National Survey of Attitudes of Wind Power Project Neighbors
February 27th, 2018: Webinar 3 of 4

Predicting Audibility Of And Annoyance To Wind Power Project Sounds Using Modeled Sound

Preliminary Results

Ryan Haac, Ken Kaliski and Matt Landis
RSG

Ben Hoen
Lawrence Berkeley National Laboratory
Electricity Markets and Policy Group

Please Note:
• All participants will be muted during the webinar
• Please submit questions via the chat window
• This webinar will be recorded

This analysis was funded by the Wind Energy Technologies Office of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
About the RSG authors

RSG’s acoustics practice supports environmentally responsible development by helping our clients understand and reduce potential noise impacts:

- Expertise in Renewable Energy and Power Transmission
- Acoustical analyses on over 80 wind power projects from Maine to Hawaii
- Previous prominent research:
  - Massachusetts Research Study on Wind Turbine Acoustics, Mass CEC and DEP
  - Wind Turbines and Health; A Critical Review of the Scientific Literature, Journal of Occupational and Environmental Medicine
- Regularly present and chair technical sessions on wind turbine acoustics at professional society meetings

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Senior Analyst

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Senior Director

R. Matthew Landis, PhD
Data Scientist
Outline Of The Presentation

Part I. National Survey Project Background

Part II. Survey Frame Overview

Part III. Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound

Part IV. Next Steps & Outreach
National Survey of Attitudes of Wind Power
Project Neighbors: Project Overview

Project PI: Ben Hoen, Research Scientist, LBNL

Collaborating Researchers:
- **LBNL**: Joe Rand, Ryan Wiser
- **University of Delaware**: Jeremy Firestone
- **Portland State University**: Debi Elliott
- **Martin Luther University**: Gundula Hübner, Johannes Pohl
- **NREL**: Eric Lantz
- **Resource Systems Group, Inc**: Ryan Haac, Ken Kaliski, Matt Landis

Project Years: FY2015-FY2018

DOE Program: Wind Energy Technologies Office
The Cumulative Number of Homes Near Turbines Is Increasing, While the Distance to the Nearest Homes Is Decreasing

Number of Homes Within 5 Miles of Industrial Scale US Wind Turbines

Mean and Median Distance to Nearest Home By Installation Year

Source: LBNL Baseline Public Acceptance Data; Note: Turbines>364 ft & 1.5 MW
National Survey of Attitudes of Wind Power Project Neighbors: Project Objectives

• Provide first-of-its kind broad-based, representative information on public acceptance issues surrounding wind facilities in the United States.

• Allow a wide array of stakeholders to better understand the attitudes & annoyances towards wind energy in local communities in the US and the main correlates to those perceptions.

• Allow greater confidence in the likely effects of proposed wind energy projects by increasing knowledge about existing projects.

• Potentially help inform wind stakeholder & DOE R&D priorities to increase benefits and reduce costs of the next-generation wind technologies and deployments.
Baseline Public Acceptance Analysis

Timeline

- Literature Review
- Data Collection
- Analysis
- Deliverable Preparation
- Outreach

FY2015
FY2016
FY2017
FY2018
Literature Review: “Thirty years of North American wind energy acceptance research: What have we learned?”

Project Lead(s): Rand

Collaborating Researchers: Hoen

Purpose: (1) to summarize North American wind energy public acceptance literature with a focus on some of the key correlates; and (2) to identify research gaps that the current research might help address.

Published in Energy Research and Social Science, July, 2017
Literature Review: Research Gaps

- A nationally representative sample of U.S. wind “neighbors”
- Larger sample of “very close” (< 1 mi) respondents
- Compare wind acceptance to other energy sources
- Distinguish those who moved-in after wind project construction from those living there prior
- Correlate attitudes / annoyance and modeled or measured sound
- Community preferences for the project development process
- Preferred compensation mechanisms (i.e., investment opportunity, reduced taxes, etc.)
- Public perceptions of property value impacts near wind projects
- Attitude changes over time around existing U.S. wind projects
- Implementation of strategies from previous wind acceptance research
Outline Of The Presentation

Part I. National Survey Project Background

Part II. Survey Frame Overview

Part III. Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound

Part IV. Next Steps & Outreach
Multi-Model Survey Conducted in 2016

Sampling Steps

– Pilot phone survey (December 2015)
– Phone survey (March 2016)
– Internet & mail survey (June-July 2016)
– 1705 valid responses (22% overall response rate)

22-minute survey
~ 50 questions

Images: www.mmrstrategy.com
www.brookmark.com
Responses Collected Near 250 Wind Power Projects Across 24 States, From The Full Sample Of 604 Projects

Random sample of residences within 5 miles of a modern wind turbine
- >= 364 feet tall
- >= 1.5 MW

Oversampled
- close to (<1 mile) turbines
- large projects (>10 turbines)
- where sound was modeled
Final Responses By Sampling Cohort ($n = 1705$)

Distance Respondent Is From Nearest Turbine

- $< 0.5$ mile: 621
- 0.5-1 mile: 500
- 1-3 miles: 320
- 3-5 miles: 264
Final Responses By Sampling Cohort ($n = 1705$)

Responses are weighted to account for over-sampling and to adjust for a sample not perfectly representative of the population.
National Survey of Attitudes of Wind Power Project Neighbors: Analysis Areas

Overall Analysis Areas

• Review of North American Wind Acceptance Literature
• Overall Analysis of Attitudes of 1,705 Wind Project Neighbors

Topic Specific Analysis Areas

• Planning Process Fairness and Attitudes
• Predicting Audibility of and Annoyance to Wind Project Sounds Using Modeled Sound
• Strongly Annoyed Individuals and U.S./Europe Comparison
*** Preliminary Results ***

- Results have not been submitted to nor reviewed for a peer-reviewed journal.
- The results could change as work progresses.
- Changes to the results could change some of the conclusions.
- If you wish to cite these results, use the following:

Outline Of The Presentation

Part I. National Survey Project Background

Part II. Survey Frame Overview

Part III. Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound

Part IV. Next Steps & Outreach
Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound

**Project Lead(s):** RSG Inc.: Haac, Kaliski, Landis

**Collaborating Researchers:** Hoen, Firestone, Rand,

**Contributing Researchers:** Hübner, Pohls, Wiser & Lantz

**Purpose:** To investigate various predictors of reported ability to hear turbines and stated sound annoyance

**Numbers of Respondents:** 651 (sound-modeled sites only)

**Primary Analysis Methodology:** Sound propagation modeling, Ordered logistic regression analysis
Audibility and Annoyance to Wind Turbine Noise

• Sound Level and Survey Data Summary
  • Sound level overview
  • Wind turbine audibility
  • Wind turbine noise annoyance
  • Annoyance and audibility in the home

• Predictors of Sound Annoyance
  • Description of regression models
  • Model validation method
  • Results!

• Preliminary Conclusions and Takeaways

• Future Work
Sound Levels Discussed in These Slides are “A-weighted”

- A-weighted sound levels represent human sensitivity and perception of sound at low and moderate levels.
Sound Level Data: Descriptions and Sources

Sound Propagation Modeling

– Modeled according to ISO 9613-2
  • G=0.5, +2 dB
– Wind turbine $L_{1h\text{-max}}$ sound pressure level (dBA)
– Sound levels calculated for
  • 651 respondents in 31 wind turbine developments

Background Sound Levels

– Estimated daytime $L_{50}$ at each respondent (dBA)
  • National Park Service: “Geospatial Sound Modeling”
  • $L_{50}$ is the median sound level

[Image] National Park Service: https://irma.nps.gov/DataStore/Reference/Profile/2217356
Audibility and Annoyance to Wind Turbine Noise

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Wind Turbine Audibility in the Sample and Population

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<th>Distance to Nearest Wind Turbine</th>
<th>Number of Respondents</th>
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<td>Between 3 to 5 miles</td>
<td>(n = 113)</td>
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Respondent Count (Sample)

Population Proportion (Weighted)

Wind Turbine Audibility
- Cannot Hear
- On Property
- In Home
### Population Summary

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<td>Over 90% cannot hear wind turbines</td>
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<tr>
<td>Between ½ to 1 mile (n = 170)</td>
<td>~40% hear wind turbines on their property</td>
</tr>
<tr>
<td>Less than ½ mile (n = 250)</td>
<td>~20% can hear a wind turbine in their home</td>
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</table>

- ~75% of the population can hear wind turbines on their property
- ~50% living within ½ mile can hear a wind turbine in home

### Wind Turbine Audibility in the Surrounding Population

- **Cannot Hear**
- **On Property**
- **In Home**

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*Image source: RSG*
Sound Levels and Audibility

**Modeled Wind Turbine Sound Levels**
Higher modeled sound levels are associated with higher audibility

* = Mean value for each audibility level
Sound Levels and Audibility

Modeled Wind Turbine Sound Levels
Higher modeled sound levels are associated with higher audibility

Local Background Sound Levels
Higher background sound levels mask wind turbine sound

* = Mean value for each audibility level
Wind Turbine Audibility - Sound Level Interaction
Curve Fit of Survey Data by Background Sound

Sound Level Interaction

Wind turbine sound level

and

Background sound level

Background Sound Level Categories (dBA)

- 30 - 35 dBA
- 35 - 40 dBA
- 40 - 45 dBA
- 45 - 50 dBA
- 50 dBA+

Note: Background Sound Level (Background L50) is continuous; it is only categorical for plotting this relationship.
Sound Level Difference

- Modeled Wind Turbine Level minus Background Level
- Positive values signify that the wind turbine was louder than the Background $L_{50}$

→ Audibility dependent on modeled wind turbine sound levels

Background Sound Level Categories (dBA)
- 30 - 35 dBA
- 35 - 40 dBA
- 40 - 45 dBA
- 45 - 50 dBA
- 50 dBA+

Note: Background Sound Level ($L_{50}$) is continuous; it is only categorical for plotting this relationship
Audibility Takeaways

• Wind turbine audibility increases with wind turbine sound level
• Higher local background sound level appear to mask turbine sound
• At higher background sound levels, respondents could hear the turbines at smaller sound level differences
Audibility and Annoyance to Wind Turbine Noise

• Sound Level and Survey Data Summary
  • Sound level overview
  • Wind turbine audibility
  • Wind turbine noise annoyance
  • Annoyance and audibility in the home

• Predictors of Sound Annoyance
  • Description of regression models
  • Model validation method
  • Results!

• Preliminary Conclusions and Takeaways

• Future Work
Classifying Respondent Annoyance Level  

Separating annoyance from sound and wind turbine audibility

22. Have you ever heard sound from the wind project?
   - Yes
   - No
   - Don't Know
   [Skip to #23]

22a. Can you hear sound from the wind project when you are on your property, but outside your home?
   - Yes
   - No
   - Don't Know
   [Skip to #23]

The next set of questions asks about any effects the local wind project has had on you. For these questions, think about the experiences you have had over the past year.

24. To what extent do you feel annoyed by each of the following effects of the local wind project?

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<th>Effect of the local wind project</th>
<th>Not at All</th>
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Classifying Respondent Annoyance Level

→ Separating annoyance from sound and wind turbine audibility

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- a. Change to the landscape
- b. Wind turbine lighting
- c. Shadow flicker
- d. Sound of the wind project

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Percentage of respondents in each response group:
- 52%
- 22%
- 8%
- 3%
- 5%
- 10%
Classifying Respondent Annoyance Level

→ Simplified classification for understanding audibility and annoyance

22. Have you ever heard sound from the wind project?
   - Yes
   - No
   - Don't Know

22a. Can you hear sound from the wind project when you are on your property, but outside your home?
   - Yes
   - No
   - Don't Know

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Percentage of respondents in each response group:
- Cannot Hear: 52%
- Not at all Annoyed: 22%
- Mildly Annoyed: 16%
- Very Annoyed: 10%

n = 656
Wind Turbine Noise Annoyance – Survey Results

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Respondent Annoyance Level:
- Cannot Hear
- Not
- Mildly
- Very
## Wind Turbine Noise Annoyance Summary

### Respondent Count (Sample)

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<td>Between ½ to 1 mile (n = 170)</td>
<td>~75% expressed no annoyance to wind turbine noise 20% were Mildly annoyed, &lt;3% were Very annoyed</td>
<td></td>
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<td>Less than ½ mile (n = 250)</td>
<td>20% of the population within a half mile was Very annoyed  Same percentage of respondents Mildly annoyed as ½ to 1 mile</td>
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### Distance to Nearest Wind Turbine

- Between 3 to 5 miles (n = 113)
- Between 1 to 3 miles (n = 105)
- Between ½ to 1 mile (n = 170)
- Less than ½ mile (n = 250)
Sound Levels and Annoyance

**Modeled Wind Turbine Sound Levels**
Higher modeled sound levels are associated with higher levels of annoyance

**Local Background Sound Levels**
Higher background sound levels are associated with relatively low annoyance levels

* = Mean value for each audibility level
Wind Turbine Sound Annoyance - Visualize Sound Level Interaction

Sound Level Interaction

Wind turbine sound level and Background sound level

In the absence of controlling variables, lower background sound levels lead to more annoyance at at similar modeled sound levels

Note: Background Sound Level (Background Lₜ₀) is continuous; it is only categorical for plotting this relationship
Classifying Respondent Annoyance Level of Those Who Reported Annoyance

Only respondents that reported sound annoyance on their property

22. Have you ever heard sound from the wind project?
- Yes
- No
- Don’t Know

22a. Can you hear sound from the wind project when you are on your property, but outside your home?
- Yes
- No
- Don’t Know

The next set of questions asks about any effects the local wind project has had on you. For these questions, think about the experiences you have had over the past year.

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Percentage of respondents in each response group:
- 46%
- 33%
- 21%
When We Only Consider Those Respondents That Could Hear the Turbines, the Sound Level Interaction Breaks Down

• There is no clear trend between wind turbine noise annoyance and A-weighted sound levels among those that can hear the turbines

• Lack of a logical trend is also non-existent for sound level difference

*No respondents with Background Levels above 50 dBA reported they could hear the turbines

Note: Background Sound Level (Background L_{50}) is continuous; it is only categorical for plotting this relationship
Annoyance Takeaways

- Wind turbine annoyance and audibility increases with wind turbine sound level
- Higher local background sound levels appear to mask turbine sound and thus produce less annoyance
- When only looking at the respondents who could hear the turbines on their property, wind turbine sound levels alone do not exhibit a clear trend to determine one’s annoyance level
Audibility and Annoyance to Wind Turbine Noise

• Sound Level and Survey Data Summary
  • Sound level overview
  • Wind turbine audibility
  • Wind turbine noise annoyance
    • Annoyance and audibility in the home

• Predictors of Sound Annoyance
  • Description of regression models
  • Model validation method
  • Results!

• Preliminary Conclusions and Takeaways

• Future Work
Annoyance and Audibility Inside the Home and On Property Grouped by Audibility

<table>
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<tr>
<th>Wind Turbine Sound Audibility</th>
<th>Respondent Count</th>
<th>Proportion of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can hear turbine in home</td>
<td>(n = 183)</td>
<td></td>
</tr>
<tr>
<td>Can hear turbines from property but not in home</td>
<td>(n = 118)</td>
<td></td>
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Wind Turbine Noise Annoyance in the Home: Takeaways

- Almost all Very annoyed respondents could hear the wind turbines in their home.
- Respondents who could hear the wind turbines in their home were distributed evenly between Not at all annoyed, Mildly annoyed, and Very annoyed.
- About 1/3 of respondents who could hear the wind turbines on their property reported being Mildly annoyed and most others were Not annoyed.
Audibility and Annoyance to Wind Turbine Noise

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Three Regression Models were Used to Assess Predictors of Annoyance

Influence of sound levels and applicable descriptors were explored through three distinct regression models:

1) **Sound Level Model**
   - Modeled wind turbine $L_{1h-max}$ sound pressure level (dBA)
   - Local estimated daytime $L_{50}$ background sound level (dBA)

2) **Objective Model**
   - All variables from Sound Level Model
   - Turbines in view from property
   - Resident prior to WT development or move-in after?
   - Project host or received compensation?

3) **Subjective Model**
   - Variables from Objective Model
   - Prior support or opposition to project?
   - Sensitive to noise (yes or no)?

*Demographic and stratification variables also included in regressions*
Regression Model Validation Method

**Leave-One-Out Cross Validation**

- “Leave-One-Out” Cross Validation provides an approach to validate our regression models.

- **Method**: For each respondent, the regression model is calculated without that individual respondent. The goal is to see if the model correctly predicts the respondent that was “left out.”

- The results of the validation are expressed as the proportion of responses that were correctly predicted for each level of the response variable.

- Green outlines show the proportion of observed responses that the model predicted correctly in the leave-one-out cross validation routine.
Regression Model Validation Method

Leave-One-Out Cross Validation

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• Green outlines show the proportion of observed responses that the model predicted correctly in the leave-one-out cross validation routine.

**EXAMPLE: 100% PREDICTED CORRECTLY**
Model Validation Results

**Sound Level Model**
- n = 278
- $R^2$ = 0.12
- Observed response correctly predicted = 75%

**Objective Model**
- n = 265
- $R^2$ = 0.21
- Observed response correctly predicted = 68%

**Subjective Model**
- n = 264
- $R^2$ = 0.38
- Observed response correctly predicted = 71%
Variable Importance in the Subjective Model

Chi-square values measure the relative importance of the variable to the model.

- Subjective variables are the strongest predictors
- A-weighted wind turbine sound level statistically significant in the model
- Host/Compensation status is also a strong predictor
- Demographic variable Age is statistically significant
Researcher Takeaways

• Within half a mile of the nearest wind turbine:
  • About 75% of respondents reported hearing wind turbines on their property
  • About 50% of respondents reported hearing wind turbines in their home

• Almost all Very annoyed respondents could hear the wind turbines in their home

• About 1/3 of respondents who could hear the wind turbines in their home were Very annoyed

• Modeled turbine sound level and local background sound level ($L_{50}$) interacted to explain audibility, but less so annoyance
  • The A-weighted turbine sound level taken alone is correlated with audibility but not annoyance

• The combination of subjective variables, objective variables, and the sound level interaction provided the best insight into annoyance predictors
  • About 45% of respondents that reported annoyance to wind turbine sound were successfully predicted by the regression model

• There is still unexplained variance, especially in predicting those who are Very annoyed
This Year The Research Will Be Expanded Upon To Further Explore Predictors of Annoyance

- Increase respondents with modeled sound levels to over 1,000
  - Additional sound propagation modeling of 24 projects for a total of 55 wind projects
- Investigate physical wind turbine and project characteristics as covariates
  - Turbine capacity, capacity factor, hub height, RPM, geographical regions, etc.
- Effect of low frequency dominance of turbine spectra
  - Analysis of low frequency content of wind turbine sound (as opposed to overall A-weighted levels)
- Build a regression model to better predict audibility and annoyance
Outline Of The Presentation

Part I. National Survey Project Background

Part II. Survey Frame Overview

Part III. Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound

Part IV. Next Steps & Outreach
Upcoming Outreach & Next Steps

Upcoming Outreach

• Webinar Series:
  – **March 13, 2018**: Comparing Strongly Annoyed Individuals with Symptoms near U.S. Turbines to Those in Surveyed European Communities

• AWEA Siting Compliance Conference, Memphis (March 2018)

Next Steps

• Submit additional journal papers (spring/summer 2018)
• Release the analysis data & survey instrument (fall 2018)

source: hingemarketing.com
Questions?

Ryan Haac: ryan.haac@rsginc.com
Ken Kaliski: ken.kaliski@rsginc.com
Matt Landis: matt.landis@rsginc.com
Ben Hoen: bhoen@lbl.gov

Visit the project webpage for more info and updates https://emp.lbl.gov/projects/wind-neighbor-survey

If you wish to cite these results use the following:


This work is supported by the US DOE Wind Energy Technologies Office
Supplemental Slides
Wind Turbine Audibility in the Surrounding Full Sample Population

**Respondent Count (Sample)**

<table>
<thead>
<tr>
<th>Distance From Nearest Turbine</th>
<th>Number of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 3-5 miles (n = 260)</td>
<td>200</td>
</tr>
<tr>
<td>Between 1-3 miles (n = 312)</td>
<td>300</td>
</tr>
<tr>
<td>Between 0.5-1 mile (n = 480)</td>
<td>400</td>
</tr>
<tr>
<td>Within 0.5 miles (n = 587)</td>
<td>500</td>
</tr>
</tbody>
</table>

**Population Proportion (Weighted)**

- **Wind Turbine Audibility**
  - Cannot Hear
  - Can Hear on Property
  - Can Hear from Home

Number of Respondents

56
## Wind Turbine Audibility in the Surrounding Full Sample Population

### Respondent Count (Sample)

<table>
<thead>
<tr>
<th>Distance From Nearest Turbine</th>
<th>Almost 100% cannot hear wind turbines</th>
<th>Over 90% cannot hear wind turbines</th>
<th>~44% hear wind turbines on property</th>
<th>~ about 25% can hear a wind turbine in their home</th>
<th>~80% hear wind turbines on property</th>
<th>~60% of the population within a half mile can hear a wind turbine in their home</th>
</tr>
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<tbody>
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</tbody>
</table>

### Population Proportion (Weighted)

Wind Turbine Audibility
- **Cannot Hear**
- **Can Hear on Property**
- **Can Hear In Home**

~90% cannot hear wind turbines
~25% can hear a wind turbine in their home
~80% hear wind turbines on property
~60% of the population within a half mile can hear a wind turbine in their home
Wind Turbine Noise Annoyance – Survey Results

Respondent Count (Sample) vs. Population Proportion (Weighted)

- **Distance from Nearest Turbine**
  - 3-5mi
  - 1-3mi
  - 0.5-1mi
  - 0-0.5mi

- **Number of Respondents**
  - 0
  - 50
  - 100
  - 150
  - 200
  - 250

- **Respondent Annoyance Level**
  - Never Heard
  - Not
  - Somewhat
  - Slightly
  - Moderately
  - Very
Annoyance and Audibility Inside the Home and On Property Grouped by Audibility

**Sound Annoyance**
- Not: 50%
- Mildly: 27%
- Very: 21%

**Proportion of Population (weighted data)**
- InHome: 52%
- YesProp: 49%

**Respondent Count**
- InHome: 150 respondents
- YesProp: 100 respondents
Most Respondents Who Could Not See Wind Turbines From Their Property Also Could Not Hear Them

• About 40% of those who could see wind turbines from their property could not hear them.
Respondents Who Were Compensated for Hosting Turbines Did Not Report Being Very Annoyed

- Those who were compensated (but were not hosting a turbine) were proportionally Very Annoyed by wind turbine sound
- Those that were compensated were likely mildly annoyed due to higher sound levels
Respondents Who Lived In The Area Prior To The Wind Turbine Development Were More Likely To Be Annoyed

- Respondents who moved in after (PostCon) were less annoyed than those who were there prior to the development (PreCon)
  - This supports the theory that more supportive residents are self-selecting into the community over time (i.e., Tiebout sorting)
Respondents Who Reported Being Sensitive To Noise Appeared To Be Slightly More Likely to Be Annoyed By Wind Turbines

• By a margin of less than 10%, respondents who reported being sensitive to noise were more often able to hear wind turbines on their property than those that were not noise sensitive.

• Proportionally, about twice as many respondents reported some level of annoyance if they indicated that they were sensitive to noise.
Respondents With A Negative Opinion Of The Local Wind Turbine Project Prior To Development Were More Likely To Be Annoyed

- Respondents who moved in after were apparently less annoyed than all other groups (including those with a prior support of the project)
  - This supports the theory that more supportive residents are self-selecting into the community over time (i.e., Tiebout sorting)
- Those with prior opposition to the project were also more likely to be able to hear the wind turbines on their property

**Observed Proportions**

<table>
<thead>
<tr>
<th>Prior Support or Opposition</th>
<th>Very Annoyed</th>
<th>Mildly Annoyed</th>
<th>Not at all Annoyed</th>
<th>Cannot Hear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
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<td></td>
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<tr>
<td>Positive</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>mi_After</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Oldest Respondents Reported the Least Amount of Annoyance and Audibility

- Respondents between the ages of 40 and 70 proportionally reported the highest levels of annoyance.
- Respondents between the ages of 50 and 60 proportionally reported the most audibility and annoyance.
• Annoyance level increases with the frequency of annoyance
• Daily annoyance with wind turbine sounds leads to being Very Annoyed by the noise
Description of Annoying Sound

- Most respondents that reported annoyance reported being annoyed by a “Swishing or Whooshing” sound.
- The second-most annoying sound is the resounding sound (i.e., endless overflight).
- None of the above represents “Other”
Wind Turbine Audibility - Visualize Sound Level Interaction

**Modeled Sound Level**

- Colored dots represent background sound level categories

![Graph showing modeled sound level interaction]

**Background Sound Level (dBA)**

- 30 - 35 dBA
- 35 - 40 dBA
- 40 - 45 dBA
- 45 - 50 dBA
- 50 dBA+

Note: Background Sound Level (Background $L_{50}$) is continuous; it is only categorical for plotting this relationship.
Wind Turbine Audibility - Visualize Sound Level Interaction

**Sound Level Difference**

- Modeled Wind Turbine Level \( \text{minus} \) Background Level
- Positive values signify that the wind turbine was *louder* than the Background \( L_{50} \)
- Colors represent modeled wind turbine sound level

Background Sound Level (dBA)

- 30 - 35 dBA
- 35 - 40 dBA
- 40 - 45 dBA
- 45 - 50 dBA
- 50 dBA+
Sound Level Interaction

Turbines tended to be less annoying and/or inaudible with higher background sound levels.

Background Sound Level Categories (dBA):
- 30 - 35 dBA
- 35 - 40 dBA
- 40 - 45 dBA
- 45 - 50 dBA
- 50 dBA+

Note: Background Sound Level (Background L_{50}) is continuous; it is only categorical for plotting this relationship.
Wind Turbine Sound Annoyance – Sound Level Difference

Sound Level Difference

• Modeled Wind Turbine Level \(\text{minus}\) Background Level

• Positive values signify that the wind turbine was *louder* than the Background \(L_{50}\)

→ Audibility driven by modeled wind turbine sound levels

Note: Background Sound Level (Background \(L_{50}\)) is continuous; it is only categorical for plotting this relationship
Sound Level Interaction Breaks Down When We Only Consider Those Respondents That Could Hear the Turbines

Sound Level Difference

- Modeled Wind Turbine Level \textit{minus} Background Level
- Positive values signify that the wind turbine was \textit{louder} than the Background $L_{50}$

*No respondents with Background Levels above 50 dBA reported they could hear the turbines

Note: Background Sound Level (Background $L_{50}$) is continuous; it is only categorical for plotting this relationship
Annoyance and Audibility Inside the Home and On Property Grouped by Annoyance Level

Proportion of Respondents

<table>
<thead>
<tr>
<th>Annoyance Level</th>
<th>Very</th>
<th>Mildly</th>
<th>Not</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeled L1h-max (dBA)</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

WT Audibility
- Blue: OnProperty
- Red: InHome

96% 37% 57%
63% 63% 43%
Annoyance and Audibility Inside the Home and On Property Grouped by Annoyance Level

Respondent Count

<table>
<thead>
<tr>
<th>Wind Turbine Sound Annoyance</th>
<th>Number of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Annoyed (n = 63)</td>
<td></td>
</tr>
<tr>
<td>Mildly Annoyed (n = 100)</td>
<td></td>
</tr>
<tr>
<td>Not at all Annoyed (n = 138)</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of Respondents

- Very Annoyed: 96%
- Mildly Annoyed: 37%, 63%
- Not at all Annoyed: 57%, 43%

Wind Turbine Audibility
- Can hear turbines from property but not home
- Can hear turbine in home
Annoyance and Audibility Inside the Home and On Property Grouped by Annoyance Level

- Very Annoyance: 96% of the population
- Mildly Annoyance: 59% of the population, with 41% in-home and 57% on property
- Not Annoyance: 43% of the population, with 57% in-home and 43% on property

Number of Respondents: 0-50-100