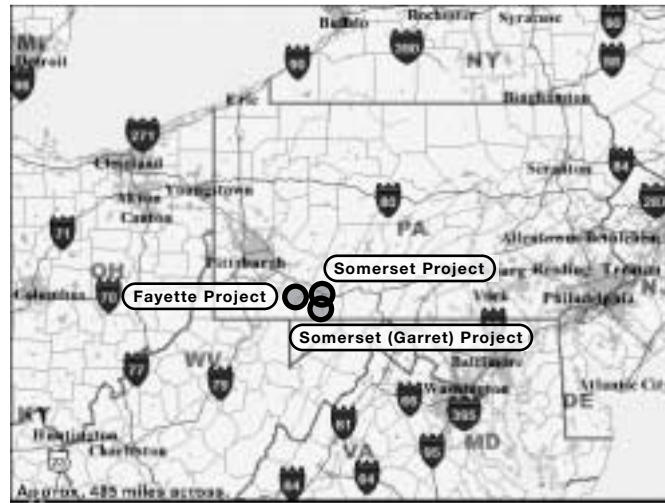


FIGURE 6.2 GENERAL LOCATION OF SOMERSET AND FAYETTE COUNTY WIND PROJECTS  
 BASE MAP IMAGE SOURCE: U.S. CENSUS BUREAU

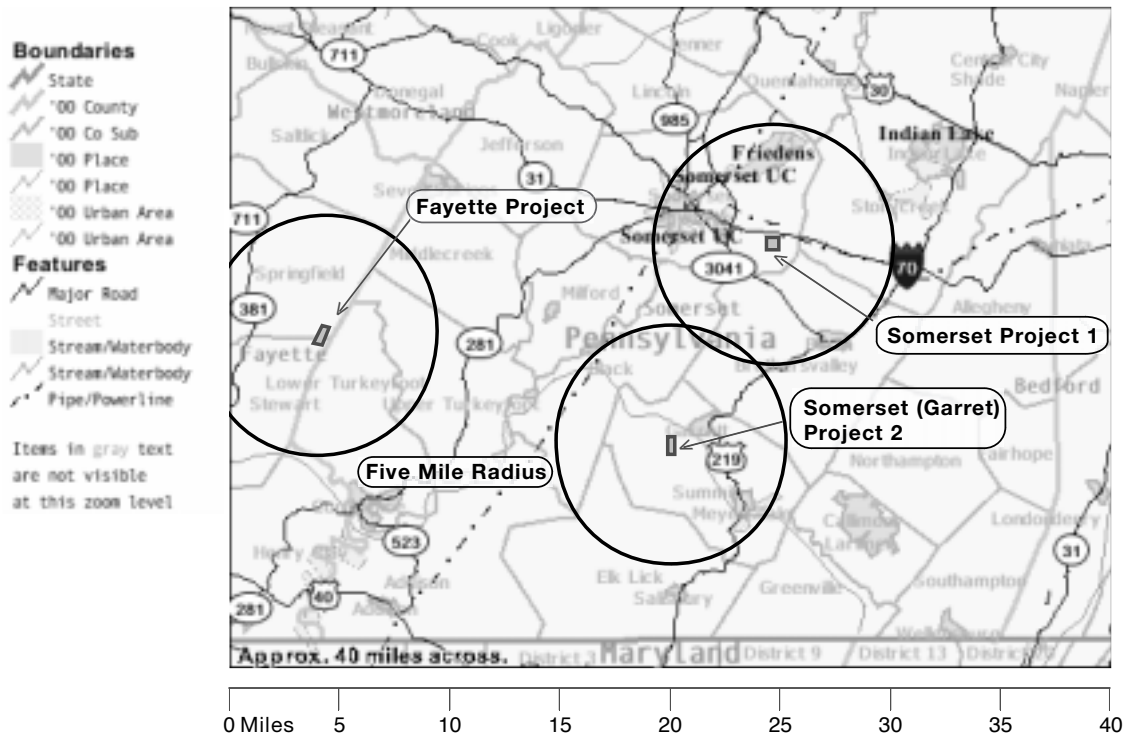


FIGURE 6.3. SOMERSET COUNTY, PENNSYLVANIA VIEW SHED  
 LOCATION SOURCE: SOMERSET COUNTY ASSESSORS OFFICE  
 BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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 farms 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**

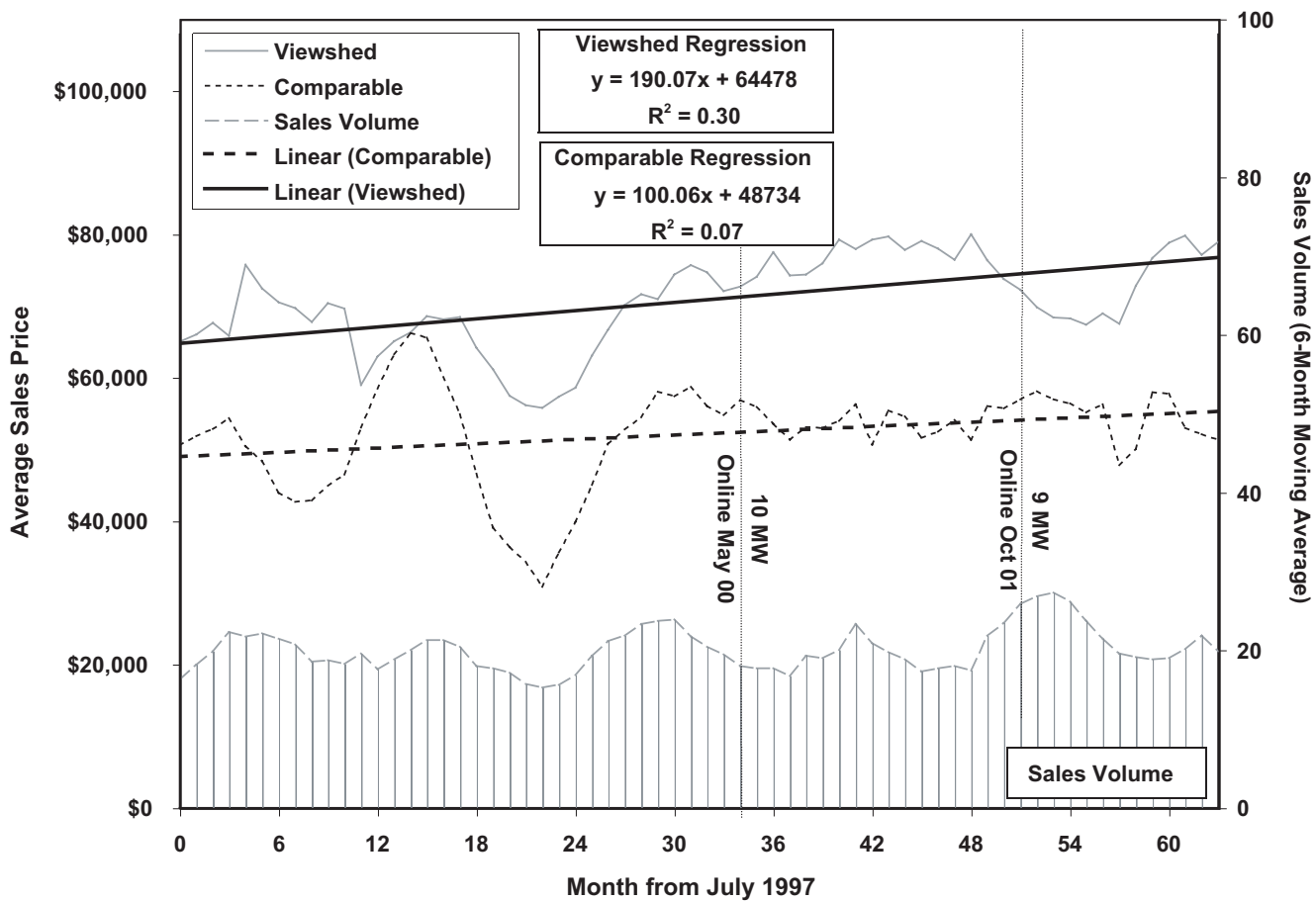
| Year                           | View shed | Location         | Population    | Median household income | % Population below poverty level | Number housing units | Median value-owner-occupied housing unit |
|--------------------------------|-----------|------------------|---------------|-------------------------|----------------------------------|----------------------|--|
| 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                                 |
| <b>VIEW SHED DEMOGRAPHICS</b>  |           |                  | <b>18,201</b> | <b>\$21,084</b>         | <b>18%</b>                       | <b>7,556</b>         | <b>\$45,950</b>                          |
| 1990                           | COMP      | Conemaugh Twsp   | 7,737         | \$25,025                | 8%                               | 3,070                | \$43,100                                 |
| <b>COMPARABLE DEMOGRAPHICS</b> |           |                  | <b>7,737</b>  | <b>\$25,025</b>         | <b>8%</b>                        | <b>3,070</b>         | <b>\$43,100</b>                          |
| 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                                 |
| <b>VIEW SHED DEMOGRAPHICS</b>  |           |                  | <b>18,898</b> | <b>\$29,791</b>         | <b>13%</b>                       | <b>8,122</b>         | <b>\$67,450</b>                          |
| 2000                           | COMP      | Conemaugh Twsp   | 7,452         | \$30,530                | 7%                               | 3,089                | \$61,800                                 |
| <b>COMPARABLE DEMOGRAPHICS</b> |           |                  | <b>7,452</b>  | <b>\$30,530</b>         | <b>7%</b>                        | <b>3,089</b>         | <b>\$61,800</b>                          |
| 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                   | Jan 97 - Oct 02                    | \$190.07                  | 0.30           | 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.                              |
|        | Comparable, all data                  | Jan 97 - Oct 02                    | \$100.06                  | 0.07           |  |
| Case 2 | View shed, before View shed, after    | Jan 97 - Apr 00<br>May 00 - Oct 02 | \$277.99<br>\$969.59      | 0.37<br>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.                 |
|        | View shed, after                      | May 00 - Oct 02                    | \$969.59                  | 0.62           |  |
| Case 3 | View shed, after<br>Comparable, after | May 00 - Oct 02<br>May 00 - Oct 02 | \$969.59<br>-\$418.73     | 0.62<br>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

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### 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)

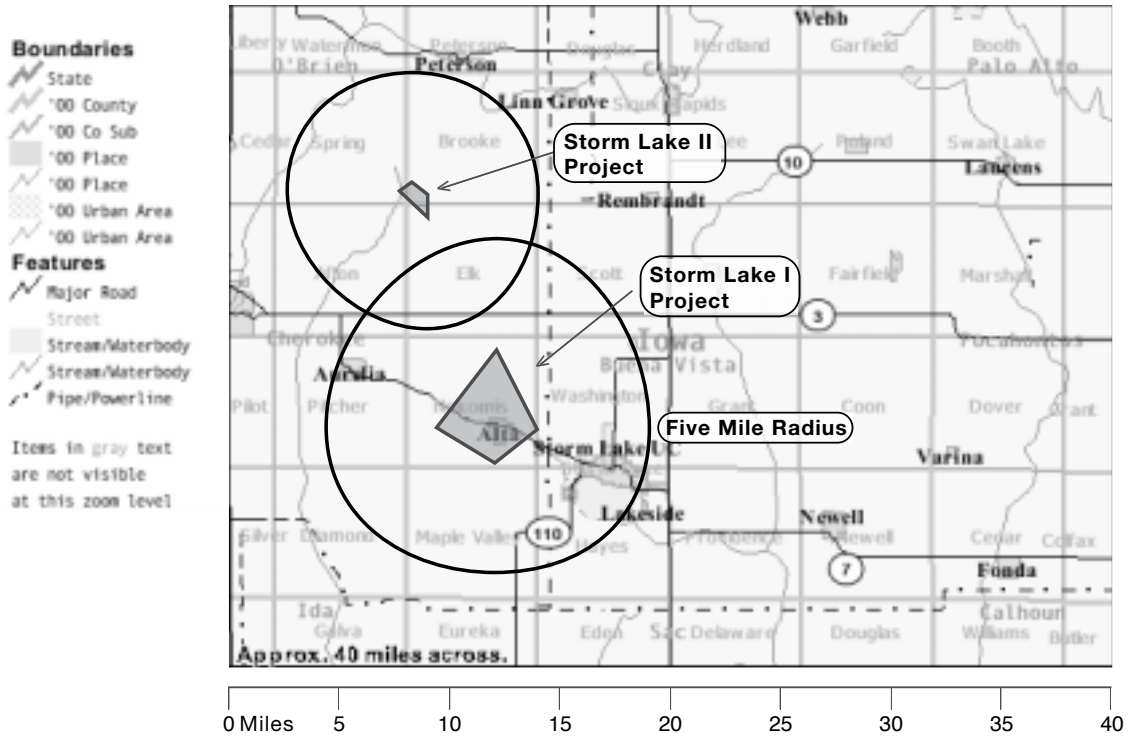


FIGURE 7.3. BUENA-VISTA, COUNTY, IOWA VIEW SHED  
LOCATION SOURCE: BUENA-VISTA COUNTY ASSESSORS OFFICE  
BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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](http://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

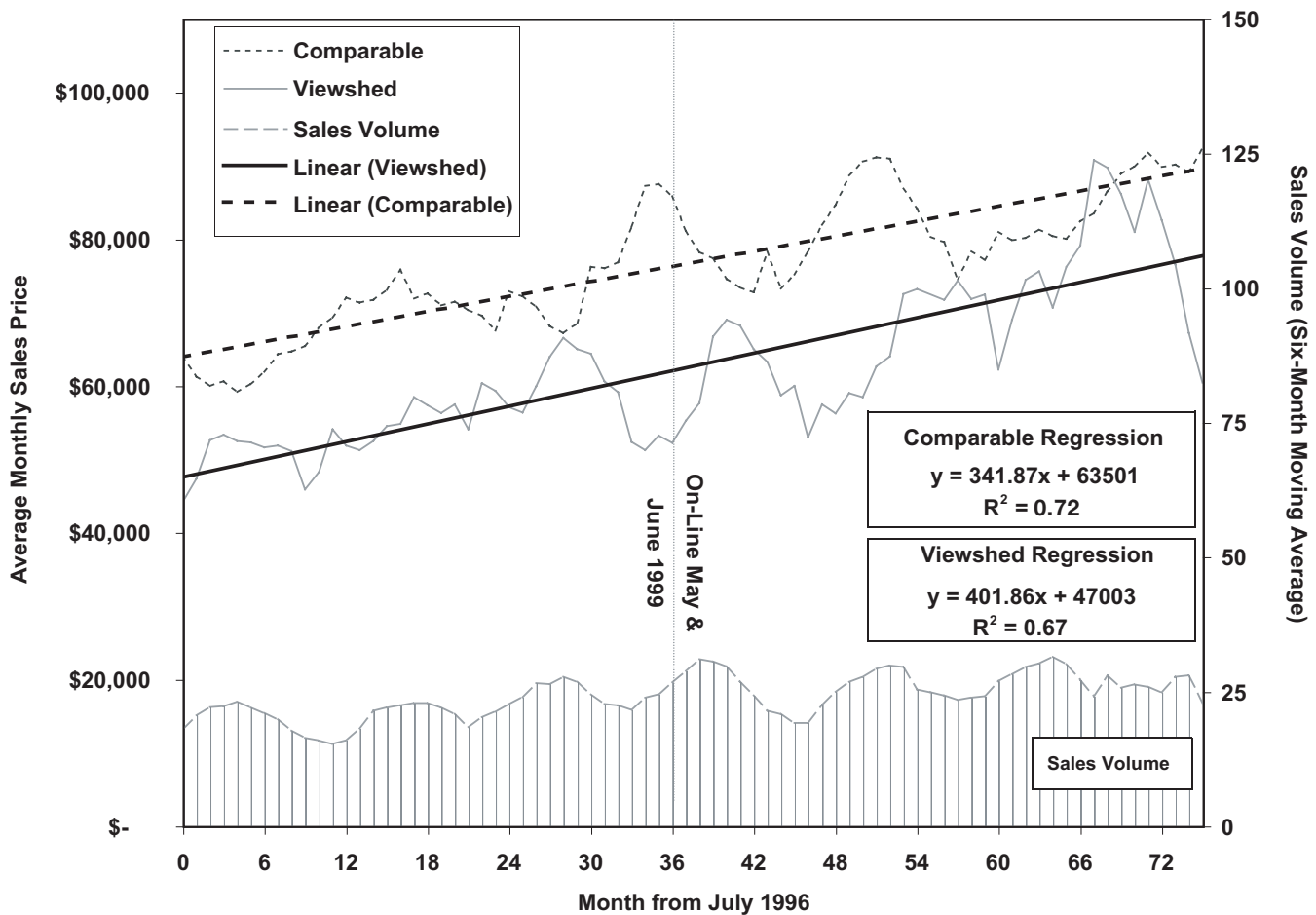
In all three of the regression models, monthly average sales prices grew slower in the view shed than in the comparable area.

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)**

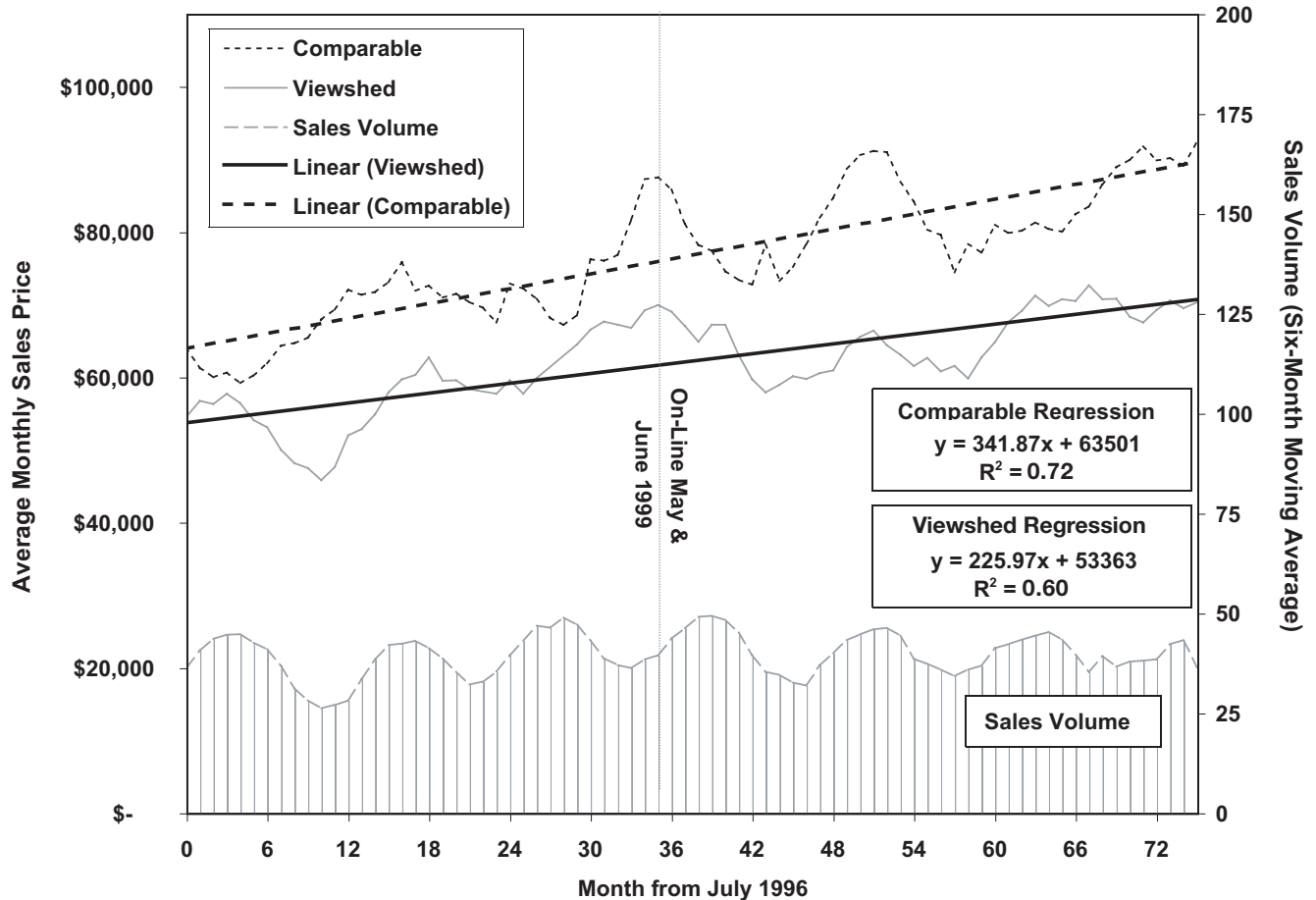
| Model  | Dataset              | Dates           | Rate of Change (\$/month) | Model Fit (R <sup>2</sup> ) | Result  |
|--------|----------------------|-----------------|---------------------------|-----------------------------|---|
| Case 1 | View shed, all data  | Jan 96 - Oct 02 | \$401.86                  | 0.67                        | 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.                               |
|        | Comparable, all data | Jan 96 - Oct 02 | \$341.87                  | 0.72                        |   |
| Case 2 | View shed, before    | Jan 96 - Apr 99 | \$370.52                  | 0.51                        | 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.                        |
|        | View shed, after     | May 99 - Oct 02 | \$631.12                  | 0.53                        |   |
| Case 3 | View shed, after     | May 99 - Oct 02 | \$631.12                  | 0.53                        | 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. |
|        | Comparable, after    | May 99 - Oct 02 | \$234.84                  | 0.23                        |   |



**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 (R <sup>2</sup> ) | 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 and 2002. 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)

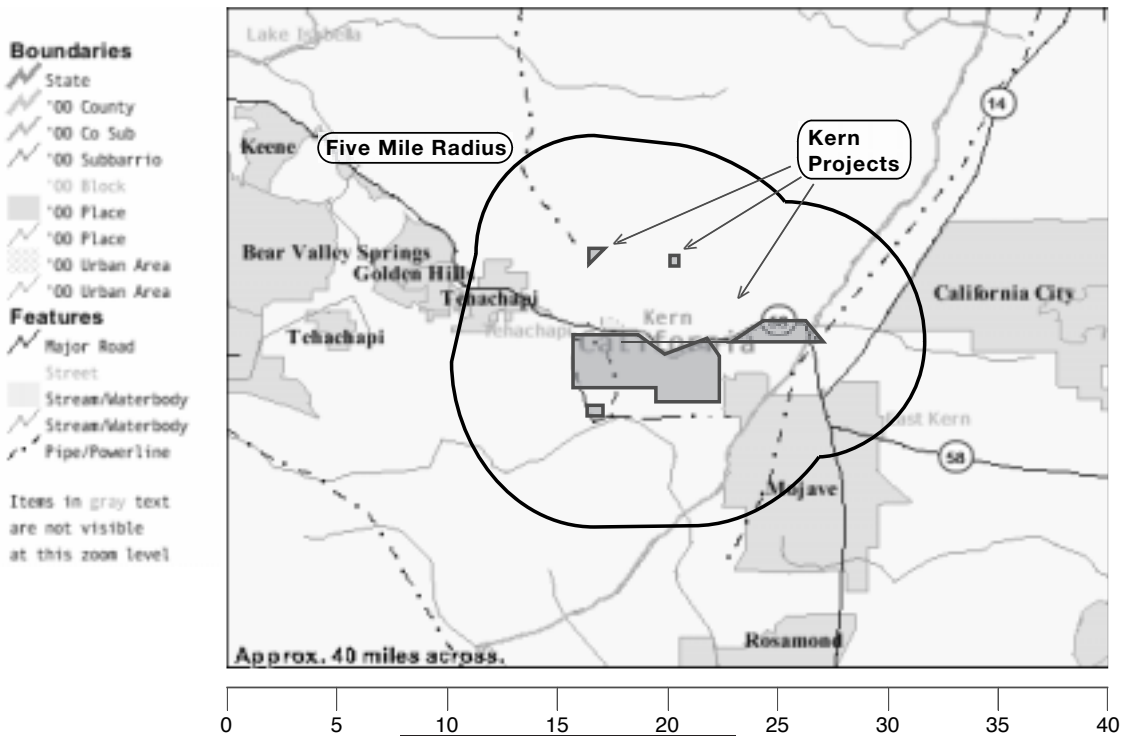


FIGURE 8.4. KERN COUNTY, CALIFORNIA VIEW SHED  
PROJECT LOCATION SOURCE: KERN COUNTY ASSESSORS OFFICE  
BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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.

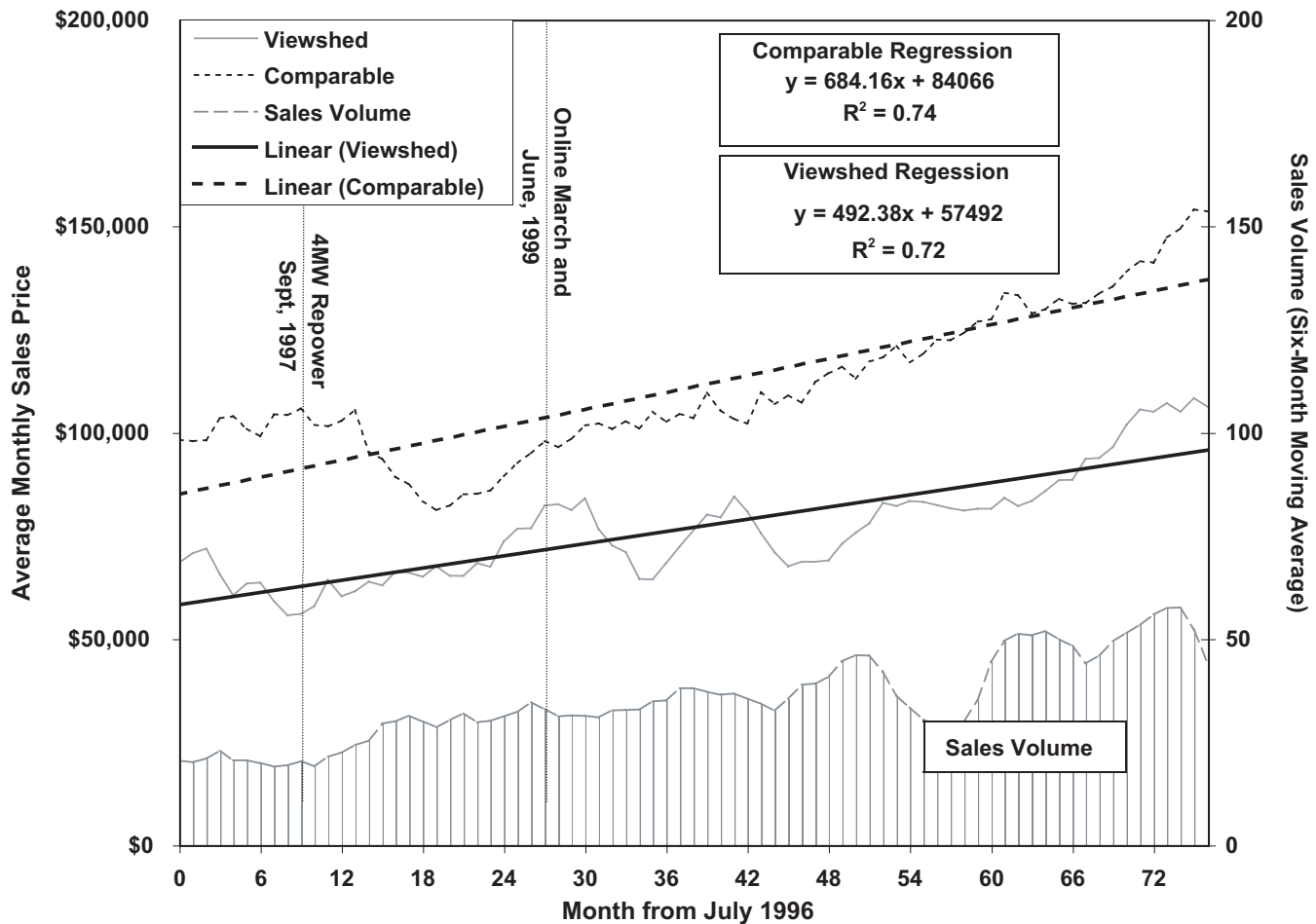
## **D. ADDITIONAL INTERVIEWEE COMMENTS**

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 (R <sup>2</sup> ) | 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

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### 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.



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FIGURE 9.1 VIEW OF A MILL RUN TURBINES  
PHOTO COURTESY GE WIND ENERGY © 2002

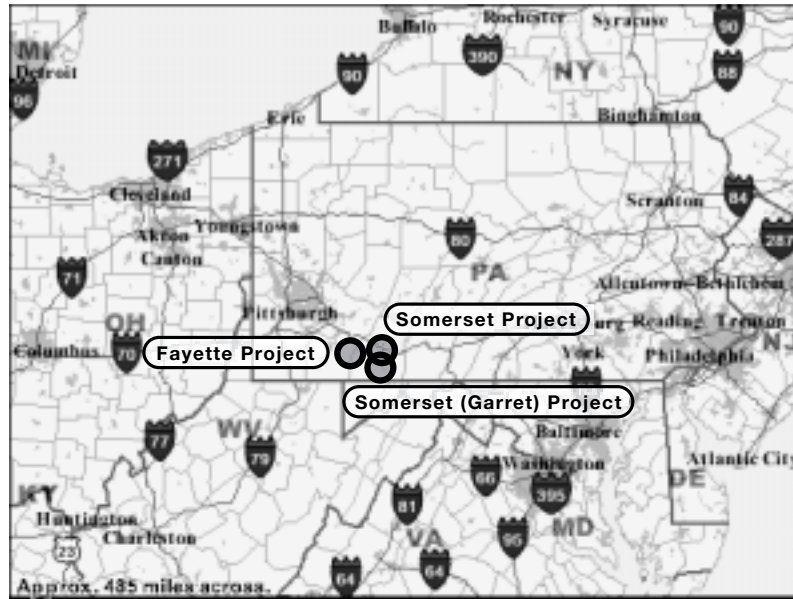


FIGURE 9.2. REGIONAL WIND PROJECT LOCATION  
(DOTS APPROXIMATE WIND FARM LOCATIONS)

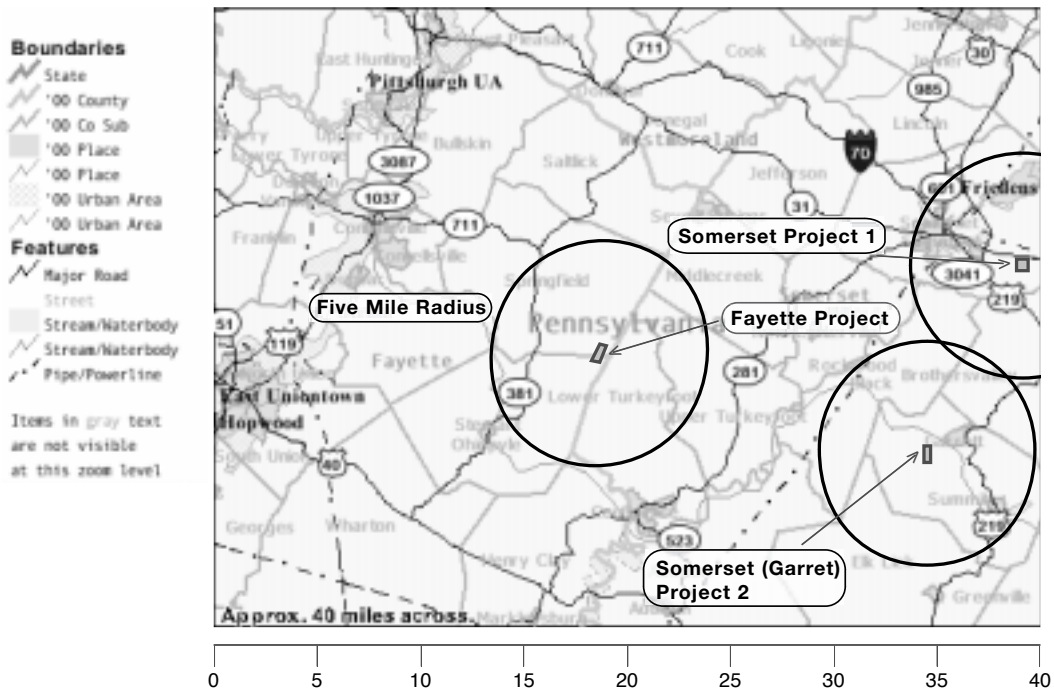


FIGURE 9.3. FAYETTE COUNTY, PENNSYLVANIA VIEW SHED  
PROJECT LOCATION SOURCE: FAYETTE COUNTY ASSESSORS OFFICE  
BASE MAP SOURCE: U.S. CENSUS BUREAU

## 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](http://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           |  |

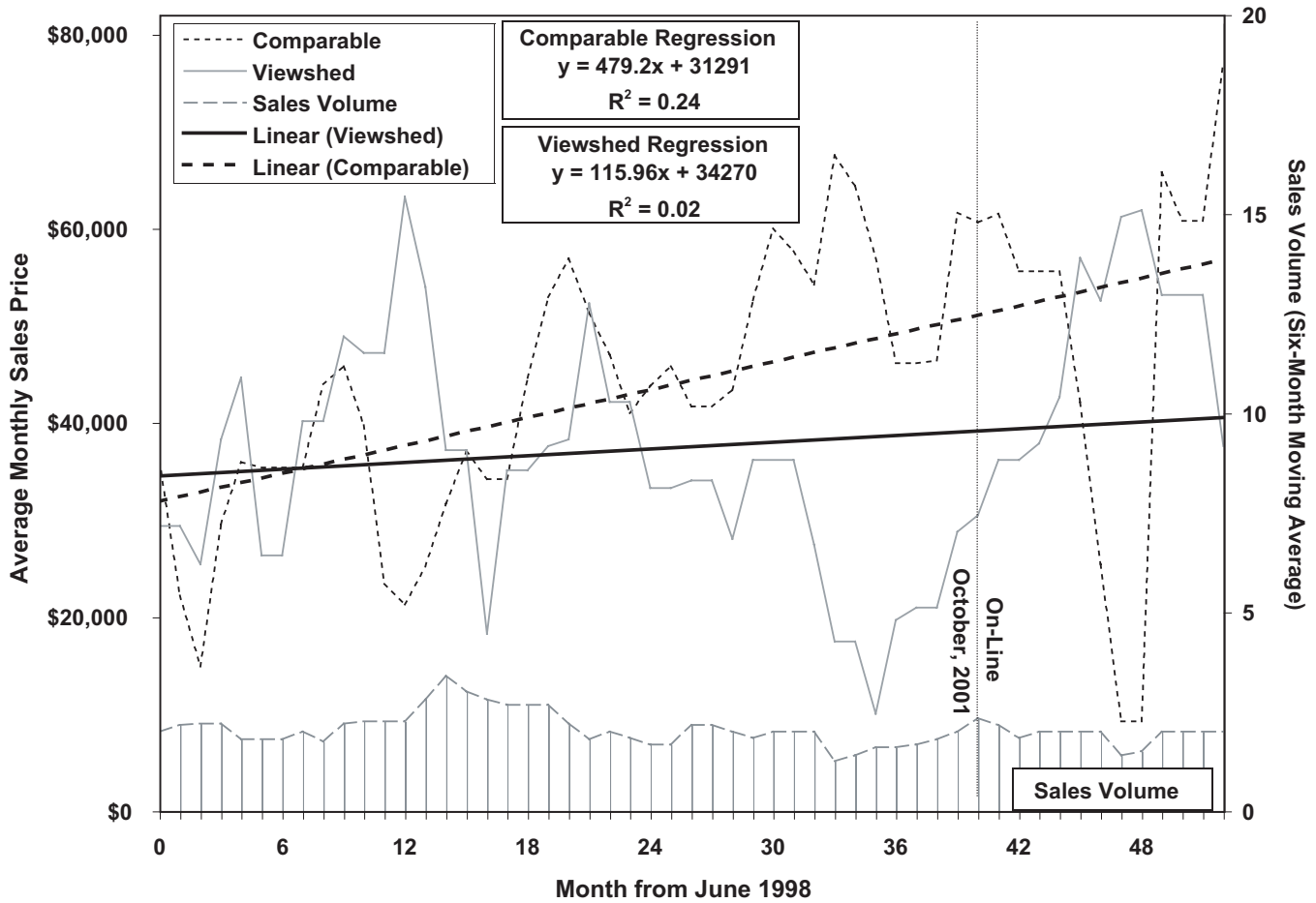


FIGURE 9.4 AVERAGE RESIDENTIAL HOUSING SALES PRICE  
FAYETTE COUNTY, PENNSYLVANIA 1998-2002

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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- California Energy Commission. Decision. Application for the Sutter Power Plant Project: Docket No. 97-AFC-2. 1999.
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- Thomas, Gareth Wyn. An Environmental Assessment of Visual and Cumulative Impacts arising from Wind farm Developments: A Welsh Planning Policy Perspective. University of Wales, Aberystwyth. March 1996. Available electronically at <http://users.aber.ac.uk/zwk/distlearn/virtlib/theses/thomas/thomas.html>
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# APPENDIX I. 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/](http://www.ers.usda.gov/briefing/rurality/RuralUrbCon/)

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## **Wind Turbine Neuro-Acoustical Issues**

Dora Anne Mills, MD, MPH Maine CDC/DHHS

June, 2009

### **1. What protections are in Maine law regarding excessive noise and vibrations?**

Maine DEP has rules that apply to all developments in unorganized areas of the state and in all municipalities without a more restrictive noise ordinance. The rules recognize in its text that excessive noise can degrade health and welfare of nearby neighbors, and they provide limits based on the type of development in the area surrounding the noise. For instance, they limit noise levels for routine operation of a proposed development: to 75 dBA at any time; to 60 dBA during the daytime and 50 dBA during the nighttime for non-commercial and non-industrial areas; and to 55 dBA daytime and 45 dBA nighttime for areas in which ambient sounds are 45 dBA or less daytime or 35 dBA or less nighttime.

Maine DEP also has retained the services of a noise expert to review noise study submissions as part of wind turbine applications and compliance evaluations.

DEP's ambient, post development monitoring at the Mars Hill wind farm shows dBA levels higher than 45, sometimes exceeding 60 when there are windy conditions both at ground level and at turbine height. This presents an example of how ambient noise from wind at these locations (which is why turbines are placed there) is in excess of the optimal nighttime 45 dBA. The DEP rules and compliance monitoring provide for distinguishing between the ambient contribution to noise and that from turbines at wind farms.

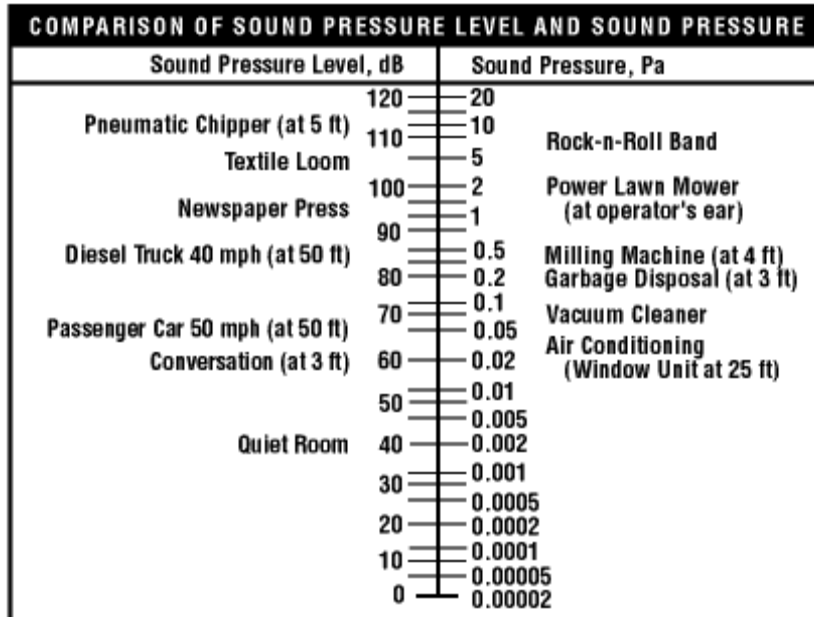
In summary: Maine law appears to essentially place a 45 dBA noise limit on most wind turbine projects in Maine. A 5 dBA variance to limits may be granted upon specific findings that concern pre-development existing ambient noises that are in excess of a particular standard. For compliance with the rule, noise levels are measured at the boundary of the property owned by the proposed developer.

Sources:

- Maine DEP rule-making authority on noise is in Title 38 Section 343  
Rules are in Chapter 375, Section 10:  
<http://www.maine.gov/sos/cec/rules/06/096/096c375.doc>
- Maine SPO Noise Technical Assistance Bulletin  
<http://www.maine.gov/spo/landuse/docs/techassist/techassistbulletins/noisetabulletin.pdf>

### **2. What do different noise levels compare to?**

40 dBA is comparable to a quiet room. 55 dBA is comparable to a household room or office in which there is normal background vibration and sounds such as is commonly found from household appliances.



Canadian Centre for Occupational Health and Safety  
 (see [www.ccohs.ca/oshanswers/phys\\_agents/noise\\_basic.html](http://www.ccohs.ca/oshanswers/phys_agents/noise_basic.html) ).

### 3. What kinds of noises are expected from wind turbines?

According to several resources, new wind turbines are relatively quiet, and meet federal and international standards and regulations for noise, including Maine’s regulations. According to the US Department of Energy, a modern wind farm at a distance of 750 – 1,000’ is no louder than a kitchen refrigerator or a moderately quiet room.

However, there are people who live about these distances from wind turbines who disagree with this federal agency statement. It appears from the research that distance from the wind turbine, height of the wind turbine relative to the surrounding topography, the quality of the sound (repetitive low frequency sound), wind conditions, and wind direction all affect how the wind turbine noise affects people. Research done on wind turbines, airport and other sources of noise indicates that annoyance levels are difficult to assess. However, taking in account the above factors as well as careful measurements need to be considered when siting wind turbines near residential properties.

Sources:

- US Dept of Energy’s Wind Energy Guide for County Commissioners:  
<http://www.nrel.gov/wind/pdfs/40403.pdf>  
 Page 6: An operating modern wind farm at a distance of 750’-1,000’ is no louder than a kitchen refrigerator or moderately quiet room.
- University of Massachusetts Renewable Research Energy Laboratory:  
[http://www.windpoweringamerica.gov/pdfs/workshops/mwmg\\_turbine\\_noise.pdf](http://www.windpoweringamerica.gov/pdfs/workshops/mwmg_turbine_noise.pdf)  
 Contains a number of resources on sounds emitted from wind turbines
- Noise levels of small residential wind turbines:

Dept of Energy's Consumer Guide on Small Wind Turbines  
[http://apps1.eere.energy.gov/consumer/your\\_home/electricity/index.cfm/mytopic=10930](http://apps1.eere.energy.gov/consumer/your_home/electricity/index.cfm/mytopic=10930)

Comparable sounds to wind turbines

- Wind Turbine Noise Issues: A white paper prepared by Renewable Energy Research Laboratory, U of Massachusetts, 2004:  
<http://www.town.manchester.vt.us/windforum/aesthetics/WindTurbineNoiseIssues.pdf>

#### **4. Are there health effects to the levels of sound heard by wind turbines?**

According to a 2003 Swedish EPA review of noise and wind turbines:

“Interference with communication and noise-induced hearing loss is not an issue when studying effects of noise from wind turbines as the exposure levels are too low.”

In my review I found no evidence in peer-reviewed medical and public health literature of adverse health effects from the kinds of noise and vibrations heard by wind turbines other than occasional reports of annoyances, and these are mitigated or disappear with proper placement of the turbines from nearby residences. Most studies showing some health effects of noise have been done using thresholds of 70 dBA or higher outdoors, much higher than what is seen in wind turbines.

Sleep disturbance is another commonly raised concern, and the WHO guidelines for community noise recommend that nighttime outdoor noise levels in residential areas not exceed 45 dBA, which is consistent with Maine law.

Sources:

- Noise Annoyance from Wind Turbines – A Review 2003 Sweden Environmental Protection Agency  
<http://www.barrhill.org.uk/windfarm/noise/10%20pederson.pdf>  
This study found no evidence of health problems, reviews the variety of noise regulation laws in place in Europe
- British Medical Journal 2007 Swedish Study (Eja Pedersen)  
<http://oem.bmj.com/cgi/content/full/64/7/480?ijkey=b1a1ae4a98c9453315a90941395e0a05262aca53>  
Survey in Sweden of residents near wind turbines found annoyance increased with increased sound pressure levels (SPLs), and increased annoyance was associated with lower sleep quality and negative emotions.
- Noise Pollution: Non-Auditory Effects on Health, 2003  
<http://bmb.oxfordjournals.org/cgi/content/full/68/1/243>
- World Health Organization Community and Occupational Noise  
<http://www.who.int/mediacentre/factsheets/fs258/en/>
- World Health Organization 2002 Technical Meeting on Relationship Between Noise and Health  
<http://www.euro.who.int/document/NOH/exposerespnoise.pdf> Page 52 says that WHO standard is for nighttime noise not to exceed 45 dB.

## 5. What about low frequency noises (LFN)?

Some have pointed to LFN emitted from wind turbines as a possible source of adverse health effects. The reasons LFN are focused on include: LFN encounter less absorption as they travel through air than higher frequency sound, so they persist for a longer distance; the amount of sound transmitted from the outside to the inside of a building is higher with LFN; and some models for assessing impact of noise do not adequately include LFN.

Low frequency and infrasound (lower than what is perceptible) vibrations are very common in our background, and known to be emitted from many household appliances and vehicles as well as in neighborhoods near airports and trains. Exposure to very intense LFN can be annoying and may adversely affect overall health, though these levels appear to be more intense than what is measured from modern wind turbines.

The DEP noise regulations are based on the “A” frequency range of noise, which measures the higher frequency end of the noise spectrum, and is denoted with the term dbA. Because the dbA measurement deemphasizes noises from the lower end of the frequency spectrum (or “C” weighted noise, dbC), Maine DEP has been evaluating noise models and predicted noise levels from proposed wind power facilities using a handicapping system that requires an applicant to prove that dbA noise levels will be at such a level at property boundaries that they are effectively controlling for low frequency noises in the dbC range. The Land Use Regulation Commission has required monitoring for dbC noise at one of its recently permitted wind turbine facilities in order to evaluate dbC noise levels at property boundaries.

One recent study commonly cited by proponents of the belief of the physiological impacts of LFN is: “Tuning and sensitivity of the human vestibular system to low-frequency vibration”, Todd, et al. Neuroscience Letters, 2008, which can be found at: <http://www.ncbi.nlm.nih.gov/pubmed/18706484>. This study indicates that the human vestibular system is sensitive, which means it shows a physiological response, to low-frequency and infrasound vibrations of -70 dB, indicating that human seismic receptor sensitivity of the vestibular system may possibly be on par with the frog ear. However, sensitivity, i.e. showing a physiological response, does not mean there are adverse effects.

### Summary:

Reviews found in peer reviewed journals of the possible health effects of low frequency noise have not found evidence of significant health effects (several references are listed below).

### Sources:

- Infrasound from Wind Turbines: Fact, Fiction, or Deception? Journal of Canadian Acoustics, Volume 34, no 2, 2006.  
<http://www.wind.appstate.edu/reports/06-06Leventhall-Infras-WT-CanAcoustics2.pdf>

*“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 in flow 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.”*

- Sources and Effects of Low-Frequency Noise 1996  
<http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=JASMANO00099000005002985000001&idtype=cvips&gifs=yes>  
J. Acoust. Soc. Am. Volume 99, Issue 5, pp. 2985-3002 (May 1996)
- Characteristics of low frequency signals emitted from home electric appliances:  
<http://sciencelinks.jp/j-east/article/200507/000020050705A0229983.php>,
- Magnetic Emission Ranking of Electrical Appliances:  
<http://rpd.oxfordjournals.org/cgi/content/abstract/ncm460v1>)
- International Meeting on Low Frequency Noise and Vibration and Its Control, the Netherlands, 2004  
[http://www.viewsofscotland.org/library/docs/LF\\_turbine\\_sound\\_Van\\_Den\\_Berg\\_Sep04.pdf](http://www.viewsofscotland.org/library/docs/LF_turbine_sound_Van_Den_Berg_Sep04.pdf)

## **6. What are the health benefits to wind turbines?**

- There are tremendous potential health benefits to wind turbines, including reductions in deaths, disability, and disease due to asthma, other lung diseases, heart disease, and cancer. Maine has among the highest rates in the country of asthma and cancer.
- Wind turbines mean less dependency on foreign oil and coal that contribute to global warming and pollution (coal produces carbon dioxide, acid rain, smog, particulate pollution, carbon monoxide, and mercury), which in turn contribute to the diseases above.
- According to the Maine DEP, if Maine generated 5% of its electricity from wind power, there would be significant pollution cuts:
  - 464,520 tons per year of CO<sub>2</sub>
  - 252 tons per year of SO<sub>2</sub>
  - 147 tons per year of NO<sub>x</sub>

## **7. What about a moratorium on wind turbine projects?**

- I do not find evidence to support a moratorium on wind turbine projects at this time. The articles cited by those who are in favor of a moratorium are either from non-peer reviewed journals (though some are labeled as “peer reviewed”) or are misinterpreted analyses from peer reviewed journals.

- If there is any evidence for a moratorium, it is most likely on further use of fossil fuels, given their known and common effects on the health of our population.

### **Basic Wind Turbine Noise-Related Resources:**

- US Dept of Energy's New England Wind Power Website on Wind Turbine Sound – this has a good summary and links to references  
[http://www.windpoweringamerica.gov/ne\\_issues\\_sound.asp](http://www.windpoweringamerica.gov/ne_issues_sound.asp)
- Massachusetts DEP Regulations  
<http://www.nonoise.org/lawlib/states/mass/mass.htm>  
*“A source of sound will be considered to be violating the Department's noise regulation (310 CMR 7.10) if the source: Increases the broadband sound level by more than 10 dB(A) above ambient, or Produces a "pure tone" condition - when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 decibels or more. These criteria are measured both at the property line and at the nearest inhabited residence. Ambient is defined as the background A-weighted sound level that is exceeded 90% of the time measured during equipment operating hours. The ambient may also be established by other means with the consent of the Department.”*
- Ongoing Research is being done by the US Dept of Energy Wind Turbine Aeroacoustic Research:  
[http://www1.eere.energy.gov/windandhydro/wind\\_research\\_enable.html#research](http://www1.eere.energy.gov/windandhydro/wind_research_enable.html#research)  
 “Turbine noise can be caused by rotor speed, blade shape, tower shadow, and other factors. The program is sponsoring both wind tunnel and field tests to develop a noise prediction code that turbine manufacturers can use to ensure that new rotor designs and full systems aren't too noisy. This is especially true for high-growth U.S. markets for small wind turbines that will demand quieter rotors, especially when turbines are sited in residential neighborhoods. Small turbines operate at high rotational speeds and tend to spin even if they are furlled (pointed out of the wind).
- **Background Information on Noise:**  
[http://www.osha.gov/dts/osta/otm/noise/health\\_effects/physics.html](http://www.osha.gov/dts/osta/otm/noise/health_effects/physics.html)  
[http://www.ccohs.ca/oshanswers/phys\\_agents/noise\\_basic.html](http://www.ccohs.ca/oshanswers/phys_agents/noise_basic.html)  
<http://www.phys.unsw.edu.au/jw/dB.html>  
 The decibel (**dB**) is used to measure the intensity of sound. It uses a logarithmic scale and describes a ratio where 0 is at the threshold of human hearing. When measuring sound, filters are usually used. The A scale filter results in sound level meters called dBA that are less sensitive to very high or very low frequencies. The C filter provides more of a measurement of low frequency noise.



**Exhibit 27**

*Health Sciences*

Public Service Commission of Wisconsin  
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Exponent®

**Evaluation of the Scientific  
Literature on the Health  
Effects Associated with Wind  
Turbines and Low Frequency  
Sound**



**Evaluation of the Scientific  
Literature on the Health Effects  
Associated with Wind Turbines  
and Low Frequency Sound**

Prepared for

Wisconsin Public Service Commission  
Docket No. 6630-CE-302

Prepared by

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October 20, 2009

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# Contents

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|  |           |
|--|-----------|
| <b>List of Figures</b>                                       | <b>5</b>  |
| <b>List of Tables</b>  | <b>6</b>  |
| <b>Executive Summary</b>                                     | <b>7</b>  |
| <b>Overview of Epidemiology</b>                              | <b>8</b>  |
| Epidemiology, Association, and Causation                     | 10        |
| <b>Peer Review Process</b>                                   | <b>13</b> |
| <b>Public Health Issues</b>                                  | <b>16</b> |
| <b>Precautionary Principle</b>                               | <b>19</b> |
| <b>Background on Infrasound and Low Frequency Sound</b>      | <b>21</b> |
| Infrasound   | 23        |
| Low Frequency Sound  | 24        |
| <b>Background on Wind Turbines and Noise</b>                 | <b>27</b> |
| <b>Evaluation of Scientific Literature on Health Effects</b> | <b>29</b> |
| Applicability and Utility                                    | 30        |
| Soundness  | 31        |
| Clarity and Completeness                                     | 31        |
| Uncertainty and Variability                                  | 32        |
| Evaluation and Review  | 32        |
| Final Included Literature                                    | 33        |
| <b>Health Effects of Infrasound and Low Frequency Sound</b>  | <b>34</b> |
| Human Effects  | 34        |
| Annoyance  | 38        |
| Disease vs. DIS-ease   | 39        |
| <b>Limitations of Scientific Literature</b>                  | <b>40</b> |

|                         |           |
|-------------------------|-----------|
| <b>Conclusions</b>      | <b>42</b> |
| <b>References</b>       | <b>45</b> |
| <b>Appendix A</b>       | <b>51</b> |
| <b>Final Literature</b> | <b>51</b> |

## List of Figures

---

|  |    |
|--|----|
| Figure 1. The Scientific Process               | 11 |
| Figure 2. The Scientific Method                | 12 |
| Figure 3. Peer Review Process                  | 14 |
| Figure 4. Normal Equal-Loudness Level Contours | 23 |
| Figure 5. Horizontal Axis Wind Turbine         | 28 |

## List of Tables

---

|          |   |    |
|----------|---|----|
| Table 1. | Risk Perception Factors For the Acceptability of Risk | 18 |
| Table 2. | Human Sound Intensity Levels                          | 22 |
| Table 3. | Sound Frequency Spectrum                              | 24 |
| Table 4. | Literature Search Queries                             | 29 |
| Table 5. | Applicability and Utility Ranking System              | 30 |
| Table 6. | Soundness   | 31 |
| Table 7. | Clarity and Completeness                              | 31 |
| Table 8. | Uncertainty and Variability                           | 32 |
| Table 9. | Evaluation and Review                                 | 32 |



## Executive Summary

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This white paper presents a review of the human health effects associated with infrasound and low frequency sound, preceded by an introduction to the basic concepts of epidemiology, causation, the peer review process, the science of public health, and the precautionary principle.

The goal of this white paper was to highlight key points regarding the health concerns of those involved with the positioning of wind turbines, rather than an in-depth review of the science of sound. The research involving sound is massive in its depth and breadth and is expanding daily. Research on health effects associated with human exposure to sound has evolved from the study of physical damage to the study of psychological and other effects, from ringing in the ears to non-specific physical symptoms. Early research in low frequency noise exposures is difficult to evaluate due to the diversity of the exposure and non-specific nature of the reported health effects. As of this review, there has not been a specific health condition documented in the peer reviewed published literature to be classified as a disease caused by exposure to sound levels and frequencies generated by the operation of wind turbines. That does not mean that there cannot be an effect. Numerous scientific papers document physiological responses to low frequency sound, but the majority of these effects are consistent with human response to environmental stimuli of varied nature and at higher decibel levels than produced by wind turbines. One of the most prominent non-physiological effects noted across the gamut of scientific as well as lay press literature is the annoying qualities of sound as was so vividly pointed out in one of the discussions when it was said that “one man’s music is another man’s unbearable noise.” Annoyance is a normal response and is not predictable based on the sound level below the painful level. It is clear that some people respond negatively to the noise qualities generated by the operation of wind turbines, but there is no peer-reviewed, scientific data to support a claim that wind turbines are causing disease or specific health conditions. Annoyance regarding the wind turbines is an elusive factor that could underlie a majority of the health complaints being attributed to wind turbine operations.

## Overview of Epidemiology

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Epidemiology is the study of the distribution and determinants of health events in populations (Last JM. 2001). The key elements of epidemiology are comparisons of health outcomes and exposures between populations (which allows for the calculation of relative risk estimates) and the careful evaluation of underlying determinants that may affect the outcome of comparisons of the study populations (bias and confounding). The study of health claims related to wind turbines is an excellent example of the potential influence of both bias (voluntary and involuntary exposures) and confounding (health outcome potentially related to direct and indirect exposure).

The scientific body of knowledge relative to a particular disease often starts with observations by clinicians (case reports and case series). These reports are not analytical studies because they have no comparison group or other means to test for associations. Case reports and reports of series of cases help generate scientific hypotheses; however, they cannot be used in testing for association or causation (Checkoway H. 2004). Surveys of only those persons claiming an effect give only one part of the total equation needed to assess the magnitude of risk associated with living near wind turbines. A collection of observations, no matter how well documented, are not sufficient to prove an increased risk, but instead are a first step in the scientific process. One must rely upon peer reviewed, published studies that are designed to reduce bias and confounding as much as possible.

The two most common types of analytical epidemiologic studies used to evaluate potential disease causation are cohort studies and case-control studies. In cohort studies, the researcher identifies two groups of individuals: individuals who have been exposed to a substance considered a possible cause of disease (“exposed” group) and individuals who have not been exposed (“unexposed” or “comparison” group). The researcher then follows both groups for a length of time and compares the rate of disease among the exposed individuals with the rate of disease among the unexposed individuals. The researchers determine whether there is an association between the exposure and the disease by calculating a relative risk (RR), which

divides the rate of disease among the exposed by the rate of disease among the unexposed, with a value statistically greater than 1.0 indicating a positive association. One type of cohort study is a standardized mortality (incidence) ratio study (SMR/SIR). In SMR/SIR studies of occupational groups, the number of observed cases for a particular occupational group is compared to the number one would expect for that group based on rates in the general population. These studies divide the observed number of cases by the expected number of cases, with a value statistically greater than 1.0 indicating a positive association.

In case-control studies, the researcher begins with a group of individuals who have the disease (cases) and then selects a group of individuals who do not have the disease (controls). The researcher then compares the case and control groups looking for differences in past exposures. An association is measured by dividing the odds of exposure among the diseased by the odds of exposure among the non-diseased, with a value statistically greater than 1.0 indicating a positive association.

Another type of epidemiologic study is a proportionate mortality (incidence) ratio study (PMR/PIR). PMR/PIR studies compare the proportions of selected causes of death or disease incidence in the exposed study group to the proportion in the unexposed study population, with a value statistically greater than 1.0 indicating a positive association.

No matter the study design, the researcher applying epidemiological principles and the reader of the studies must have a clear understanding of what constitutes the “disease” being studied. The description of the disease has to be sufficiently specific and described such that the comparisons are truly comparing “like to like.” In the case of health complaints related to wind turbines, there is a lack of specificity as to the health complaints. A disease or group of symptoms classified as “Wind Turbine Syndrome” has not been adopted by the medical community. The underlying complaint of annoyance is in and of itself not a disease or a specific manifestation of a specific exposure but instead a universal human response to a condition or situation that is not positively appreciated by the human receptor. Annoyances are highly variable in type (noise, smell, temperature, taste, vision) and vary from person to person. One can be annoyed by the action of others, as well as their own individual actions. Thus, “annoyance” is not a disease but

a universal human response that is highly non-specific. In conclusion, it has been found that there is a lack of epidemiologic research studies showing an association between health effects and exposure to noise at low frequency in combination with low sound pressure (dBA) generated by wind turbines.

## **Epidemiology, Association, and Causation**

Historically, there have been careful clinical observations (case reports and series) that have stimulated a number of now-classic epidemiology research efforts that have identified important associations and ultimately the determinants of causal relationships. There have also been case reports identifying associations that did not hold up under epidemiological scrutiny, for example, those associating blunt force trauma and cancer. For this reason, case studies cannot be used to determine causation. A causal association can only be established by the evaluation of well designed and executed epidemiologic studies.

A landmark discussion of the process of moving from a disease being associated with a risk factor to a point where the scientific community is comfortable attributing causation to a risk factor was put forth by Sir Austin Bradford Hill in 1965. It was during this time that a number of papers, including the Surgeon General Report issued in 1964, began to more formally delineate the scientific reasoning process that justifies a conclusion that observed associations between an exposure and a disease are the result of a causal relationship between the exposure and the disease. Key statements from scientists during that time include the following:

“Disregarding then any such problem in semantics we have this situation. Our observations reveal *an association between two variables, perfectly clear-cut* and beyond what we would care to attribute to chance. What aspects of that association should we especially consider before deciding that the most likely interpretation of it is causation?” [italics added] (Hill AB. 1965). Hill’s nine criteria for causation have been described in a number of ways. They are commonly referred to as strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experiment, and analogy (Hill AB. 1965).

“*If it be shown that an association exists*, then the question is asked, ‘Does the association have a causal significance?’ ... To judge or evaluate the causal significance of the association between the attribute or agent and the disease, or effect on health, a number of criteria must be utilized...” [italics added] (Bayne-Jones S et al. 1964).

Finally, it should be noted that greater weight can be provided to the strength of an association when several epidemiologic studies performed by different researchers arrive at the same conclusions. And as a final step, researchers often submit their work for publication which then typically undergoes a peer review process for completeness and scientific soundness.



Figure 1. The Scientific Process

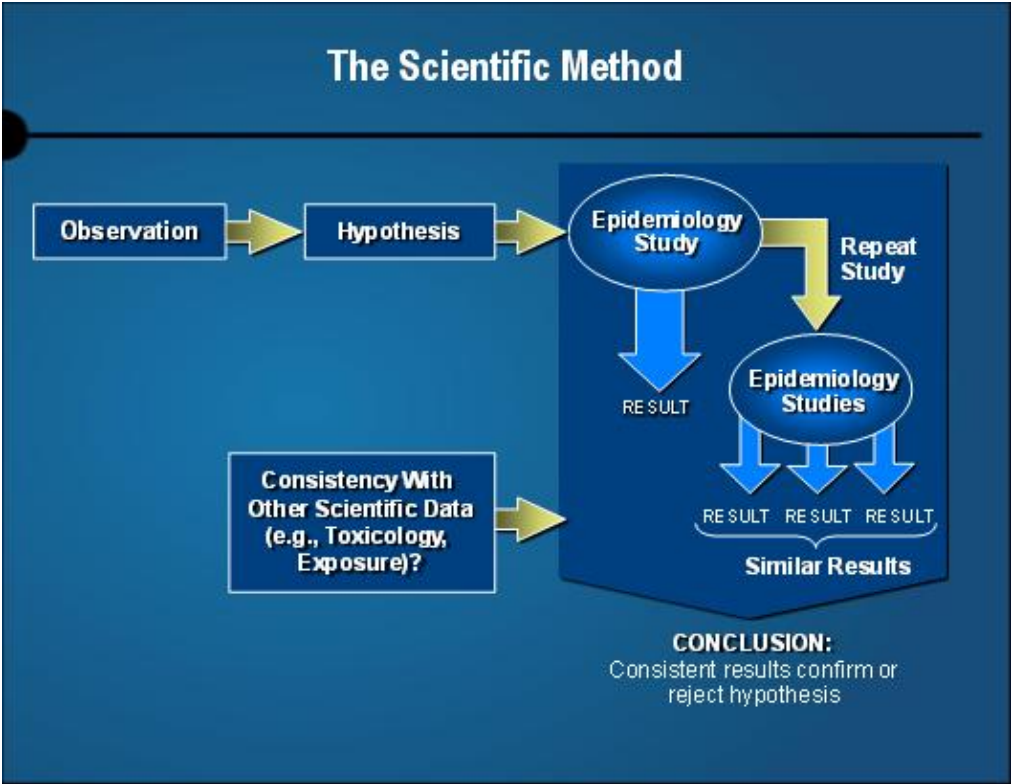


Figure 2. The Scientific Method



## Peer Review Process

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According to the Centers of Disease Control and Prevention (CDC), the peer review process is an “independent assessment of the scientific merit of research by panels of experts who provide written assurance that their reviews are free of real or perceived conflicts of interest. Results of the peer review process should therefore be without inherent bias and can be viewed as fair and just...” (CDC 2009).

Publication in a peer-reviewed journal remains the standard means of disseminating scientific results and has been since 1665, when the first recorded peer review process was performed at The Royal Society by the founding editor, Henry Oldenburg (UK Parliament and House of Commons 2004). Consequently, publications that have not undergone a peer review are likely to be regarded with skepticism and doubt by scholars and professionals.

Generally, the peer review process uses anonymity and employs a double-blind process whereby the authors and peer reviewers remain unknown or blinded to each other. Reviewers are often required to disclose conflicts of interest. The use of anonymity preserves the integrity of the peer review process and discourages favoritism shown by colleagues, friends, or relatives. Although not fool-proof, the peer review process can also maintain and enhance the quality of work by detecting flaws, plagiarism, fraud, unsound science, or personal views. Hence, the peer review process fosters scholarship and encourages authors to meet the accepted standards of their discipline.

The typical peer review process for scientific journals begins with the author submitting a manuscript. The editor of the journal reviews the article and determines whether or not the article is appropriate for the journal. If the article is determined to be appropriate, the editor assigns peer reviewers to read and critique the work. The reviewers then submit their comments to the editor and a decision is made with respect to the publication status of the article: (1) accept for publication; (2) accept for publication with modifications; (3) reject for publication (Figure 3). An average acceptance rate for publication in peer reviewed journals has been

reported to be between 25% and 50%, although journals such as New England Journal of Medicine and the British Medical Journal have been known to be much lower (Elsevier 2009).

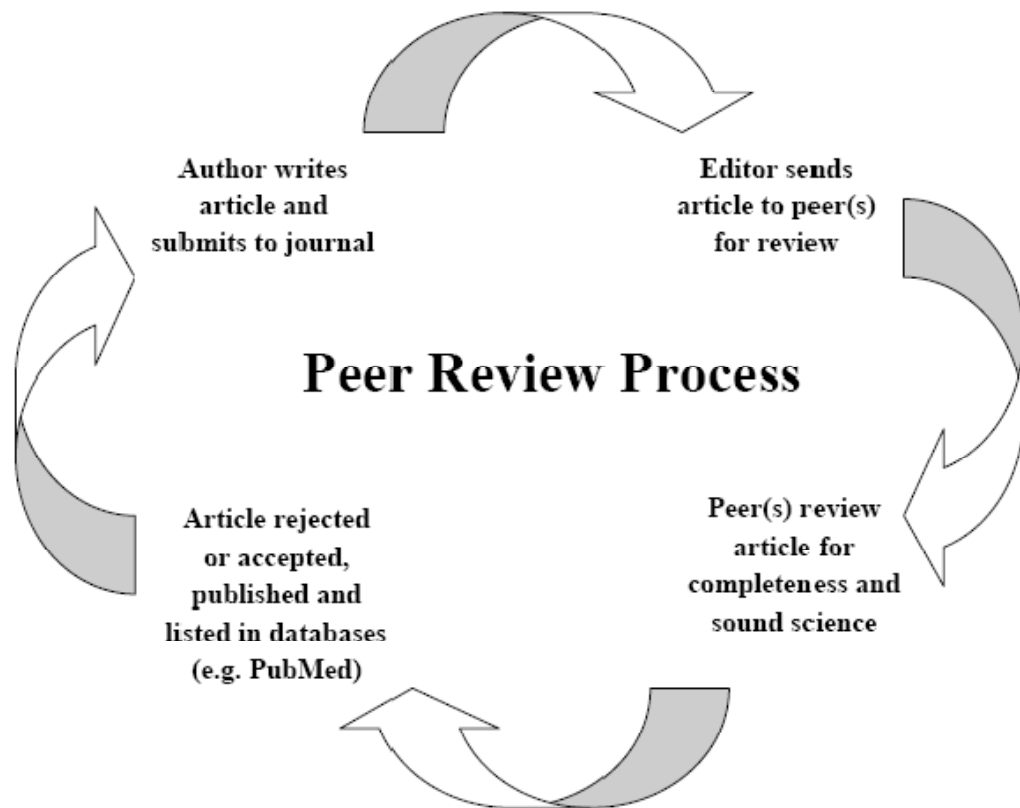


Figure 3. Peer Review Process

A thorough and complete peer review gives the reader some confidence that the article meets appropriate scientific rigor. Seldom does an article submitted for publication get accepted without addressing issues brought to light in the peer review process. At one point in time, “publication” of a scientific work in a peer-reviewed journal was a stamp of quality; however, in today’s world, opinions, ideas, and hypothesis can be “published” by a number of methods (websites, blogs, and media articles), without the scientific rigor of critical peer review.

The key aspect of the peer review is a critical appraisal of the research, a continuous challenge of the scientific hypothesis and comparison with the body of scientific knowledge relevant to

that research. While the process can never be totally free of bias (we all have opinions that influence our thinking), a clear effort to seek out those who are not directly connected to the researcher(s) is an important first step. The second part of the review process and assessment of the scientific merit of the research is the publication of the research so that others interested in the topic can benefit from the knowledge, apply it in their research efforts, or learn from the mistakes of other researchers. Opinion pieces, media interviews, court testimony, and testimony before legislative bodies, while informative, do not have the weight, standing, or status of peer-reviewed published scientific work. Unfortunately, because of their high visibility, emotional nature, and understandability, these sources outside of the peer-reviewed journals are often perceived as being of high reliability without having the benefit of careful scrutiny and response from those most knowledgeable in the research field being discussed. For example, Dr. Nina Pierpont has received a considerable amount of attention regarding the upcoming publication of her book, *Wind Turbine Syndrome: A Report on a Natural Experiment*, which uses non-traditional references such as newspaper articles and television interviews. In addition, this book is apparently being published by a publishing company which will have only one published book (this one) and that consists of an editorial board of which Dr. Pierpont and her husband make up two of the members.

## Public Health Issues

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“Public Health” refers to the overall wellbeing of a group of people. The description of Public Health incorporates the science of identifying major effectors of health status of a population and taking measures to prevent disease, prolong life, and promote health through private, academic, governmental, and corporate efforts. A physician treats a patient and considers the family, whereas a public health professional “examines” populations and takes broader actions to improve the health of the individuals that make up the population. Public health efforts primarily focus on prevention rather than treatment of disease. The United Nations' World Health Organization defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.” This is a lofty goal to strive for, but if public health history is any indication of things to come, as we conquer the leading causes of disease, new diseases become more prominent.

There have been major successes in Public Health (e.g., smallpox eradication, control of malaria, nationwide immunization programs to prevent vaccine-preventable diseases, chlorination of municipal water supplies). However, for every public health accomplishment, there have been new health challenges related to lifestyle issues and changing health expectations. According to the U.S. Census Bureau, the final data for 2003 indicated that life expectancy at birth for the total population in America has reached an all-time high level of 77.5 years. This is up from 49.2 years at the turn of the 20th century. Record-high life expectancies were found for white females (80.5 years) and black females (76.1 years), as well as for white males (75.3 years) and black males (69.0 years). With this increase in life expectancy, there has also been an expectation of a life as free of health concerns as possible. Unfortunately, this public health progress has brought the realization of the health effects of the very activities that helped extend our lives (e.g. chlorination of drinking water, mercury-based preservatives in some vaccines).

Along with these advances has come the development of a very expansive information system called the internet, a growing environmental awareness, and a growing expectation of a long and

healthy life. The advances that have been made to support a growing and aging population have brought risks with them such as automobiles, massive highway systems, and large-city problems such as crime and pollution. These more familiar risks have been generally accepted or forgotten, but new risks are less tolerated. Herein lays the difficulty of public health today. Population growth and societal demands have pressured public health professionals to provide guidance in the assessment of risks of new technological advancements and to reduce or eliminate risk.

While assessing a level of risk may be done in a sterile, scientific fashion, assessing the acceptability of that risk level risk becomes a preference choice. A community may choose to accept a level of risk that an individual finds unacceptable. That discrepancy between community and individual acceptability moves the decision from a public health issue to a political and social decision. Public health can bring science to the discussion, but in the end, a decision that weighs all the factors must be made for the larger group as a matter of policy.

In addition to the debate over what levels of risk are acceptable or tolerable, there is also the pressure of clearly delineating between actual risks and perceived risks. Once the analysis of the risk assessment is completed, the responsibility of the risk manager is to explain to the public and all involved stakeholders. A common perception among risk assessors and managers is that individuals who have a lack of information or information that is distorted about a risk are often subjected to unreasonable fears (Vertinsky I. And Wehrung D. 1989). These fears typically are not calmed even when accurate information is provided and unfortunately many expect a level of certainty from science that is almost always impossible to achieve. Several identified risk perception factors have been found to dictate the acceptability of risk regardless of the presentation of science which quantifies and qualifies the actual risk (Table 1).

Table 1. Risk Perception Factors For the Acceptability of Risk

| <b>“Acceptable” Risk</b>       | <b>“Unacceptable” Risk</b>      |
|--------------------------------|---------------------------------|
| Controllable                   | Uncontrollable                  |
| Voluntary                      | Involuntary                     |
| Not Dread                      | Dread                           |
| Natural                        | Man-made                        |
| Beneficial                     | Of Little or No Benefit         |
| Immediate Effects              | Delayed Effects                 |
| Not Global Catastrophic        | Global Catastrophic             |
| Consequences Not Fatal         | Fatal Consequences              |
| Equitable                      | Inequitable                     |
| Affects Adults                 | Affects Children                |
| Low Risk to Future Generations | High Risk to Future Generations |
| Easily Reduced                 | Not Easily Reduced              |
| Risk Decreasing                | Risk Increasing                 |
| Doesn't Affect Me              | Affects Me                      |

Reference: (Slovic P. et al. 1982)

There are many examples in public health where the assessed risk of an event or environmental conditions is perceived differently than an interested segment of the population. In these situations, the public health officials must make the best decision they can using the scientific method. There comes a point where a decision must be made for the good of the largest segment of the population. The ramifications and effectiveness of these decisions are not always seen as positive from a historical perspective. Take for example the “Swine Flu” immunization program of 1976 under the Ford Administration. That program resulted in a segment of the immunized population developing Guillain-Barre Syndrome. The same sort of decision process is being carried out now as public health officials embark on a campaign to protect the population for an H1N1 Pandemic. Part of the analysis included an estimation of how many persons can be expected to develop Guillain-Barre Syndrome from the new vaccine.

Societal decisions, like Public Health decisions, must be made with the benefit of the best, most sound information. Few historical efforts to advance health or societal development have come without concerns from many segments of the population and a few that may be affected.



## Precautionary Principle

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Some groups and organizations have addressed the acceptability of risk by adopting a position or philosophy that when risk may exist, but the level of risk is in doubt, actions should be taken to avoid the risk much in tune with the idea that “if in doubt, don’t.” Similarly, a process potentially producing risk is “guilty until proven innocent.” This view is commonly referred to as the “precautionary principle.” While seemingly attractive, the precautionary principle fails to acknowledge that in reality, every human activity has risk, and the balance between the potential risk and the value of that activity depends on the individual.

The precautionary principle is an attempt to set a goal for environmental planning and response to perceived health threats based less on science and more on the social basis of the issue being examined. While the principle was developed during the discussion of environmental issues, it can be applied to any function of mankind and all our activities. It is a high standard to compare activities of the earth’s inhabitants based on social values and less on science. There are few arguments when a solid body of science has been amassed showing an association and meeting the criteria for “causation.” The difficulty arises when new discoveries and applications are evaluated on what effect they “could have” rather than on the scientific data obtained during their development and regulatory review. The philosophy of “new is not necessarily good” and the “fear of the unknown” result in an almost instant increased level of concern in a segment of most populations. This is partially due to the easy access to information provided by media and the internet, the risk aversion that has become prevalent in our society, and the pressures of our evolving societies. The precautionary principle should be applied in the light of the science of the day and with the understanding that no scientific study of a sample of the population can “prove” there is no association between a technology and a perceived health threat.

The precautionary principle has evolved in both the legal and social context to the point of being prominent in national and international treaty and agreements. While the principle incorporates an extremely cautious approach, it embodies concepts that we have embraced in

our daily lives e.g. “an ounce of prevention is worth a pound of cure,” “look before you leap,” and “better safe than sorry.” On an individual basis, the precautionary principle is relatively easy to apply, and the risk and benefit directly applies to the individual. Application of the precautionary principle at a community or national level involves societal decisions that may include legal, economic, and political aspects. The application of the scientific process and sharing of knowledge gained through scientific investigation can provide objective information to assist in these decisions. Science will reduce the uncertainty, but not eliminate it entirely. Society must decide what is an acceptable level of risk (e.g. allowing passengers to fly in airplanes without parachutes, allowing people to ride ferryboats without wearing lifejackets). Delineation and comparison of risk is a scientific process, but determination of acceptable risk is beyond the realm of science.

## **Background on Infrasound and Low Frequency Sound**

Sound is an energy generated by a source (e.g., bell), transmitted through a medium (e.g., air), and received by a receiver (e.g., human ear). Sound travels from the source in the form of waves or fluctuations of pressure within the medium. As the human ear detects these vibrating waves, they are translated into electrical signals that are transmitted to the brain for decoding.

Sound is perceived and recognized by its loudness (pressure) and pitch (frequency). The indicator of loudness is the decibel (dB), which is a logarithmic ratio of sound pressure level to a reference level.<sup>1</sup> With a logarithmic scale, sound levels from two or more different sources cannot be arithmetically added together to determine a combined sound level. Specifically, the dB is a logarithmic unit of measurement that expresses the magnitude of a physical quantity such as power or intensity relative to a specified reference level. Human hearing of sound loudness ranges between 0 dB (threshold of sound for humans) and 140 dB (very loud and painful sound for most humans) (NMCPHC 2009; NASD 1993) (Table 2). Not all sound pressures are perceived as being equally loud by the human ear due to the fact that the human ear does not respond equally to all frequencies. The frequency range of human hearing has been found to be between 20 Hz and 20,000 Hz for young individuals with a declining upper frequency range correlating with increasing age (Berglund B. et al. 1996). The frequency of sound is expressed in Hertz (Hz)<sup>2</sup> which is equal to 1 cycle per second. The sound perception, “hearing,” for humans is less sensitive to lower frequency (low pitch) and higher frequency (high pitch) sounds. As a result, the human ear can most easily recognize sounds in the middle of the audible spectrum, which is ideally between 1 kHz to 4 kHz (1,000 to 4,000 vibrations per second) (UNSW 2005). As a result, devices used to measure sound (sound meters<sup>3</sup>) are

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<sup>1</sup> Reference Level - A special value of a quantity expressing the degree of modulation of a recording medium, in terms of which other degrees of modulation are expressed, usually in decibels (IEC).

<sup>2</sup> Hertz (Hz) - A unit of frequency defined as the number of cycles per second (1 Hz equals 1 cycle per second). Hertz can be used to measure any periodic event within a sinusoidal context, such as radio and audio frequencies (IEC).

<sup>3</sup> Sound Level Meter – Instrument used for the measurement of sound level with a standard frequency weighting and a standard exponential time weighting (IEC).

designed with filters that have a response to frequency similar to human. The A scale is the most commonly used sound level filter and the sound pressure level is given in units of dB(A) or dBA. With the A weighting filter, the sound level meter is less sensitive to very high and very low frequencies. Sound measurements made on the C scale, which are linear over several octaves and suitable for subjective measurements of very high frequency sound levels, are expressed as dB(C) or dBC. Another weighting filter, the B scale, is a rarely used intermediate between the A and C scales (UNSW 2005).

Table 2. Human Sound Intensity Levels

| <b>Decibel Level (dB)</b> | <b>Source</b>   |
|---------------------------|---|
| 140                       | Threshold of pain: gunshot, siren at 100 feet                                 |
| 135                       | Jet take off, amplified music   |
| 120                       | Chain saw, jack hammer, snowmobile  |
| 100                       | Tractor, farm equipment, power saw  |
| 90                        | OSHA limit - hearing damage if excessive exposure to noise levels above 90 dB |
| 85                        | Inside acoustically insulated tractor cab                                     |
| 75                        | Average radio, vacuum cleaner   |
| 60                        | Normal conversation   |
| 45                        | Rustling leaves, soft music   |
| 30                        | Whisper   |
| 15                        | Threshold of hearing  |
| 0                         | Acute threshold of hearing  |

Reference: (NASD 1993)

In the 1930s, researchers Fletcher and Munson conducted experiments on the response of the human ear and the relationship between sound frequency and pressure (Fletcher H. and Munson WA. 1933). Fletcher and Munson developed curves to approximate this relationship which were then revised by the International Organization for Standardization (ISO) and are now referred to as Normal Equal-Loudness Level Contours. Hence, an equal-loudness contour is a measure of the sound pressure (dB) level required to cause a given loudness for a listener as a function of frequency (Hz) (Figure 2).

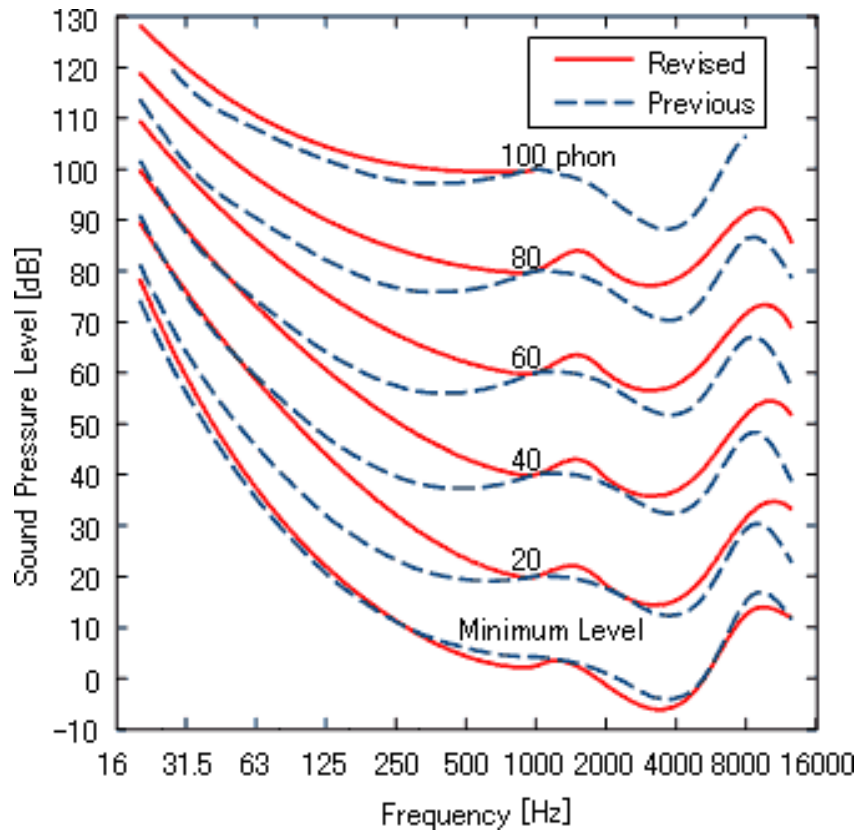


Figure 4. Normal Equal-Loudness Level Contours

## Infrasound

Infrasound is generally accepted to be sound between 0 Hz and 20 Hz (Leventhall G. 2007) (Table 3). Infrasound occurs when the frequency of acoustic oscillations (Hz) is lower than the low frequency limit of audible sound, which is approximately 16 Hz according to the International Electrotechnical Commission (IEC) (Leventhall 2007). Although the human hearing threshold has been found to be as low as 4 Hz in an acoustic chamber, a level of 20 Hz, arises from the lower frequency limit of the Normal Equal-Loudness Level Contours. At 1,000 Hz, the contour ranges a span of 100 dB, but at lower frequencies the contours are grouped more closely together. Thus, the change of grouping at 20 Hz or below leads to a greater rate of growth in loudness with increasing level for frequencies in the infrasound region (Leventhall G. 2007).

Although it has been believed that infrasound is inaudible, that belief has been determined to be a misconception (Berglund B. et al. 1996; Leventhall G. 2007; Maschke C. 2004). Infrasound at frequencies lower than 20 Hz are audible at very high levels and these sounds may occur from many natural sources, such as meteors or volcanic eruptions. Anthropogenic (i.e., human-caused) sources, which often are the predominant type of source, can also generate infrasonic noise and include machinery, ventilation, or large combustion processes (Berglund B. et al. 1996; Leventhall G. 2007; Sienkiewicz Z. 2007). In addition, the human body has multiple sources of sound. For example, heart sounds are in the range of 27 to 35 dB at 20-40 Hz (Sakai A. et al. 1971) and lung sounds are reported in the range of 5-35 dB at 150-600 Hz (Fiz JA. Et al. 2008).

The threshold of human hearing has been found to be well in the range of infrasound, but it has been suggested that detection does not occur through hearing in the normal sense. Infrasound detection has been theorized to result from nonlinearities of conduction in the middle and inner ear which produces a harmonic distortion in the higher frequency range (Berglund B. et al. 1996). Also, the definition of infrasound detection has not only considered direct hearing, but also subjective reactions such as annoyance as well as detection occurring through the resonance of other body organs (Berglund B. et al. 1996).

Table 3. Sound Frequency Spectrum

| <b>Frequency (Hz)</b>                  |            |                        |                                       |               |
|--|------------|------------------------|---------------------------------------|---------------|
| <b>0</b>                               | <b>10</b>  | <b>20</b>              | <b>100/250</b>                        | <b>20,000</b> |
| Infrasound<br>(With Body<br>Resonance) | Infrasound | Low Frequency<br>Sound | Non-Low Frequency<br>Audible<br>Sound | Ultrasound    |

### **Low Frequency Sound<sup>4</sup>**

The low frequency sound range is approximately between 10 or 20 Hz and 100 or 250 Hz (Berglund B. et al. 1996). The setting of a lower and upper limit of a continuum has been

<sup>4</sup> The word “sound” and “noise” are terms that can be used interchangeably. “Noise” often implies an unwanted sound. The use of “noise” also depends on the intensity of the sound or the complex temporal pattern. The classification of a “sound” or “noise” may also depend of cultural factors, the individual, or the time and circumstance (Berglund B. et al. 1996).



problematic due to the arbitrary nature of setting those limits. However, it has generally been accepted that low frequency sound is below 100 Hz (Takahashi Y. et al. 2005) or 200 Hz (Maschke C. 2004). Due to the long wavelengths of low frequency noise, it has been known to travel long distances and pass through walls and windows with little attenuation (Waye K. 2004).

With respect to reception, the hearing sensitivity of the human ear declines at low frequencies (Takahashi Y. et al. 2005). Occupational and residential activities have been found to be a common source of low frequency sound (Berglund B. et al. 1996). Many sources of low frequency noise are transportation vehicles such as buses, trains, and some aircraft. Other stationary sources of low frequency noise include heating, cooling, or ventilation of buildings (Waye K. 2004). Low frequency sound possesses features that are not commonly shared by higher pitch noises.

A review of the literature related to sound indicates that there are uncertainties associated with the measurement and characterization of low frequency sound. As mentioned previously, the A scale is the most commonly used sound level filter (Sienkiewicz Z. 2007; Takahashi Y. et al. 2005; Takahashi Y. et al. 2001; Takahashi Y. et al. 1999). Furthermore, it was recommended that either a scale with a more appropriate response be developed and used for characterizing low frequency sound or that the details of the acoustic environment be provided for each exposure scenario (Sienkiewicz Z. 2007).

As mentioned previously, human hearing becomes less sensitive for decreasing frequency. In addition to the sensitivity of sound, the perceived character of that sound also changes at lower frequencies. The threshold<sup>5</sup> for hearing is standardized by ISO for frequencies down to 20 Hz, but there has been research and some agreement among investigators regarding a possible threshold for frequencies below this level (Moller H. and Pedersen CS. 2004). Men and women have the same hearing threshold with the standard deviation between individuals being

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<sup>5</sup> Threshold - For a specified signal and method of presentation, amount in decibels by which the threshold of hearing for a listener, for either one or two ears, exceeds a specified standard threshold of hearing (IEC).

approximately 5dB. Furthermore, low frequency sound may be inaudible to some, but that same sound may be loud to others.

## **Background on Wind Turbines and Noise**

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There are two types of noise generated from wind turbines. One is a mechanical noise originating from the gearbox, generator, and yaw motors. The other type of noise, aerodynamic noise, originates from the flow of air around the components of the wind turbine (blades and tower) produces a “whooshing” sound in the range of 500 to 1000 Hz (Hau E. 2006). This type of noise is typically the dominant component of wind turbine noise because manufacturers have been able to reduce the mechanical noise to a level that is below the aerodynamic noise (Pedersen E. and Waye KP. 2004). However, the whooshing sound is highly variable and dependent upon mechanical as well as atmospheric conditions. Hence, the sound power levels reached by wind turbines are determined by the mechanical and aerodynamic specifications.

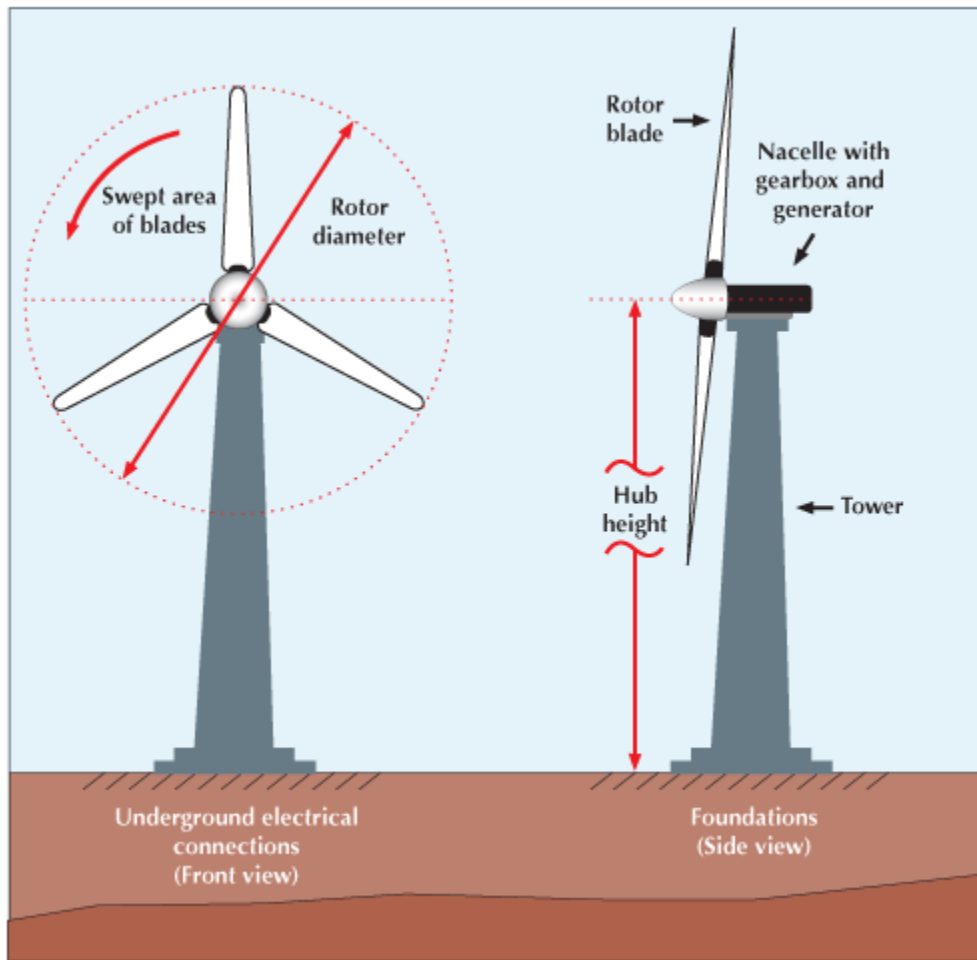


Figure 5. Horizontal Axis Wind Turbine

# Evaluation of Scientific Literature on Health Effects

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A thorough search was performed of the peer-reviewed scientific literature using the PubMed<sup>6</sup> search engine which is maintained by the United States National Library of Medicine. The purpose of the search was to identify literature that has addressed the known or unknown health effects associated with infrasound and low frequency sound. The following search criteria terms were used for each search query with some overlapping results.

Table 4. Literature Search Queries

| Search Query                           | Number of Articles Found |
|--|--------------------------|
| Infrasound AND Health Effects          | 16                       |
| Low-Frequency Noise AND Health Effects | 59                       |
| Low-Frequency Sound AND Health Effects | 40                       |
| Wind Power AND Noise                   | 18                       |
| Wind Turbines                          | 20                       |
| Wind Turbines AND Noise                | 3                        |
| <b>Total</b>                           | <b>156</b>               |

In 2003, the U.S. Environmental Protection Agency (EPA) published a document entitled “A Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information” which outlined general assessment factors to evaluate the quality and relevance of scientific and technical information (U.S. EPA 2003). The assessment factors include (1) soundness; (2) applicability and utility; (3) clarity and completeness; (4) uncertainty and variability; and (5) evaluation and review. These factors use a weight-of-evidence approach that considers the information provided in an integrative assessment. These factors also take into account the quality and quantity as well as the strengths and weaknesses of the information. These EPA guidelines were used to evaluate the articles identified in this literature search.

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<sup>6</sup> Pub Med is a searchable database that comprises more than 19 million citations for biomedical articles from MEDLINE and life science journals.

## Applicability and Utility

*The extent to which the information is relevant for the intended use, or how relevant the study is to current conditions of interest (U.S. EPA 2003).*

With each identified article, the research and research subjects were ranked as a whole based on the applicability to the overall purpose of the literature search. The following ranking system was employed, and then we eliminated articles with a rank of one or two from further review (Table 6). These ratings and those used in later tables were also used in the appendix. Although it has been found in animal experiments, during the last 50 years, that high levels of low frequency noise and vibration can influence the respiratory rate, cardiac, digestive and central nervous systems, (Maschke C. 2004) animal studies were not reviewed in this white paper. At this time only human studies were reviewed and evaluated, which also eliminated articles with a rank of three. It was assumed that animal studies would not provide the necessarily applicability to effects of wind turbines on humans, thus resulting in an extrapolation layered with assumptions. Articles that were not written in the English language were also eliminated. Background research consisted of articles that reviewed infrasound and low frequency sound in general.

Table 5. Applicability and Utility Ranking System

| <b>Rank</b> | <b>Rank Description</b>                                |
|-------------|--|
| 1           | No applicability at all                                |
| 2           | Limited applicability (e.g. <i>in vitro</i> studies)   |
| 3           | Some applicability (e.g. animal studies)               |
| 4           | Applicable (e.g. human studies)                        |
| 5           | Very applicable (e.g. human studies and wind turbines) |
| **          | Background research                                    |



## Soundness

*The extent to which the scientific and technical procedures, measures, methods or models employed to generate the information are reasonable for, and consistent with, the intended application (U.S. EPA 2003).*

The articles were evaluated based on whether or not the study purpose was reasonable and consistent with its design. If articles did not employ sound scientific theory or accepted approaches, such as the use of an adequate sample size or the validation of a survey instrument, they were graded accordingly.

Table 6. Soundness

| <b>Rank</b> | <b>Rank Description</b>  |
|-------------|--|
| 1           | Not sound (e.g. study instrument not validated)                              |
| 2           | Sound with limitations (e.g. useful research but not consistent with design) |
| 3           | Very sound (e.g. study reasonable and consistent with design)                |
| **          | Background research  |

## Clarity and Completeness

*The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information are documented (U.S. EPA 2003).*

Articles were assessed for clarity and completeness and whether or not the results were clearly described and comparable to other study results. The description of the study design and methods was also assessed to determine if the description was clear enough for reproducibility.

Table 7. Clarity and Completeness

| <b>Rank</b> | <b>Rank Description</b>                            |
|-------------|--|
| 1           | Several limitations                                |
| 2           | Complete with some limitations                     |
| 3           | Very complete (e.g. clear enough to be reproduced) |
| **          | Background research                                |

## Uncertainty and Variability

*The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods or models are evaluated and characterized (U.S. EPA 2003).*

The level of uncertainty and variability of the study methodology and results and how these uncertainties were handled were also evaluated. Potential sources of error and study bias were considered as well.

Table 8. Uncertainty and Variability

| <b>Rank</b> | <b>Rank Description</b>            |
|-------------|------------------------------------|
| 1           | High uncertainty and variability   |
| 2           | Medium uncertainty and variability |
| 3           | Low uncertainty and variability    |
| **          | Background research                |

## Evaluation and Review

*The extent of independent verification, validation and peer review of the information or of the procedures, measures, methods or models (U.S. EPA 2003).*

Independent verification was measured by whether or not the methodology used and survey instruments were used on other similar, peer-reviewed studies. The consistency of the results with other relevant studies performed by the same or different authors was also accounted for in this analysis.

Table 9. Evaluation and Review

| <b>Rank</b> | <b>Rank Description</b>  |
|-------------|--|
| 1           | Low validation (e.g. no independent verification or similar results) |
| 2           | Medium validation (e.g. result consistent with same author)          |
| 3           | High validation (e.g. results consistent in peer-review literature)  |
| **          | Background research  |

## **Final Included Literature**

Of the original 156 articles identified, 21 were included for the literature review (Appendix A). Based on the previously outlined five assessment factors, the most relevant and scientifically appropriate articles were selected for this review. Many articles were excluded from this review due to the fact that the research focused in animal responses as opposed to human. Furthermore, with the exception of articles dealing with annoyance, articles were excluded if the sound studied was above the established range of low frequency sound.

# **Health Effects of Infrasound and Low Frequency Sound**

## **Human Effects**

It has been demonstrated that high levels of low frequency sound can excite body vibrations, such as a chest resonance vibration that can occur at a frequency of 50 Hz to 80 Hz (Leventhall G. 2007). These chest wall and body hair vibrations have also been shown to occur at the infrasonic range (Mohr GC. et al. 1965; Schust M. 2004). It is of interest to note that various body organs and physical activities of the human body produce low frequency, low amplitude sounds, some of which are key diagnostic tools for physicians (e.g., heart, lung, and gastrointestinal).

Vibroacoustic disease, a thickening of cardiovascular structures, such as cardiac muscle and blood vessels, was first described and documented by Castelo Branco *et al.* among airplane technicians, commercial and military pilots, mechanical engineers, restaurant workers, and disc jockeys for exposure to large pressure amplitude and low frequency (LPALF) sound ( $> \text{ or } = 90 \text{ dB SPL, } < \text{ or } = 500 \text{ Hz}$ ) (Maschke C. 2004; Castelo Branco NA. and Rodriguez E. 1999). Castelo Branco *et al.* concluded that workers who were exposed to high level low frequency noise for more than 10 years exhibited extra-aural<sup>7</sup> symptoms such as thickening of heart valve issue (Castelo Branco NA. and Rodriguez E. 1999; Takahashi Y. et al. 2001; Maschke C. 2004). However, this association was not determined to be causally related and a dose response relationship was not established.

Takahashi *et al.* has explored the effects of acoustic excitation by measuring the resulting vibration (Takahashi Y. et al. 1999; Takahashi Y et al. 2001; Takahashi Y. et al 2005). In 1999, six male subjects were exposed to pure tones in the 20 Hz to 50 Hz frequency range, and vibration was measured on the subjects' chest and abdomen. There were 15 kinds of the low frequency noise stimuli (5 frequencies x 3 sound pressure levels) reproduced by loud speakers.

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<sup>7</sup> Aural - Of or relating to the ear or to the sense of hearing

All of them were pure tones frequencies of 20, 25, 30.5, 40 and 50 Hz with each of the corresponding sound pressure levels of 100,105 and 110 dB (SPL).

It was found that measured noise induced vibration negatively correlated with the subject's body mass index and the researchers concluded that the health effects of low frequency noise depended on the physical constitution of the human body (Takahashi Y. et al. 1999). However, it was also concluded by the researchers that it was still unknown if or how vibrations measured on the body surface related to vibrations in the body's internal organs, and that no conclusions could be determined as to the possible chronic health effects caused by long term exposure to low frequency noise (Takahashi Y. et al. 1999). Similarly, in a later article, Takahashi *et al.* reported that low frequency noise (same frequency and sound pressure levels as previously reported) induced vibration measured on the chest was higher than the vibration measured on other parts of the body (Takahashi Y. et al. 2001). By taking this research a step further; Takahashi *et al.* examined the level of unpleasantness of human body vibration and low frequency sound (same frequency and sound pressure levels as previously reported). It was found through the use of a rough rating scale for subjective unpleasantness that there was a significant correlation between the measured body surface vibration induced by the low frequency noise and the rating of unpleasantness (Takahashi Y. et al. 2005). This finding was similar to research conducted by Inukai *et al.*, who discovered that the slopes of the equal-unpleasantness level contours are very similar to those of the equal-loudness level contours. This similarity supported the fact that hearing sensation was an influential component in the perception of unpleasantness or annoyance among those exposed to low frequency noise (Inukai Y. et al. 2000; Takahashi Y. et al. 2005). This perception of unpleasantness was also determined to be independent of the audibility of the noise (Takahashi Y. et al. 2005). Inukai *et al.* also recognized the fact that the human psychological responses to low frequency noise, such as unpleasantness or annoyance, were based not only on hearing sensation, but also on three other factors: sound pressure, vibration, and loudness (Inukai Y. et al. 1986; Takahashi Y. et al. 2005).

In a general review of the effects of low frequency noise up to 100 Hz, Schust stated that the use of frequency weighting with an attenuation of low frequencies, such as G-weighting, was not appropriate for evaluating the health risk caused by low frequency noise (Schust M. 2004). Karprova *et al* (1970) ((5, 10 Hz / 100, 135 dB) for 15 minutes) and Slarve *et al.* (1975) (144 dB / 1 Hz - 20 Hz for 8 minutes) also indicated that study subjects reported aural complaints after exposure to high level industrial infrasound in the range of 1 Hz to 20 Hz (Karprova NI. et al. 1970; Schust M. 2004; Slarve RN. and Johnson DL. 2009). Non-aural effects, such as a significantly increased diastolic blood pressure and decreased systolic blood pressure, were also mentioned after exposure to high levels of low frequency noise (125 dB, 16 Hz for 1 hour) (Danielsson A. and Landstroem U. 1985; Schust M. 2004). Karprova *et al* also reported complaints of fatigue, feelings of apathy, loss of concentration, somnolence, and depression following exposure to high levels of low frequency noise (5 Hz and 10 Hz (100 dB and 135 dB) for 15 minutes) (Karprova NI. et al. 1970; Schust M. 2004). Furthermore, the effects of low frequency noise among 439 employees working in offices, laboratories, and industries were also evaluated in another study. It was shown that there was a relationship between fatigue and tiredness after work and increasing low frequency noise. There were no employees that were exposed to low frequency noise with C-A differences greater than 20 dB (Schust M. 2004; Tesarz M. et al. 1997).

Ising *et al.* conducted a study that examined the effect of low frequency nighttime traffic noise by measuring saliva cortisol concentrations in children. Based on a previous study, the authors stated that the full spectrum of truck noise in the children's bedroom was at a maximum of 100 Hz (Ising H. et al. 2004; Ising H. and Kruppa B. 2004). It was found that the children under high noise exposure (8h = 54-70dB(A)) had a significantly increased morning saliva cortisol concentration compared to a control population, which indicated an activation of the hypothalamus-pituitary-adrenal (HPA) axis (Ising H. et al. 2004). This endocrine change was found to be an indication of restless sleep and a further aggravation of bronchitis in the children.

Finally, in 2000, a multidisciplinary group of clinicians and researchers called the Study Group on Neonatal Intensive Care Unit (NICU) Sound and the Expert Panel gathered and reviewed



over 50 studies on the effects of sound on the fetus, newborn, and preterm infants. Upon the completion of review, the panel recommended that women should avoid prolonged exposure to low frequency sound levels (< 250 Hz) above 65 dB(A) during pregnancy (Graven SN. 2000). This recommendation was based on research that was conducted on sheep fetuses, which determined that after sustained periods of intense low frequency sound, the fetuses experienced injury to the hair cells of cochlea (Graven SN. 2000).

There have been some studies that have looked at the effect of low frequency noise on nighttime sleep (Maschke C. 2004). Unfortunately, for many of these studies, it was difficult to determine what percentage of the nightly noise was actually low frequency noise. Case studies have reported that low frequency noise (low-frequency noise reaching levels between 72 and 85 dB(A)) affects sleep quality and results in insomnia and concentration problems (Berglund B. et al. 1996; Waye K. 2004). A cross-sectional study of 279 individuals, it was determined that there were no significant differences detected in reported sleep among those exposed to flat frequency noise (>100 Hz; 24 to 33 dBA and 41 to 49 dBC) in their homes as compared to low frequency noise (50 Hz – 200 Hz; 26 to 36 dBA and 49 to 60 dBC) from ventilation and heat pumps (Persson Waye K. and Rylander R. 2001; Waye K. 2004). However, it was determined that fatigue, difficulty falling asleep, feeling tense and irritable were reported significantly more often among those individuals who were annoyed by low frequency noise than those who were exposed to the same noise but did not report being annoyed. Additionally, a dose-response relationship was identified between reported annoyance/disturbed rest and degree of low frequency noise before and after correction for differences in A-weighted sound pressure levels (Persson Waye K. and Rylander R. 2001; Waye K. 2004). In another study, six individuals were exposed to sinusoidal tones as 10, 20, 40, and 63 Hz with sound pressure levels ranging from 75 to 105 dB for 10 Hz and 20 Hz and 50 to 100 dB for 40 Hz and 63 Hz. No significant difference was found between the exposure and control nights in sleep efficiency index, number of changes in sleep state, or changes in the proportion of each sleep stage evaluated by electroencephalogram recordings (Inaba R. and Okada A. 1988; Waye K. 2004).

## Annoyance

The World Health Organization (WHO) definition of the adverse effects of noise is as follows:

*Change in the morphology and physiology of an organism that results in impairment of functional capacity to compensate for additional stress, or increases in the susceptibility of an organism to the harmful effects of other environmental influences. Includes any temporary or long-term lowering of the physical, psychological or social functioning of humans or human organs (WHO 2001).*

An earlier definition of annoyance was "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them" (Koelega HS.(ed.) 1987; Lindvall T. and Radford EP.(eds.) 1973; WHO 1999). The WHO considers annoyance an adverse health effect of noise in addition to sleep disturbance, performance effects, and psychological effects such as irritability (WHO 2001). Annoyance was also defined as a feeling of displeasure with varying tolerance levels. WHO also characterized annoyance as a feeling that increases with noise impulses as opposed to a steady noise (WHO 2001).

As specifically related to low frequency noise generated from wind turbines, Pedersen *et al.* noted a dose response relationship between calculated A-weighted sound pressure levels from wind turbines and noise annoyance in a cross-sectional study that was conducted in five dwelling areas in Sweden. It was determined that the study respondents were annoyed by the wind turbines at a higher level than other community noises, such as road traffic (Pedersen E. and Waye KP. 2004). It was also found the noise annoyance was related to visual or aesthetic interference, and attitude or sensitivity toward to wind turbine (Pedersen E. and Waye KP. 2004). Importantly, it should be noted that the Swedish wind turbines were all upwind devices which had a blade passage frequency of 1.4 Hz, but unlike earlier downwind turbines which contained low frequency noise, these turbines had upwind rotor blades and the noise was much more broadband (Pedersen E. and Waye KP. 2004).

In addition to annoyance, the relationship between wind turbine noise and self-reported health and well-being factors was also researched by Pedersen *et al.* It was confirmed that there was no correlation between A-weighted sound pressure levels from wind turbines and any health or

well-being factors, such as the respondent's status of chronic disease, diabetes, or cardiovascular disease (Pedersen E. and Persson, Waye K. 2007). However, among the 31 respondents who stated that they were annoyed by the wind turbine noise, out of 754 respondents, 36% reported that their sleep was disturbed and 19% reported being tired (Pedersen E. and Persson, Waye K. 2007). Both of these findings were statistically significantly higher in comparison to those respondents who were not annoyed. Recall bias is likely to occur among annoyed individuals, and it is not apparent that this bias was considered in this study. Furthermore, Pedersen *et al.* also identified that living in a rural area, as opposed to an urban area, increased the risk of perceiving wind turbine noise and being annoyed by it (Pedersen E. and Persson, Waye K. 2007).

The underlying complaint of annoyance is, in and of itself, not a disease or a specific manifestation of a specific exposure, but instead a universal human response to a condition or situation that is not positively appreciated by the human receptor. The variability of annoyance and its link to undesirable factors makes it a prime indicator for the possibility of recall bias. Annoyances are highly variable in types (noise, smell, temperature, taste, vision) and vary from person to person. One can be annoyed by the action of others as well as their own individual actions. Thus “annoyance” is not a disease but a human response that is highly non-specific.

## **Disease vs. DIS-ease**

The state of being in which individuals are uneasy, agitated or without (“dis”) freedom from labor, pain, anxiety or physical annoyance (“ease”) can often be undistinguishable from the state of disease as related to morbidity. Both states of being can be assessed objectively and subjectively. However, with physical illnesses, objective measureable indicators can be obtained through instrumentation testing that is typically absent of human error or influence. Subjective responses to stimuli are much harder to prove or disprove which is why it is very important to supplement a subjective response with an objective assessment.

## Limitations of Scientific Literature

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The research and scientific literature on the human health effects of low frequency noise exposure are limited. Most researchers have agreed that there are some uncertainties associated with the measurement and characterization of low frequency sound. The most important limitation of the current research involves the use of the A-weight scale. The WHO and other researchers have stated that the conventional method of using an A-weighted equivalent sound level may be inadequate for low frequency noise. There are other researchers who advocate that the current research using various weighted measures is sufficiently robust to be depended upon for the evaluation of the potential for sound related health effects. As a result of these diverse opinions, biased or conflicting conclusions may have been made about the level of low frequency sound and its human health effects.

Another significant limitation of the current research is the use of a small number of subjects or those with prejudicial views of wind turbines. Although it was noted in some studies that the questionnaires used were masked, it was quite possible the participants still had negative or unfavorable attitudes about the wind turbines and the low frequency noise that was generated. The presence of wind turbines has instigated heightened levels of annoyance and NIMBY (*Not In My Back Yard*) attitudes by the nearby residents. With such levels of annoyance and discontent, it is very plausible that the associated anxiety can engender health effects or amplify already existing health conditions. It would be beneficial to examine the health effects of low frequency noise among residents that did not experience the annoyance of the presence of wind turbines. There are health effects and adverse health effects and it is important to differentiate the between the two types of effects.

A common effect that has been observed with low frequency noise is vibration. Although the effects of low frequency noise and vibration have not been well characterized, objective body vibration results only from very high levels of low frequency noise, greater than those produced by wind turbines. Sleeplessness and insomnia have also been associated with low frequency

noise, but this finding has been poorly correlated and lacking in consistency. However, the level of annoyance with low frequency noise was found to be correlated with insomnia.

## Conclusions

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Noise exposures outside the workplace have not been studied as extensively as those that occur in the workplace. There have been pockets of research centering on population exposures to highway traffic noise, noise exposures associated with living near commercial airports, and a scattering of other community noise sources, but there is not an extensive amount of research specifically on the health effects related to the sound exposure generated by wind turbines. However, wind turbines have been used in the U.S. since the late 1800s that has provided a baseline of knowledge and experience of their usage and presence in American lives. The first windmill for electricity production in the United States was built in Cleveland, Ohio by Charles Brush (Windpower.org 2003). In addition, wind turbines have continued to evolve (e.g. vertical to horizontal designs, downwind to upwind blade positioning and numerous sound reduction design changes with the mechanics of the turbine.) This evolution of design and the use of improved technology have resulted in quieter and more efficient wind turbines. Possibly the biggest change beyond these design changes is the trend to build more wind farms.

The implementation of wind turbines has resulted in a steadily growing population of individuals who live in their geographical and visual proximity. The literature clearly delineates a subset of this population that is annoyed by the nearby presence of wind turbines, but there has not been a specific disease or condition that has been found by the research community to be caused by the wind turbines. However, there have been illnesses, symptom complexes, and other health events attributed to wind turbines. This is to be expected given the circumstances and emotions that often surround the presence of wind turbine farms. This is a common phenomenon that is associated with activities that are perceived as a social disruption or infringement on personal rights or freedom.

The literature, both scientific and lay, clearly indicates the diversity of concerns regarding the presence of wind turbines near residences and communities. The science of sound is robust and has identified a number of health-related links to high level industrial sound in the workplace. This same science has not identified a causal link between any specific



health condition and exposure to the sound patterns generated by wind turbines of the type used today, perhaps because they generate far lower decibel levels than most vocational sources. However, the same science has determined that there is a range of sounds (some would say noise) that is clearly described by some as annoying. The process of being annoyed is a universal response that is not specific to wind turbines. The nonspecificity of annoyance leads to confusion and concern that the peer reviewed published scientific literature has not been able to adequately clarify. It appears that the scientific process of research and discussion before acceptance of new principles, or redefinition of previously accepted principles, has to some extent gotten caught up in rush of the lay media. Jumping from observations and speculation to cause and effect has been the result of this rush. This type of short cut has historically led to misdirection of resources and efforts.

The subjective nature of annoyance makes the job of epidemiological investigation difficult due to the biases that this subjectivity brings to any study. One cannot assess the level of effect of an activity by analyzing the experience and perceptions of those who are annoyed, without an appropriate comparison group and study design that reduces or delineates the biases that commonly hamper studies of emotionally-charged activities such as the positioning of wind turbines.

Believing without question can lead to positions of unnecessary vulnerability. It is often stated that the best advocate for a patient's rights, well-being and infallible medical care is the actual patient. Therefore, second medical opinions are often highly recommended despite who is giving the first opinion or what that opinion may be. Likewise, the rush to accept opinions without an adequate scientific or medical basis (e.g. objective medical tests) may actually lead to adverse health outcomes originating from the perception of health effects. From the positive perspective, there can be a healing effect or belief, as in the "placebo effect", which is often a key part of a medical encounter. Unfortunately, the reverse can also occur in the situation where a person is given "bad health news" that is unfounded or incorrect and person actually becomes physically and/or emotionally ill. It

is a delicate balance that must be maintained as health care professionals and public health officials weigh the science in making decisions.

Based on the literature review that was conducted for this white paper, there was not any scientifically peer-reviewed information found demonstrating a link between wind turbines and negative health effects.

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## **Appendix A**

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### **Final Literature**

| List #  | Year | Author                   | Title   | Journal                         | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|---|------|--------------------------|---|---------------------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| <b>Search Term: Infrasound AND Health Effects</b> |      |                          |   |                                 |           |                           |                          |                             |                       |                |
| 1   | 2007 | Sienkiewicz Z.           | Rapporteur report: Roundup, discussion and recommendations.   | Prog Biophys Mol Biol.          | **        | **                        | **                       | **                          | **                    |                |
| 2   | 2007 | Leventhall G.            | What is infrasound?   | Prog Biophys Mol Biol.          | **        | **                        | **                       | **                          | **                    |                |
| 3   | 2004 | Feldmann J. et al.       | Effects of low frequency noise on man--a case study.  | Noise Health.                   |           | 4                         |                          |                             |                       | x              |
| 4   | 1999 | Pawlaczyk-Luszczyńska M. | Evaluation of occupational exposure to infrasonic noise in Poland.  | Int J Occup Med Environ Health. |           | 4                         |                          |                             |                       | x              |
| 5   | 1996 | Pawlaczyk-Luszczyńska M. | Infrasound in the occupational and general environment: a three-element microphone measuring method for locating distant sources of infrasound. | Int J Occup Med Environ Health. |           | 4                         |                          |                             |                       | x              |

| List #   | Year | Author             | Title   | Journal              | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|--|------|--------------------|---|----------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| <b>Search Term: Low-Frequency Noise AND Health Effects</b> |      |                    |   |                      |           |                           |                          |                             |                       |                |
| 6  | 2005 | Hori K. et al.     | Influence of sound and light on heart rate variability  | J Hum Ergol (Tokyo). |           | 4                         |                          |                             |                       | x              |
| 7  | 2005 | Takahashi Y et al. | A study on the relationship between subjective unpleasantness and body surface vibrations induced by high-level low-frequency pure tones. | Ind Health.          | 2         | 4                         | 2                        | 2                           | 2                     |                |
| 8  | 2004 | Schust M. et al.   | Effects of low frequency noise up to 100 Hz   | Noise Health.        | **        | **                        | **                       | **                          | **                    |                |
| 9  | 2004 | Ising H. et al.    | Low frequency noise and stress: bronchitis and cortisol in children exposed chronically to traffic noise and exhaust fumes                | Noise Health.        | 1         | 4                         | 1                        | 1                           | 2                     |                |

| List # | Year | Author             | Title  | Journal                   | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|--------|------|--------------------|--|---------------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| 10     | 2002 | Silva MJ. et al.   | Low frequency noise and whole-body vibration cause increased levels of sister chromatid exchange in splenocytes of exposed mice. | Teratog Carcinog Mutagen. | 2         | 3                         | 2                        | 1                           | 1                     |                |
| 11     | 2001 | Takahashi Y et al. | A new approach to assess low frequency noise in the working environment  | Ind Health.               | 2         | 4                         | 1                        | 2                           | 1                     |                |
| 12     | 2000 | Graven SN.         | Sound and the developing infant in the NICU: conclusions and recommendations for care  | J Perinatol.              | **        | **                        | **                       | **                          | **                    |                |
| 13     | 1999 | Silva MJ. et al.   | Sister chromatid exchange analysis in workers exposed to noise and vibration   | Aviat Space Environ Med.  |           | 4                         |                          |                             |                       | x              |
| 14     | 1999 | Alves-Pereira M.   | Noise-induced extra-aural pathology: a review and commentary   | Aviat Space Environ Med.  |           | 4                         |                          |                             |                       | x              |



| List #   | Year | Author             | Title  | Journal               | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|--|------|--------------------|--|-----------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| 15   | 1999 | Takahashi Y et al. | A pilot study on the human body vibration induced by low frequency noise   | Ind Health.           | 2         | 4                         | 2                        | 2                           | 1                     |                |
| 16   | 1996 | Berglund B. et al. | Sources and effects of low-frequency noise.  | J Acoust Soc Am.      | **        | **                        | **                       | **                          | **                    |                |
| 17   | 1993 | Seidel H.          | The problem of a "vibration disease" caused by low-frequency whole-body vibration (wbv) is critically discussed.                             | Am J Ind Med.         | **        | **                        | **                       | **                          | **                    |                |
| <b>Search Term: Low-Frequency Sound AND Health Effects</b> |      |                    |  |                       |           |                           |                          |                             |                       |                |
| 18   | 2008 | Carrubba S. et al. | The effects of low-frequency environmental-strength electromagnetic fields on brain electrical activity: a critical review of the literature | Electromagn Biol Med. |           | 4                         |                          |                             |                       | x              |

**Search Term: Wind Power AND Noise**

| List # | Year | Author               | Title   | Journal          | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|--------|------|----------------------|---|------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| 19     | 2005 | Shields FD.          | Low-frequency wind noise correlation in microphone arrays   | J Acoust Soc Am. | **        | **                        | **                       | **                          | **                    |                |
| 20     | 2004 | Pedersen E. et al.   | Perception and annoyance due to wind turbine noise--a dose-response relationship                                | J Acoust Soc Am. | 3         | 5                         | 5                        | 2                           | 3                     |                |
| 21     | 1998 | Munro KJ. et al.     | Are clinical measurements of uncomfortable loudness levels a valid indicator of real-world auditory discomfort? | Br J Audiol.     |           | 4                         |                          |                             |                       | x              |
| 22     | 1992 | McConnell SO. et al. | Ambient noise measurements from 100 Hz to 80 kHz in an Alaskan fjord.   | J Acoust Soc Am. | **        | **                        | **                       | **                          | **                    |                |

**Search Term: Wind Turbines**

|    |      |                   |  |            |    |    |    |    |    |  |
|----|------|-------------------|--|------------|----|----|----|----|----|--|
| 23 | 2008 | Harding G. et al. | Wind turbines, flicker, and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them | Epilepsia. | ** | ** | ** | ** | ** |  |
|----|------|-------------------|--|------------|----|----|----|----|----|--|

| List # | Year | Author             | Title   | Journal            | Soundness | Applicability and Utility | Clarity and Completeness | Uncertainty and Variability | Evaluation and Review | Did Not Review |
|--------|------|--------------------|---|--------------------|-----------|---------------------------|--------------------------|-----------------------------|-----------------------|----------------|
| 24     | 2007 | Pedersen E. et al. | Wind turbine noise, annoyance and self-reported health and well-being in different living environments. | Occup Environ Med. | 3         | 5                         | 5                        | 2                           | 3                     |                |

**Search Term: Wind Turbines AND Noise**

ALREADY INCLUDED IN OTHER SEARCHES

**Other articles found in *Noise and Health***

|    |      |                   |   |                  |    |    |    |    |    |  |
|----|------|-------------------|---|------------------|----|----|----|----|----|--|
| 25 | 2004 | Waye K.           | Effects of low frequency noise on sleep.  | Noise and Health | ** | ** | ** | ** | ** |  |
| 26 | 2004 | Moller H. et al.  | Hearing at low and infrasonic frequencies   | Noise and Health | ** | ** | ** | ** | ** |  |
| 27 | 2004 | Maschke C.        | Introduction to the special issue on low frequency noise                                    | Noise and Health | ** | ** | ** | ** | ** |  |
| 28 | 2004 | Leventhall H.     | Low frequency noise and annoyance   | Noise and Health | ** | ** | ** | ** | ** |  |
| 29 | 2004 | Findeis H. et al. | Disturbing effects of low frequency sound emissions and vibrations in residential buildings | Noise and Health | ** | ** | ** | ** | ** |  |



# The Potential Health Impact of Wind Turbines

Chief Medical Officer of Health (CMOH) Report  
May 2010

# Summary of Review

This report was prepared by the Chief Medical Officer of Health (CMOH) of Ontario in response to public health concerns about wind turbines, particularly related to noise.

Assisted by a technical working group comprised of members from the Ontario Agency for Health Protection and Promotion (OAHPP), the Ministry of Health and Long-Term Care (MOHLTC) and several Medical Officers of Health in Ontario with the support of the Council of Ontario Medical Officers of Health (COMOH), this report presents a synopsis of existing scientific evidence on the potential health impact of noise generated by wind turbines.

The review concludes that while some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects. The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct health effects, although some people may find it annoying.





# Introduction

In response to public health concerns about wind turbines, the CMOH conducted a review of existing scientific evidence on the potential health impact of wind turbines in collaboration and consultation with a technical working group composed of members from the OAHPP, MOHLTC and COMOH.

A literature search was conducted to identify papers and reports (from 1970 to date) on wind turbines and health from scientific bibliographic databases, grey literature, and from a structured Internet search. Databases searched include MEDLINE, PubMed, Environmental Engineering Abstracts, Environment Complete, INSPEC, Scholars Portal and Scopus. Information was also gathered through discussions with relevant government agencies, including the Ministry of the Environment and the Ministry of Energy and Infrastructure and with input provided by individuals and other organizations such as Wind Concerns Ontario.

In general, published papers in peer-reviewed scientific journals, and reviews by recognized health authorities such as the World Health Organization (WHO) carry more weight in the assessment of health risks than case studies and anecdotal reports.

The review and consultation with the Council of Ontario Medical Officers of Health focused on the following questions:

- What scientific evidence is available on the potential health impacts of wind turbines?
- What is the relationship between wind turbine noise and health?
- What is the relationship between low frequency sound, infrasound and health?
- How is exposure to wind turbine noise assessed?
- Are Ontario wind turbine setbacks protective from potential wind turbine health and safety hazards?
- What consultation process with the community is required before wind farms are constructed?
- Are there data gaps or research needs?

The following summarizes the findings of the review and consultation.

# 2

## Wind Turbines and Health

### 2.1 Overview

A list of the materials reviewed is found in Appendix 1. It includes research studies, review articles, reports, presentations, and websites.

Technical terms used in this report are defined in a Glossary (Page 11).

The main research data available to date on wind turbines and health include:

- Four cross-sectional studies, published in scientific journals, which investigated the relationships between exposure to wind turbine noise and annoyance in large samples of people (351 to 1,948) living in Europe near wind turbines (see section 2.2).
- Published case studies of ten families with a total of 38 affected people living near wind turbines in several countries (Canada, UK, Ireland, Italy and USA) (Pierpont 2009). However, these cases are not found in scientific journals. A range of symptoms including dizziness, headaches, and sleep disturbance, were reported by these people. The researcher (Pierpont) suggested that the symptoms were related to wind turbine noise, particularly low frequency sounds and infrasound, but did not investigate the relationships between noise and symptoms. It should be noted that no conclusions on the health impact of wind turbines can be drawn from Pierpont's work due to methodological limitations including small sample size, lack of exposure data, lack of controls and selection bias.
- Research on the potential health and safety hazards of wind turbine shadow flicker, electromagnetic fields (EMFs), ice throw and ice shed, and structural hazards (see section 2.3).

A synthesis of the research available on the potential health impacts of exposure to noise and physical hazards from wind turbines on nearby residents is found in sections 2.2 and 2.3, including research on low frequency sound and infrasound. This is followed by information on wind turbine regulation in Ontario (section 3.0), and our conclusions (section 4.0).

### 2.2. Sound and Noise

Sound is characterized by its sound pressure level (loudness) and frequency (pitch), which are measured in standard units known as decibel (dB) and Hertz (Hz), respectively. The normal human ear perceives sounds at frequencies ranging from 20Hz to 20,000 Hz. Frequencies below 200 Hz are commonly referred to as “low frequency sound” and those below 20Hz as “infrasound,” but the boundary between them is not rigid. There is variation between people in their ability to perceive sound. Although generally considered inaudible, infrasound at high-enough sound pressure levels can be audible to some people. Noise is defined as an unwanted sound (Rogers et al. 2006, Leventhall 2003).

Wind turbines generate sound through mechanical and aerodynamic routes. The sound level depends on various factors including design and wind speed. Current generation upwind model turbines are quieter than older downwind models. The dominant sound source from modern wind turbines is aerodynamic, produced by the rotation of the turbine blades through air. The aerodynamic noise is present at all frequencies, from infrasound to low frequency to the normal audible range, producing the characteristic “swishing” sound (Leventhall 2006, Colby et al. 2009).

Environmental sound pressure levels are most commonly measured using an A-weighted scale. This scale gives less weight to very low and very high frequency components that is similar to the way the human ear perceives sound. Sound levels around wind turbines are usually predicted by modelling, rather than assessed by actual measurements.

The impact of sound on health is directly related to its pressure level. High sound pressure levels (>75dB) could result in hearing impairment depending on the duration of exposure and sensitivity of the individual. Current requirements for wind turbine setbacks in Ontario are intended to limit noise at the nearest residence to 40 dB (see section 3). This is a sound level comparable to indoor background sound. This noise limit is consistent with the night-time noise guideline of 40 dB that the World Health Organization (WHO) Europe recommends for the protection of public health from community noise. According to the WHO, this guideline is below the level at which effects on sleep and health occurs. However, it is above the level at which complaints may occur (WHO 2009).

Available scientific data indicate that sound levels associated with wind turbines at common residential setbacks are not sufficient to damage hearing or to cause other direct adverse health effects, but some people may still find the sound annoying.

Studies in Sweden and the Netherlands (Pedersen et al. 2009, Pedersen and Waye 2008, Pedersen and Waye 2007, Pedersen and Waye 2004) have found direct relationships between modelled sound pressure level and self-reported perception of sound and annoyance. The association between sound pressure level and sound perception was stronger than that with annoyance. The sound was annoying only to a small percentage of the exposed people; approximately 4 to 10 per cent were very annoyed at sound levels between 35 and 45dBA. Annoyance was strongly correlated with individual perceptions of wind turbines. Negative attitudes, such as an aversion to the visual impact of wind turbines on the landscape, were associated with increased annoyance, while positive attitudes, such as direct economic benefit from wind turbines, were associated with decreased annoyance. Wind turbine noise was perceived as more annoying than transportation or industrial noise at comparable levels, possibly due to its swishing quality, changes throughout a 24 hour period, and lack of night-time abatement.

## **2.2.1 Low Frequency Sound, Infrasound and Vibration**

Concerns have been raised about human exposure to “low frequency sound” and “infrasound” (see section 2.2 for definitions) from wind turbines. There is no scientific evidence, however, to indicate that low frequency sound generated from wind turbines causes adverse health effects.

Low frequency sound and infrasound are everywhere in the environment. They are emitted from natural sources (e.g., wind, rivers) and from artificial sources including road traffic, aircraft, and ventilation systems. The most common source of infrasound is vehicles. Under many conditions, low frequency sound below 40Hz from wind turbines cannot be distinguished from environmental background noise from the wind itself (Leventhall 2006, Colby et al 2009).

Low frequency sound from environmental sources can produce annoyance in sensitive people, and infrasound at high sound pressure levels, above the threshold for human hearing, can cause severe ear pain. There is no evidence of adverse health effects from infrasound below the sound pressure level of 90dB (Leventhall 2003 and 2006).

Studies conducted to assess wind turbine noise indicate that infrasound and low frequency sounds from modern wind turbines are well below the level where known health effects occur, typically at 50 to 70dB.

A small increase in sound level at low frequency can result in a large increase in perceived loudness. This may be difficult to ignore, even at relatively low sound pressures, increasing the potential for annoyance (Jakobsen 2005, Leventhall 2006).

A Portuguese research group (Alves-Pereira and Castelo Branco 2007) has proposed that excessive long-term exposure to vibration from high levels of low frequency sound and infrasound can cause whole body system pathology (vibro-acoustic disease). This finding has not been recognized by the international medical and scientific community. This research group also hypothesized that a family living near wind turbines will develop vibro-acoustic disease from exposure to low frequency sound, but has not provided evidence to support this (Alves-Pereira and Castelo Branco 2007).

## 2.2.2 Sound Exposure Assessment

Little information is available on actual measurements of sound levels generated from wind turbines and other environmental sources. Since there is no widely accepted protocol for the measurement of noise from wind turbines, current regulatory requirements are based on modelling (see section 3.0).

## 2.3 Other Potential Health Hazards of Wind Turbines

The potential health impacts of electromagnetic fields (EMFs), shadow flicker, ice throw and ice shed, and structural hazards of wind turbines have been reviewed in two reports (Chatham-Kent Public Health Unit 2008; Rideout et al 2010). The following summarizes the findings from these reviews.

- **EMFs**  
Wind turbines are not considered a significant source of EMF exposure since emissions levels around wind farms are low.
- **Shadow Flicker**  
Shadow flicker occurs when the blades of a turbine rotate in sunny conditions, casting moving shadows on the ground that result in alternating changes in light intensity appearing to flick on and off. About 3 per cent of people with epilepsy are photosensitive, generally to flicker frequencies between 5-30Hz. Most industrial turbines rotate at a speed below these flicker frequencies.
- **Ice Throw and Ice Shed**  
Depending on weather conditions, ice may form on wind turbines and may be thrown or break loose and fall to the ground. Ice throw launched far from the turbine may pose a significant hazard. Ice that sheds from stationary components presents a potential risk to service personnel near the wind farm. Sizable ice fragments have been reported to be found within 100 metres of the wind turbine. Turbines can be stopped during icy conditions to minimize the risk.
- **Structural hazards**  
The maximum reported throw distance in documented turbine blade failure is 150 metres for an entire blade, and 500 metres for a blade fragment. Risks of turbine blade failure reported in a Dutch handbook range from one in 2,400 to one in 20,000 turbines per year (Braam et al 2005). Injuries and fatalities associated with wind turbines have been reported, mostly during construction and maintenance related activities.

# 3

## Wind Turbine Regulation in Ontario

The Ministry of the Environment regulates wind turbines in Ontario. A new regulation for renewable energy projects came into effect on September 24, 2009. The requirements include minimum setbacks and community consultations.

### 3.1 Setbacks

Provincial setbacks were established to protect Ontarians from potential health and safety hazards of wind turbines including noise and structural hazards.

The minimum setback for a wind turbine is 550 metres from a receptor. The setbacks rise with the number of turbines and the sound level rating of the selected turbines. For example, a wind project with five turbines, each with a sound power level of 107dB, must have its turbines setback at a minimum 950 metres from the nearest receptor.

These setbacks are based on modelling of sound produced by wind turbines and are intended to limit sound at the nearest residence to no more than 40 dB. This limit is consistent with limits used to control noise from other environmental sources. It is also consistent with the night-time noise guideline of 40 dB that the World Health Organization (WHO) Europe recommends for the protection of public health from community noise. According to the WHO, this guideline is below the level at which effects on sleep and health occurs. However, it is above the level at which complaints may occur (WHO 2009).

Ontario used the most conservative sound modelling available nationally and internationally, which is supported by experiences in the province and in other jurisdictions (MOE 2009). As yet, a measurement protocol to verify compliance with the modelled limits in the field has not been developed. The Ministry of the Environment has recently hired independent consultants to develop a procedure for measuring audible sound from wind turbines and also to review low frequency sound impacts from wind turbines, and to develop recommendations regarding low frequency sound.

Ontario setback distances for wind turbine noise control also take into account potential risk of injury from ice throw and structural failure of wind turbines. The risk of injury is minimized with setbacks of 200 to 500 metres.

### 3.2 Community Consultation

The Ministry of the Environment requires applicants for wind turbine projects to provide written notice to all assessed land owners within 120 metres of the project location at a preliminary stage of the project planning. Applicants must also post a notice on at least two separate days in a local newspaper. As well, applicants are required to notify local municipalities and any Aboriginal community that may have a constitutionally protected right or interest that could be impacted by the project.

Before submitting an application to the Ministry of the Environment, the applicant is also required to hold a minimum of two community consultation meetings to discuss the project and its potential local impact. To ensure informed consultation, any required studies must be made available for public review 60 days prior to the date of the final community meeting. Following these meetings the applicant is required to submit as part of their application a Consultation Report that describes the comments received and how these comments were considered in the proposal.

The applicant must also consult directly with local municipalities prior to applying for a Renewable Energy Approval on specific matters related to municipal lands, infrastructure, and services. The Ministry of the Environment has developed a template, which the applicant is required to use to document project-specific matters raised by the municipality. This must be submitted to the ministry as part of the application. The focus of this consultation is to ensure important local service and infrastructure concerns are considered in the project.

For small wind projects (under 50 kW) the public meeting requirements above are not applicable due to their limited potential impacts.

# 4

## Conclusions

The following are the main conclusions of the review and consultation on the health impacts of wind turbines:

- While some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects.
- The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct adverse health effects. However, some people might find it annoying. It has been suggested that annoyance may be a reaction to the characteristic “swishing” or fluctuating nature of wind turbine sound rather than to the intensity of sound.
- Low frequency sound and infrasound from current generation upwind model turbines are well below the pressure sound levels at which known health effects occur. Further, there is no scientific evidence to date that vibration from low frequency wind turbine noise causes adverse health effects.
- Community engagement at the outset of planning for wind turbines is important and may alleviate health concerns about wind farms.
- Concerns about fairness and equity may also influence attitudes towards wind farms and allegations about effects on health. These factors deserve greater attention in future developments.

The review also identified that sound measurements at residential areas around wind turbines and comparisons with sound levels around other rural and urban areas, to assess actual ambient noise levels prevalent in Ontario, is a key data gap that could be addressed. An assessment of noise levels around wind power developments and other residential environments, including monitoring for sound level compliance, is an important prerequisite to making an informed decision on whether epidemiological studies looking at health outcomes will be useful.



# Glossary

## **A-weighted decibels (dBA)**

The sound pressure level in decibels as measured on a sound level meter using an A-weighted filter. The A-weighted filter de-emphasizes the very low and very high frequencies of the sound in a manner similar to the frequency response of the human ear.

## **Decibel (dB)**

Unit of measurement of the loudness (intensity) of sound. Loudness of normal adult human voice is about 60-70 dB at three feet. The decibel scale is a logarithmic scale and it increases/decreases by a factor of 10 from one scale increment to the next adjacent one.

## **Downwind model turbines**

Downwind model turbines have the blades of the rotor located behind the supporting tower structure, facing away from the wind. The supporting tower structure blocks some of the wind that blows towards the blades.

## **Electromagnetic fields (EMFs)**

Electromagnetic fields are a combination of invisible electric and magnetic fields. They occur both naturally (light is a natural form of EMF) and as a result of human activity. Nearly all electrical and electronic devices emit some type of EMF.

## **Grey literature**

Information produced by all levels of government, academics, business and industry in electronic and print formats not controlled by commercial publishing, i.e., where publishing is not the primary activity of the producing body.

## **Hertz (Hz)**

A unit of measurement of frequency; the number of cycles per second of a periodic waveform.

## **Infrasound**

Commonly refers to sound at frequencies below 20Hz. Although generally considered inaudible, infrasound at high-enough sound pressure levels can be audible to some people.

## **Low frequency sound**

Commonly refers to sound at frequencies between 20 and 200 Hz.

## **Noise**

Noise is an unwanted sound.

## **Shadow Flicker**

Shadow flicker is a result of the sun casting intermittent shadows from the rotating blades of a wind turbine onto a sensitive receptor such as a window in a building. The flicker is due to alternating light intensity between the direct beam of sunlight and the shadow from the turbine blades.

## **Sound**

Sound is wave-like variations in air pressure that occur at frequencies that can be audible. It is characterized by its loudness (sound pressure level) and pitch (frequency), which are measured in standard units known as decibel (dB) and Hertz (Hz), respectively. The normal human ear perceives sounds at frequencies ranging from 20Hz to 20,000 Hz.

## **Upwind model turbines**

Upwind model turbines have the blades of the rotor located in front of the supporting tower structure, similar to how a propeller is at the front of an airplane. Upwind turbines are a modern design and are quieter than the older downwind models.

## **Wind turbine**

Wind turbines are large towers with rotating blades that use wind to generate electricity.

# Appendix 1: List of Documents on Wind Turbines

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# **Wind Turbine Sound and Health Effects An Expert Panel Review**

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# Contents

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| Section  | Page        |
|--|-------------|
| <b>Executive Summary .....</b>   | <b>ES-1</b> |
| <b>1 Introduction.....</b>   | <b>1-1</b>  |
| 1.1 Expert Panelists.....  | 1-1         |
| 1.2 Report Terminology .....   | 1-2         |
| <b>2 Methodology .....</b>   | <b>2-1</b>  |
| 2.1 Formation of Expert Panel .....  | 2-1         |
| 2.2 Review of Literature Directly Related to Wind Turbines .....                                     | 2-1         |
| 2.3 Review of Potential Environmental Exposures.....   | 2-1         |
| <b>3 Overview and Discussion.....</b>  | <b>3-1</b>  |
| 3.1 Wind Turbine Operation and Human Auditory Response to Sound.....                                 | 3-1         |
| 3.1.1 Overview .....   | 3-1         |
| 3.1.2 The Human Ear and Sound .....  | 3-2         |
| 3.1.3 Sound Produced by Wind Turbines .....  | 3-3         |
| 3.1.4 Sound Measurement and Audiometric Testing.....   | 3-5         |
| 3.2 Sound Exposure from Wind Turbine Operation .....   | 3-6         |
| 3.2.1 Infrasound and Low-Frequency Sound .....   | 3-6         |
| 3.2.2 Vibration.....   | 3-9         |
| 3.2.3 Vestibular System.....   | 3-11        |
| 3.3 Potential Adverse Effects of Exposure to Sound .....   | 3-12        |
| 3.3.1 Speech Interference .....  | 3-12        |
| 3.3.2 Noise-Induced Hearing Loss .....   | 3-13        |
| 3.3.3 Task Interference .....  | 3-13        |
| 3.3.4 Annoyance.....   | 3-13        |
| 3.3.5 Sleep Disturbance.....   | 3-13        |
| 3.3.6 Other Adverse Health Effects of Sound .....  | 3-13        |
| 3.3.7 Potential Health Effects of Vibration Exposure .....   | 3-14        |
| 3.4 Peer-Reviewed Literature Focusing on Wind Turbines, Low-Frequency<br>Sound, and Infrasound ..... | 3-15        |
| 3.4.1 Evaluation of Annoyance and Dose-Response Relationship of Wind<br>Turbine Sound .....          | 3-15        |
| 3.4.2 Annoyance.....   | 3-16        |
| 3.4.3 Low-Frequency Sound and Infrasound .....   | 3-17        |
| <b>4 Results .....</b>   | <b>4-1</b>  |
| 4.1 Infrasound, Low-Frequency Sound, and Annoyance .....   | 4-1         |
| 4.1.1 Infrasound and Low-Frequency Sound .....   | 4-2         |
| 4.1.2 Annoyance.....   | 4-2         |
| 4.1.3 Other Aspects of Annoyance .....   | 4-3         |
| 4.1.4 Nocebo Effect .....  | 4-4         |

| <b>Section</b>  | <b>Page</b> |
|---|-------------|
| 4.1.5 Somatoform Disorders .....                              | 4-4         |
| 4.2 Infrasound, Low-frequency Sound and Disease .....         | 4-5         |
| 4.2.1 Vibroacoustic Disease.....                              | 4-5         |
| 4.2.2 High-Frequency Exposure.....                            | 4-6         |
| 4.2.3 Residential Exposure: A Case Series .....               | 4-6         |
| 4.2.4 Critique.....   | 4-7         |
| 4.3 Wind Turbine Syndrome .....                               | 4-8         |
| 4.3.1 Evaluation of Infrasound on the Vestibular System ..... | 4-8         |
| 4.3.2 Evaluation of Infrasound on Internal organs.....        | 4-9         |
| 4.4 Visceral Vibratory Vestibular Disturbance .....           | 4-10        |
| 4.4.1 Hypothesis .....  | 4-10        |
| 4.4.2 Critique.....   | 4-11        |
| 4.5 Interpreting Studies and Reports.....                     | 4-11        |
| 4.6 Standards for Siting Wind Turbines.....                   | 4-13        |
| 4.6.1 Introduction.....                                       | 4-13        |
| 4.6.2 Noise Regulations and Ordinances .....                  | 4-13        |
| 4.6.3 Wind Turbine Siting Guidelines.....                     | 4-13        |
| <b>5 Conclusions.....</b>                                     | <b>5-1</b>  |
| <b>6 References .....</b>                                     | <b>6-1</b>  |

### Appendices

|   |                       |
|---|-----------------------|
| A | Fundamentals of Sound |
| B | The Human Ear         |
| C | Measuring Sound       |
| D | Propagation of Sound  |
| E | Expert Panel Members  |

### Tables

|     |  |     |
|-----|--|-----|
| 1-1 | Definitions of Acoustical Terms.....   | 1-2 |
| 3-1 | Typical Sound Pressure Levels Measured in the Environment and Industry ..... | 3-2 |
| 3-2 | Hearing Thresholds in the Infrasonic and Low Frequency Range .....           | 3-7 |

### Figures

|     |  |      |
|-----|--|------|
| 3-1 | Sound Produced by Wind Turbine Flow.....                             | 3-4  |
| 3-2 | Hearing Contours for Equal Loudness Level (ISO:226, 2003) .....      | 3-9  |
| 3-3 | Comparison of Excitation of an Object by Vibration and by Sound..... | 3-10 |
| C-1 | Weighting Networks .....   | C-2  |

# Acronyms and Abbreviations

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|                |   |
|----------------|---|
| $\mu\text{Pa}$ | 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      | <i>Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition</i>                    |
| 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

- 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.

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TABLE 1-1  
Definitions of Acoustical Terms

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| 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 ( $\mu\text{Pa}$ ).   |
| 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.<br><br>(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.  |

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Source: HPA, 2009.

# Methodology

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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

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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<br>At a Given Distance | A-Weighted Sound<br>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)             | 100                                   |   |
| Shout (0.5 feet)                    |                                       |   |
| N.Y. subway station                 | 90                                    | Very annoying                                   |
| Heavy truck (50 feet)               |                                       | Hearing damage (8-hour,<br>continuous exposure) |
| Pneumatic drill (50 feet)           | 80                                    | Annoying  |
| Freight train (50 feet)             | 70 to 80                              |   |
| Freeway traffic (50 feet)           |                                       |   |
|                                     | 70                                    | Intrusive<br>(Telephone use difficult)          |
| Air conditioning unit (20 feet)     | 60                                    |   |
| Light auto traffic (50 feet)        | 50                                    | Quiet   |
| Living room                         | 40                                    |   |
| Bedroom                             |                                       |   |
| Library                             | 30                                    | Very quiet                                      |
| Soft whisper (5 feet)               |                                       |   |
| Broadcasting/Recording studio       | 20                                    |   |
|                                     | 10                                    | Just audible                                    |

Adapted from Table E, “Assessing and Mitigating Noise Impacts”, NY DEC, February 2001.

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

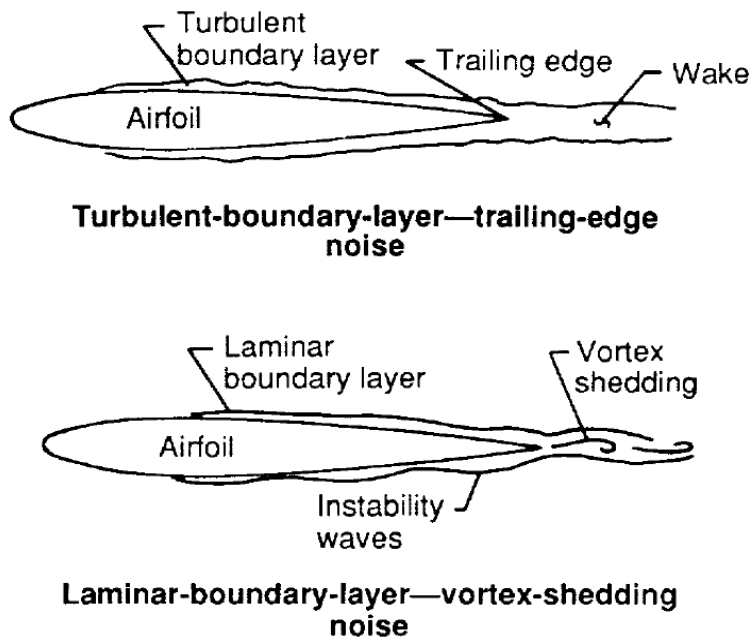
Wind turbine sound originates from either a mechanical or aerodynamic generation mechanism. Mechanical sound originates from the gearbox and control mechanisms. Standard noise control techniques typically are used to reduce mechanical sound. Mechanical noise is not typically the dominant source of noise 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.

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).

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

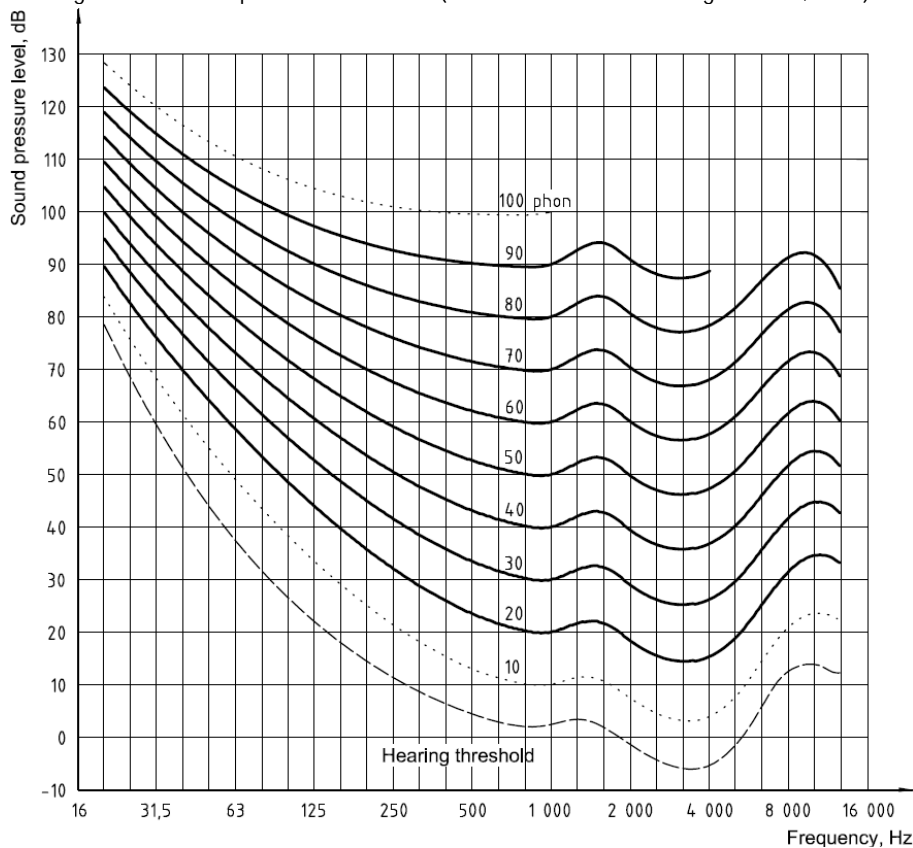


from a neighbor's stereo is heard within their home – the bass notes are more pronounced than the higher frequency sounds. Any unwanted sound, whether high frequency or low frequency, can be irritating and stressful to some people.

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.

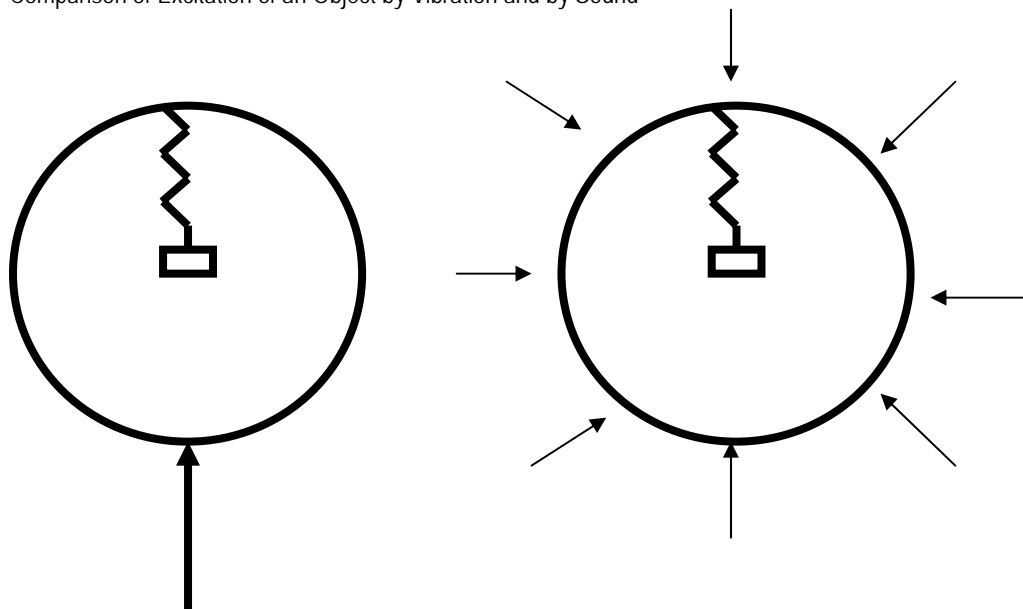
Vibration is often measured by the acceleration of the surface in meters per second, squared ( $m/s^2$ ), although other related units are used. Vibration can also be expressed in decibels, where the reference excitation level used in buildings is often  $10^{-5}m/s^2$  and the vibration level is  $20\log(A/10^{-5})$  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<sup>1</sup> 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

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<sup>1</sup> 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<sup>2</sup> (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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<sup>2</sup> 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

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<sup>2</sup>.

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<sup>2</sup>, 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<sup>2</sup>).

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.



### 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 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).

# Results

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This section discusses the results of the analysis 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.

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.<sup>3</sup> 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

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<sup>3</sup> 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<sup>4</sup> 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.<sup>5</sup>

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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<sup>4</sup> 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.

<sup>5</sup> 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) 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](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.

# Conclusions

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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

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

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# Fundamentals of Sound

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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 ( $\text{N}/\text{m}^2$ ), and a sound pressure of 94 dB re  $20\mu\text{Pa}$  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,  $\lambda$
- Velocity,  $c = 340\text{m}/\text{s}$  approx, depending on temperature

The velocity and wavelength are related by: velocity = wavelength  $\times$  frequency,

Relating frequency and wavelength by velocity gives

|                 |    |      |     |     |     |      |      |      |       |
|-----------------|----|------|-----|-----|-----|------|------|------|-------|
| Freq Hz         | 16 | 31.5 | 63  | 125 | 250 | 500  | 1000 | 2000 | 4000  |
| Wavelength<br>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  $\text{N}/\text{m}^2$ , 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:

$$\begin{aligned}\log_{10}10 &= 1 \\ \log_{10}100 &= 2 \\ \log_{10}1000 &= 3\end{aligned}$$

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 ( $\mu\text{Pa}$ ) ( $2 \times 10^{-5} \text{Pa}$ ) 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.

$$\text{Pressure level } L_p = 20 \log_{10} \left[ \frac{P}{P_0} \right] \text{ dB}$$

where  $P$  is the measured pressure and  $P_0$  is the reference pressure level of  $2 \times 10^{-5} \text{ Pa}$

A little calculation allows us to express the sound pressure level at a distance from a source of known sound power level as

$$\text{Sound pressure level, } L_P = L_w - 20 \log[r] - 11 \text{ dB}$$

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 ( $L_{eq}$ ): 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  $L_{Aeq}$ , 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  $L_{90}$  and  $L_{10}$ . The  $L_{90}$  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

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# The Human Ear

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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**

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# Measuring Sound

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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.

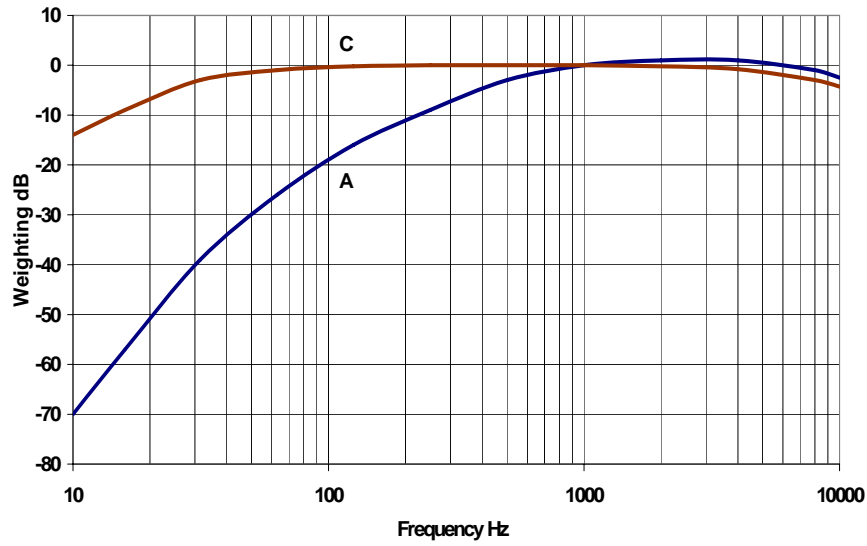
The weighting network and electrical filters are an important part of the sound level meter, as they give an indication of the frequency components of the sound. The filters are as follows:

- 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



APPENDIX D

# Propagation of Sound

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# Propagation of Sound

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The propagation of noise from wind turbines is determined by a number of factors, including:

- Geometrical spreading, given by  $K = 20\log[r] - 11$  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

$$L_P = L_W - K - D - A_A - A_G \quad (\text{dB})$$

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.

APPENDIX E

# Expert Panel Members

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# Expert Panel Members

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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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**Richard K. Jennings, M.D. —Psychiatrist, Retired**