Energy Technologies Area Lawrence Berkeley National Laboratory

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

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

Ryan Haac, Ken Kaliski and Matt Landis
RSG

Ben Hoen
Lawrence Berkeley National Laboratory
Electricity Markets and Policy Group

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

T. Ryan Haac
Senior Analyst

Ken Kaliski, PE, INCE BD. CERT.
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

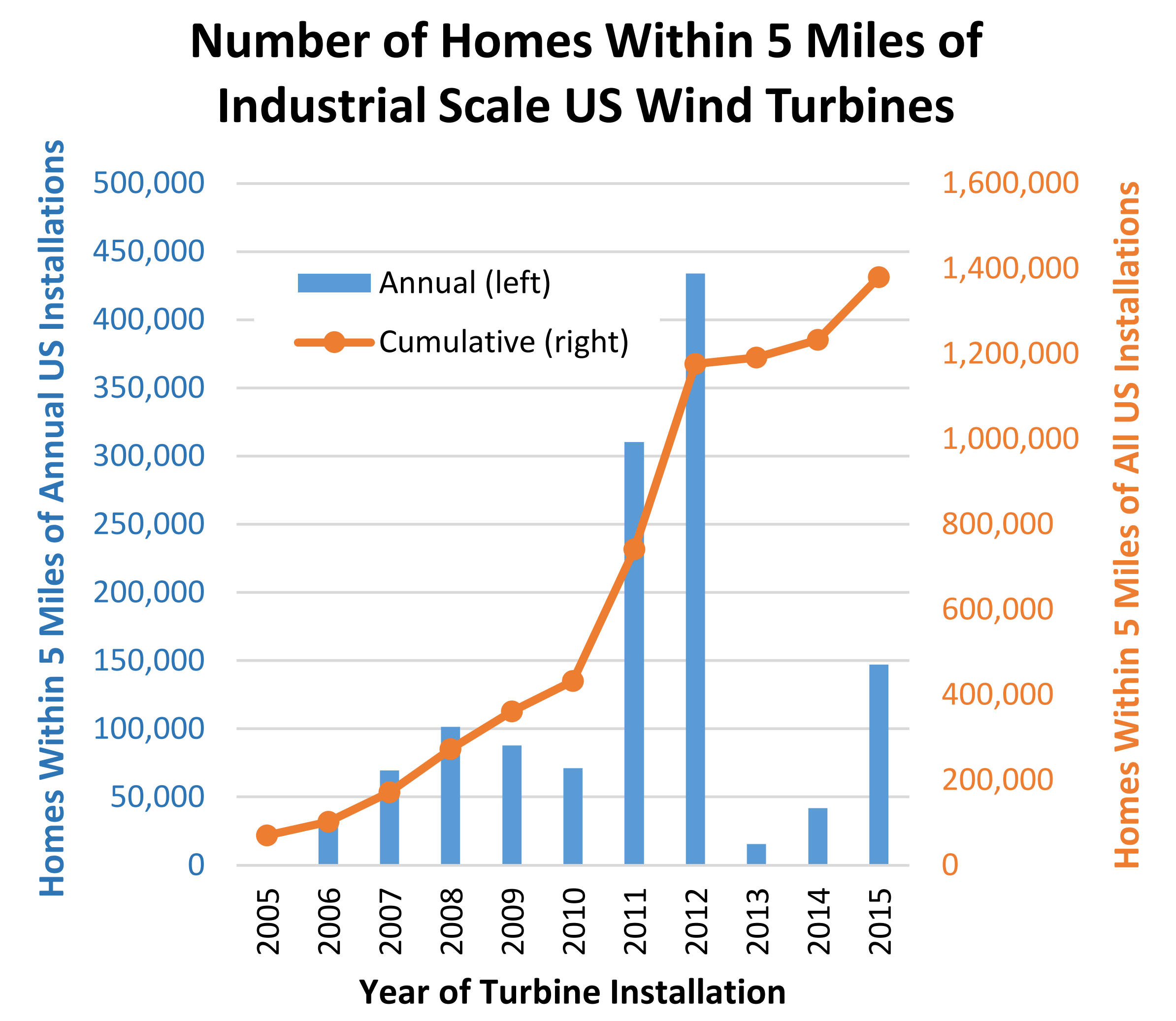
Collaborating Researchers:

- **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

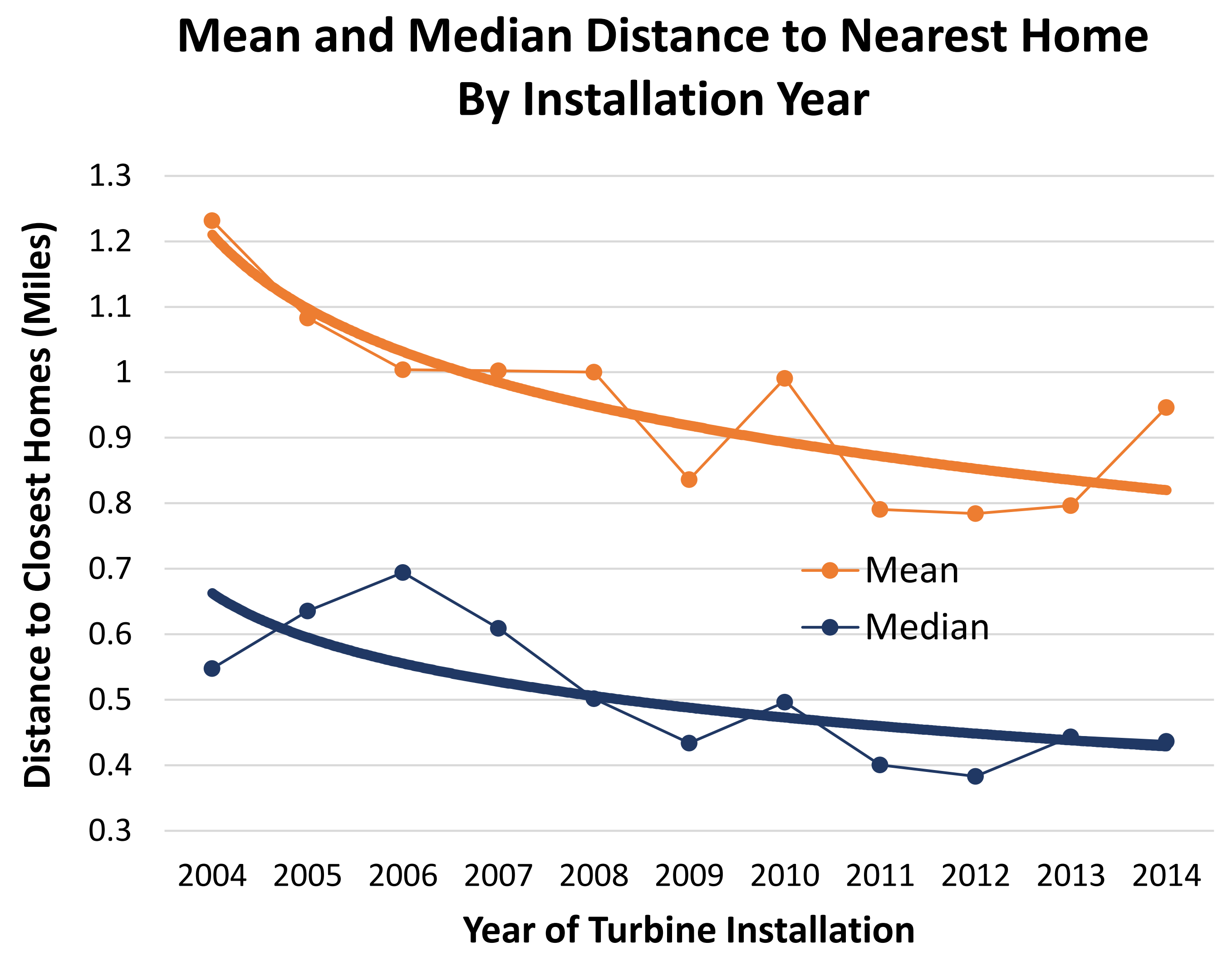
Project Years: FY2015-FY2018

DOE Program: Wind Energy Technologies Office

The Cumulative Number of Homes Near Turbines Is Increasing, While the Distance to the Nearest Homes Is Decreasing



Source: LBNL Baseline Public Acceptance Data; Note: Turbines>364 ft & 1.5 MW



Source: LBNL Baseline Public Acceptance Data; Note: Turbines>364 ft & 1.5 MW

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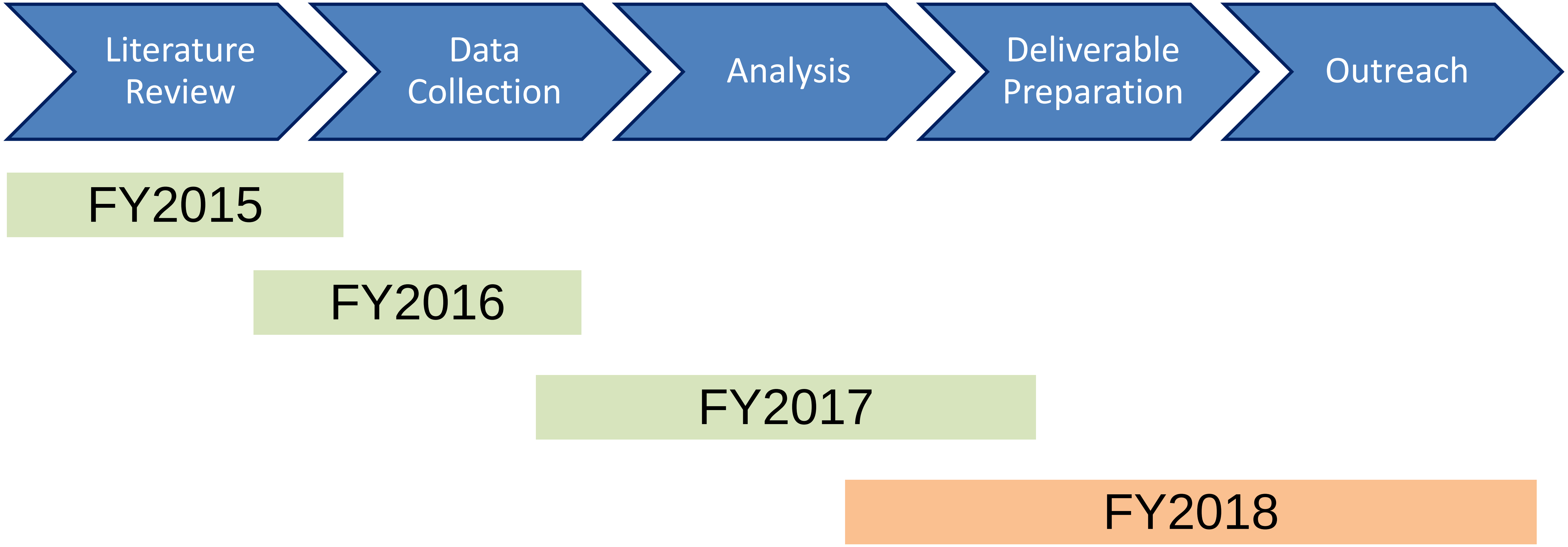
National Survey of Attitudes of Wind Power Project Neighbors: Project Objectives

- 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

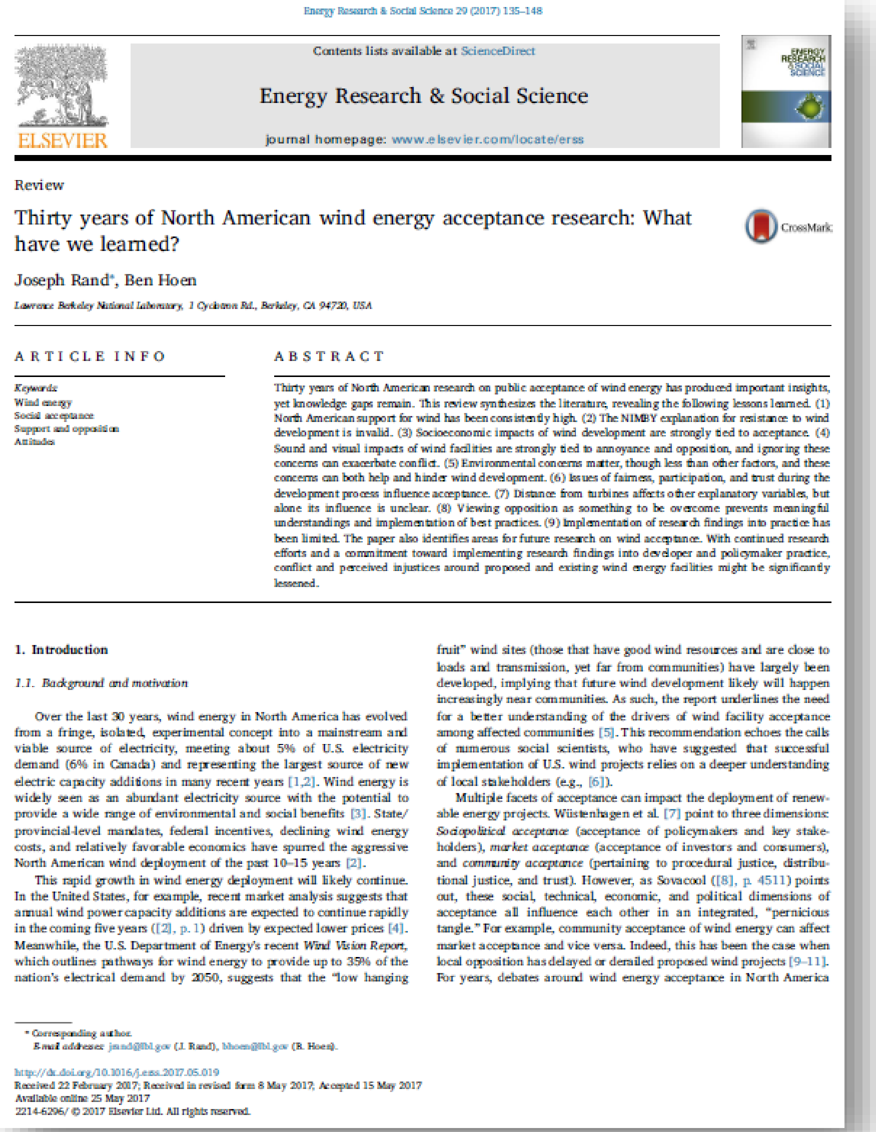


Literature Review: *"Thirty years of North American wind energy acceptance research: What have we learned?"*

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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journal homepage: www.elsevier.com/locate/erss

Review

Thirty years of North American wind energy acceptance research: What have we learned?

Joseph Rand*, Ben Hoen

Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720, USA

ARTICLE INFO

Keywords:
Wind energy
Social acceptance
Support and opposition
Attitudes

ABSTRACT

Thirty years of North American research on public acceptance of wind energy has produced important insights, yet knowledge gaps remain. This review synthesizes the literature, revealing the following lessons learned. (1) North American support for wind has been consistently high. (2) The NIMBY explanation for resistance to wind development is invalid. (3) Socioeconomic impacts of wind development are strongly tied to acceptance. (4) Sound and visual impacts of wind facilities are strongly tied to annoyance and opposition, and ignoring these concerns can exacerbate conflict. (5) Environmental concerns matter, though less than other factors, and these concerns can both help and hinder wind development. (6) Issues of fairness, participation, and trust during the development process influence acceptance. (7) Distance from turbines affects other explanatory variables, but alone its influence is unclear. (8) Viewing opposition as something to be overcome prevents meaningful understandings and implementation of best practices. (9) Implementation of research findings into practice has been limited. The paper also identifies areas for future research on wind acceptance. With continued research efforts and a commitment toward implementing research findings into developer and policymaker practice, conflict and perceived injustices around proposed and existing wind energy facilities might be significantly lessened.

1. Introduction

1.1. Background and motivation

Over the last 30 years, wind energy in North America has evolved from a fringe, isolated, experimental concept into a mainstream and viable source of electricity, meeting about 5% of U.S. electricity demand (6% in Canada) and representing the largest source of new electric capacity additions in many recent years [1,2]. Wind energy is widely seen as an abundant electricity source with the potential to provide a wide range of environmental and social benefits [3]. State/provincial-level mandates, federal incentives, declining wind energy costs, and relatively favorable economics have spurred the aggressive North American wind deployment of the past 10–15 years [2].

This rapid growth in wind energy deployment will likely continue. In the United States, for example, recent market analysis suggests that annual wind power capacity additions are expected to continue rapidly in the coming five years ([2], p. 1) driven by expected lower prices [4]. Meanwhile, the U.S. Department of Energy's recent *Wind Vision Report*, which outlines pathways for wind energy to provide up to 35% of the nation's electrical demand by 2050, suggests that the "low hanging fruit" wind sites (those that have good wind resources and are close to loads and transmission, yet far from communities) have largely been developed, implying that future wind development likely will happen increasingly near communities. As such, the report underlines the need for a better understanding of the drivers of wind facility acceptance among affected communities [5]. This recommendation echoes the calls of numerous social scientists, who have suggested that successful implementation of U.S. wind projects relies on a deeper understanding of local stakeholders (e.g., [6]).

Multiple facets of acceptance can impact the deployment of renewable energy projects. Wüstenhagen et al. [7] point to three dimensions: *Sociopolitical acceptance* (acceptance of policymakers and key stakeholders), *market acceptance* (acceptance of investors and consumers), and *community acceptance* (pertaining to procedural justice, distributional justice, and trust). However, as Sovacool ([8], p. 4511) points out, these social, technical, economic, and political dimensions of acceptance all influence each other in an integrated, "pernicious tangle." For example, community acceptance of wind energy can affect market acceptance and vice versa. Indeed, this has been the case when local opposition has delayed or derailed proposed wind projects [9–11]. For years, debates around wind energy acceptance in North America

* Corresponding author.
E-mail addresses: jrand@lbl.gov (J. Rand), bhoen@lbl.gov (B. Hoen).

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2214-6296/

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

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Multi-Model Survey Conducted in 2016

Sampling Steps

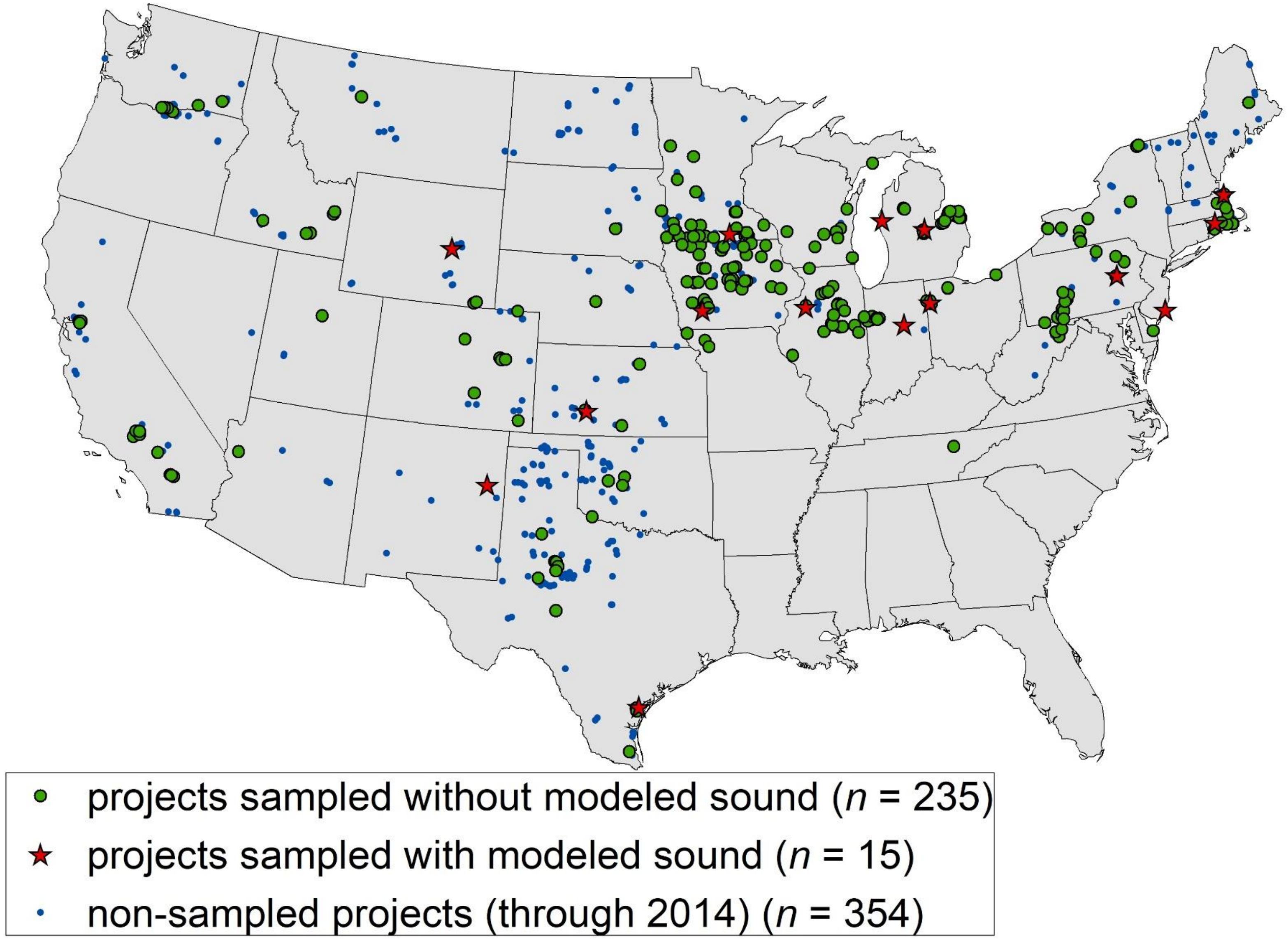
- Pilot phone survey (December 2015)
- Phone survey (March 2016)
- Internet & mail survey (June-July 2016)
- 1705 valid responses (22% overall response rate)

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



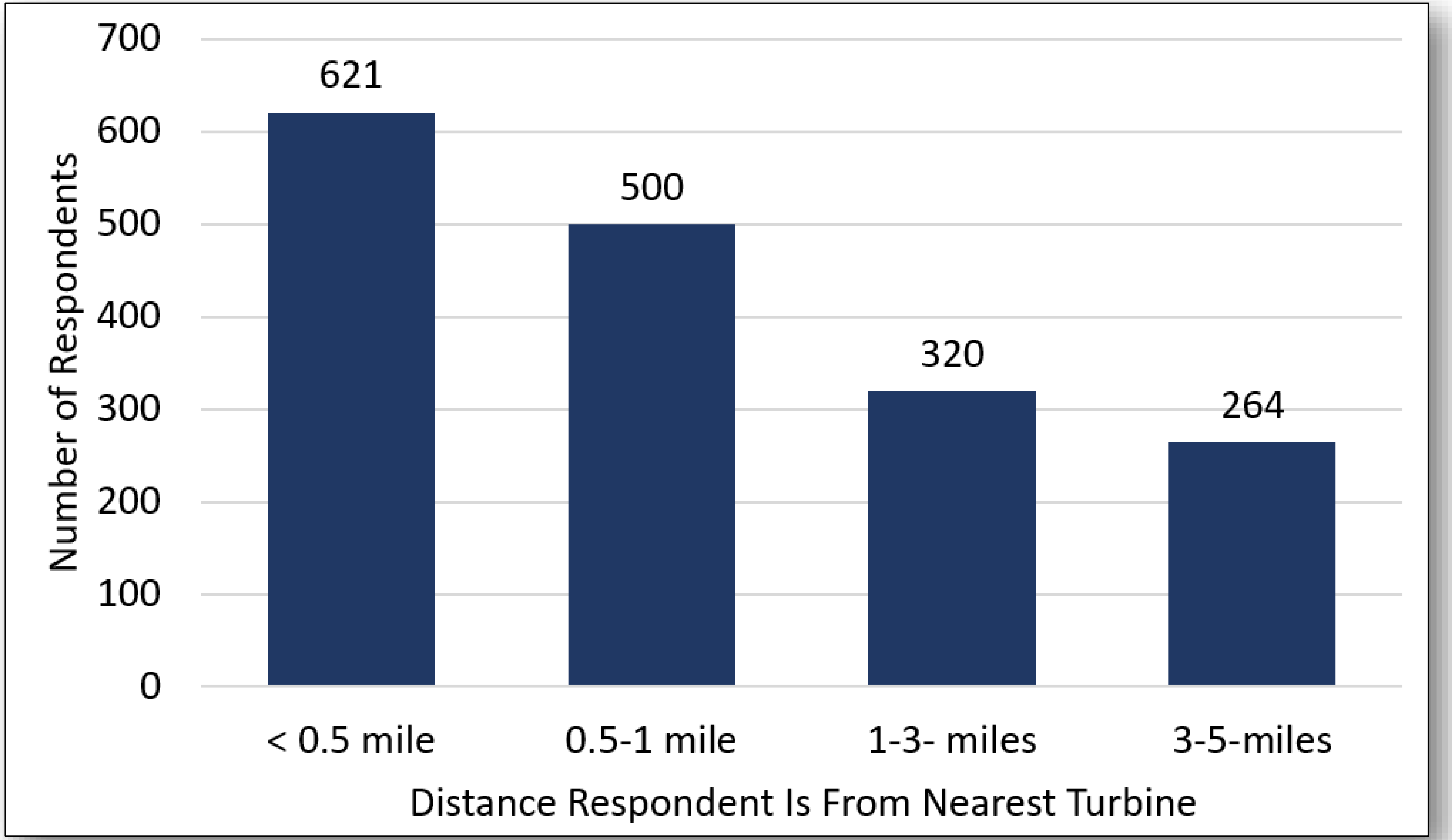
Random sample of residences within 5 miles of a modern wind turbine

- >= 364 feet tall
- >= 1.5 MW

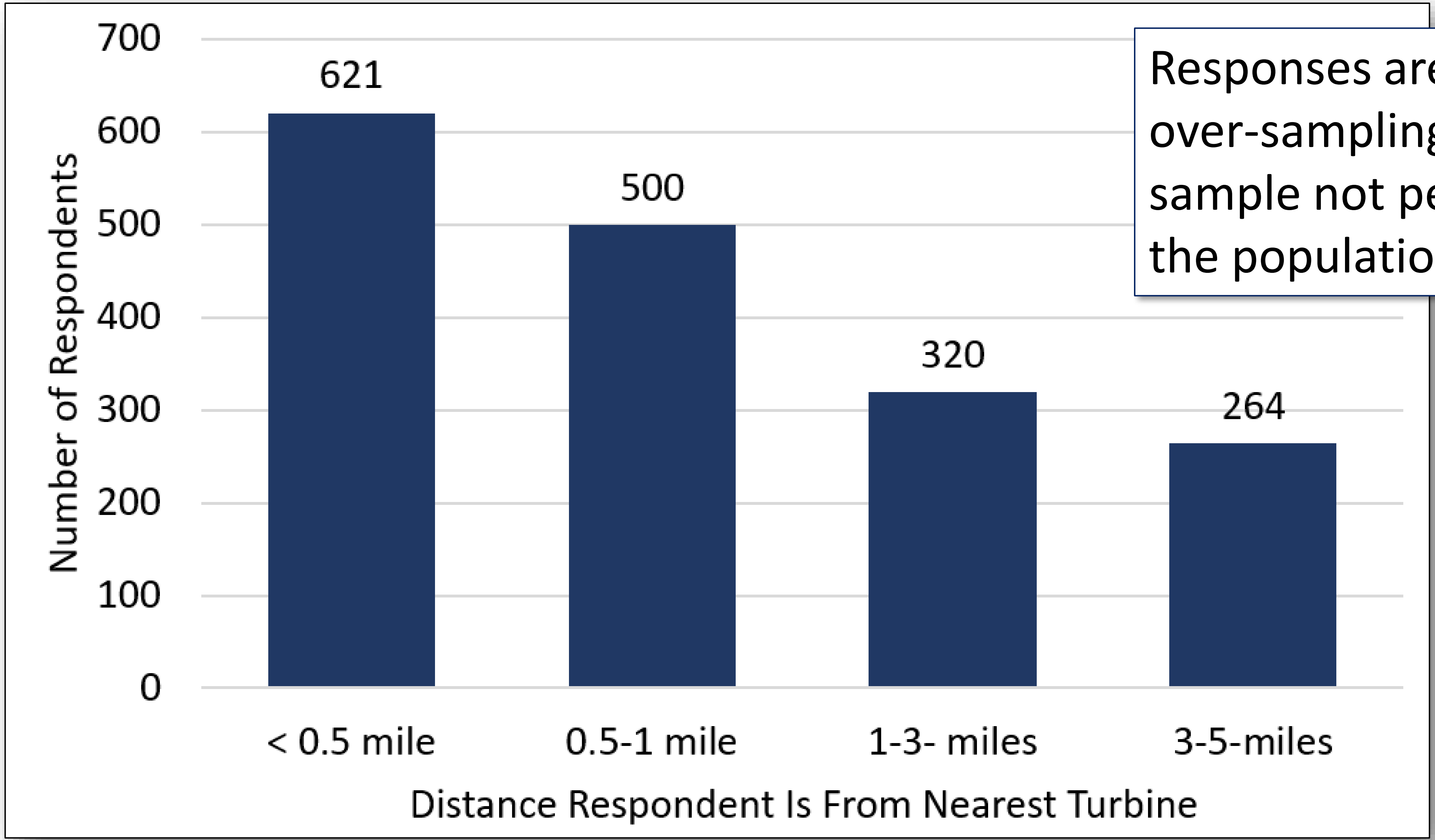
Oversampled

- close to (<1 mile) turbines
- large projects (>10 turbines)
- where sound was modeled

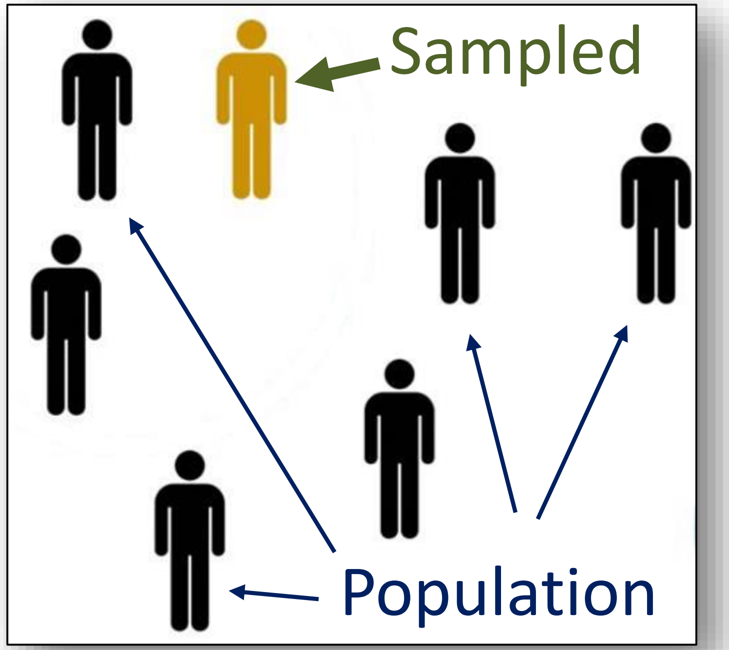
Final Responses By Sampling Cohort (*n* = 1705)



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:

  Haac, R., K. Kaliski, M. Landis, B. Hoen, J. Firestone, J. Rand, (2018) Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound. Lawrence Berkeley National Laboratory. Preliminary Results Webinar. February 27, 2018.

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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)

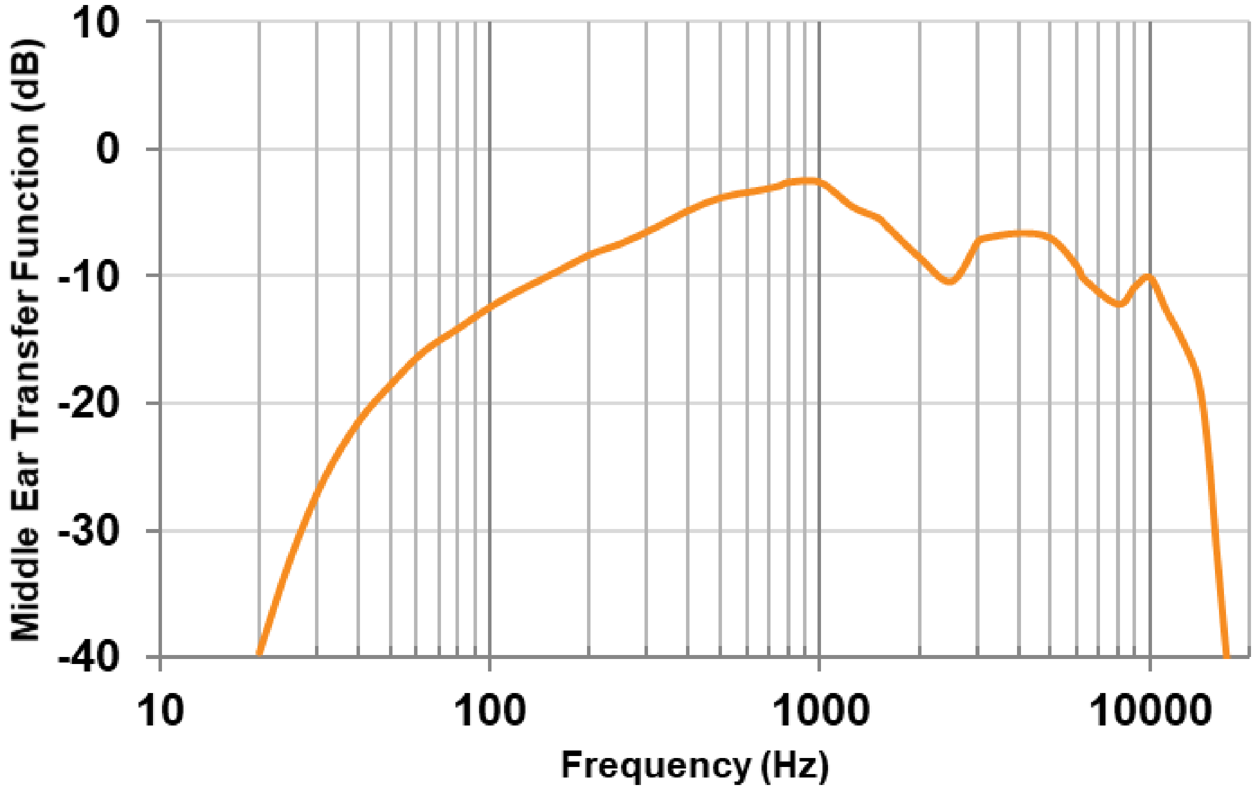
Primary Analysis Methodology: Sound propagation modeling, Ordered logistic regression analysis

Audibility and Annoyance to Wind Turbine Noise

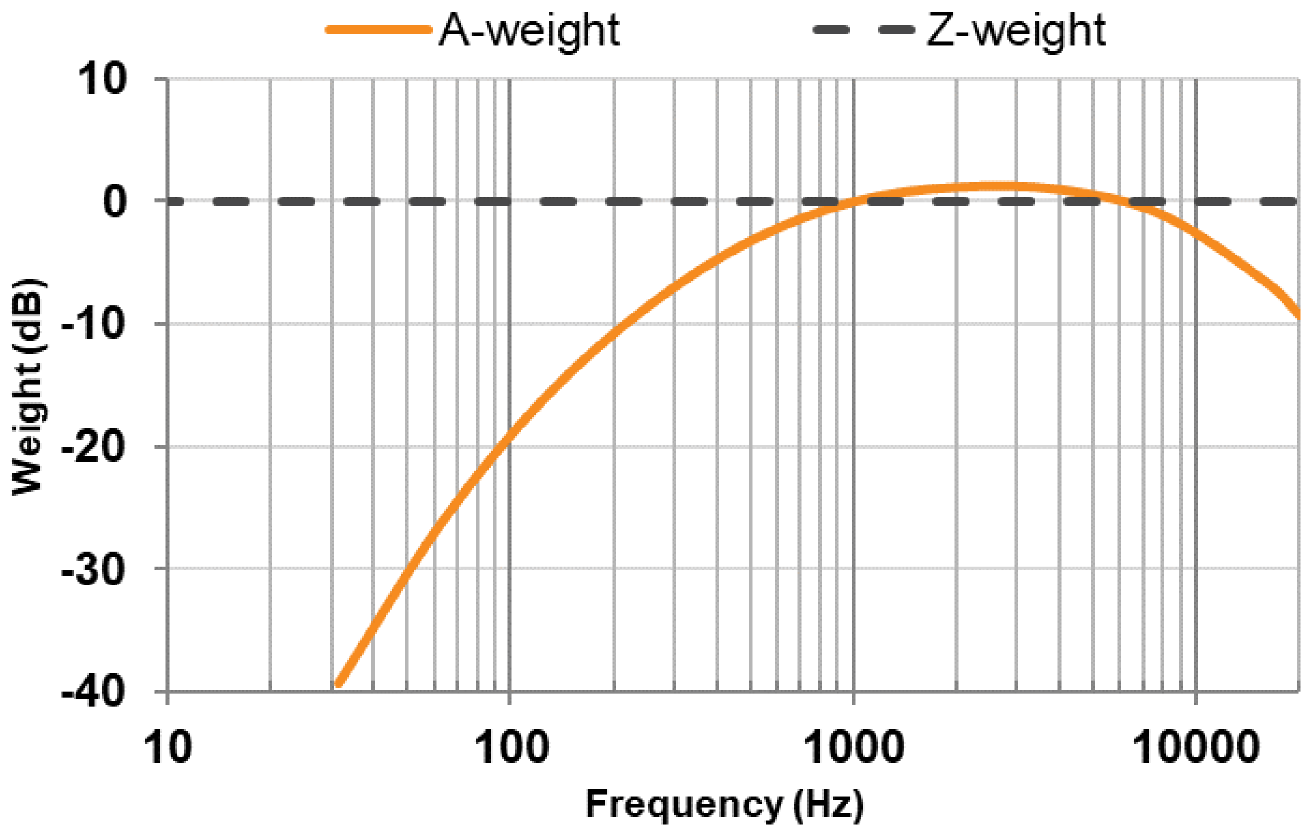
- Sound Level and Survey Data Summary
  - Sound level overview
  - Wind turbine audibility
  - Wind turbine noise annoyance
  - Annoyance and audibility in the home
- Predictors of Sound Annoyance
  - Description of regression models
  - Model validation method
  - Results!
- Preliminary Conclusions 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



Inner-ear Response



Sound Level Weighting

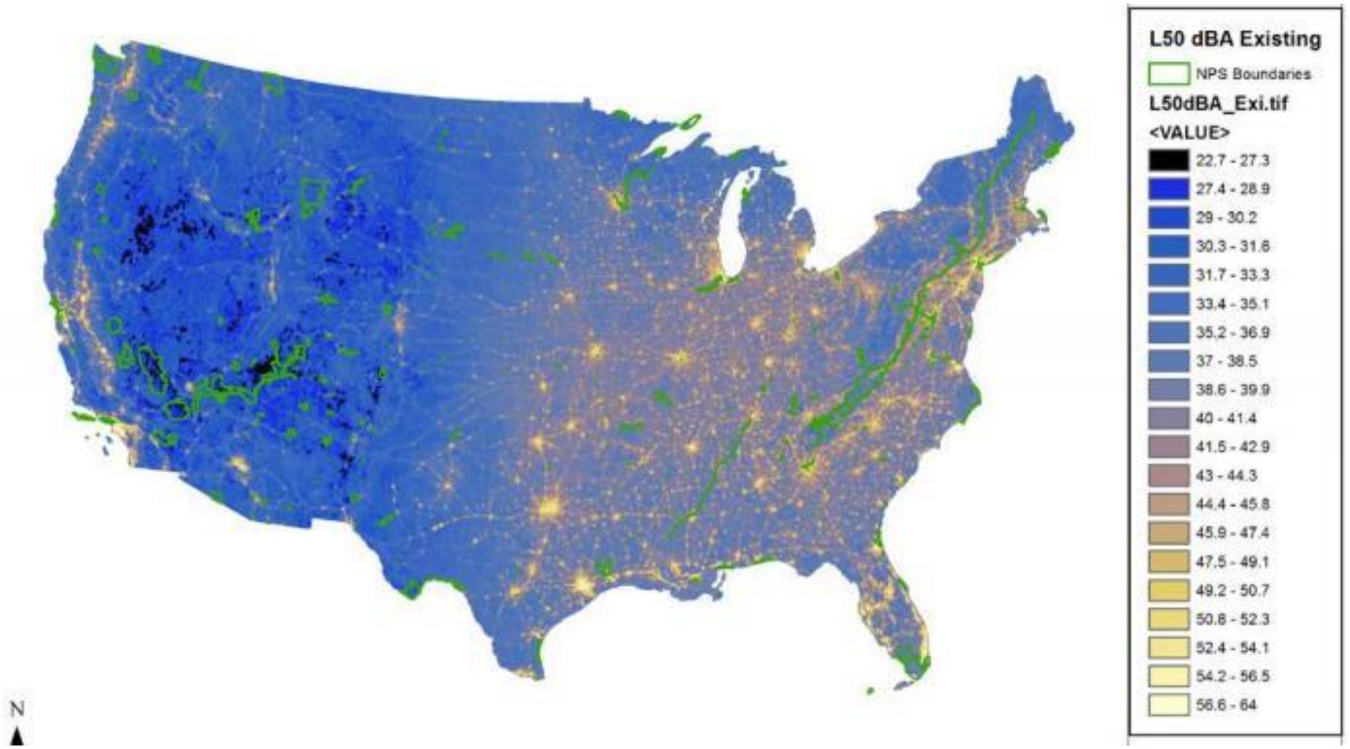
Sound Level Data: Descriptions and Sources

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

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Audibility and Annoyance to Wind Turbine Noise

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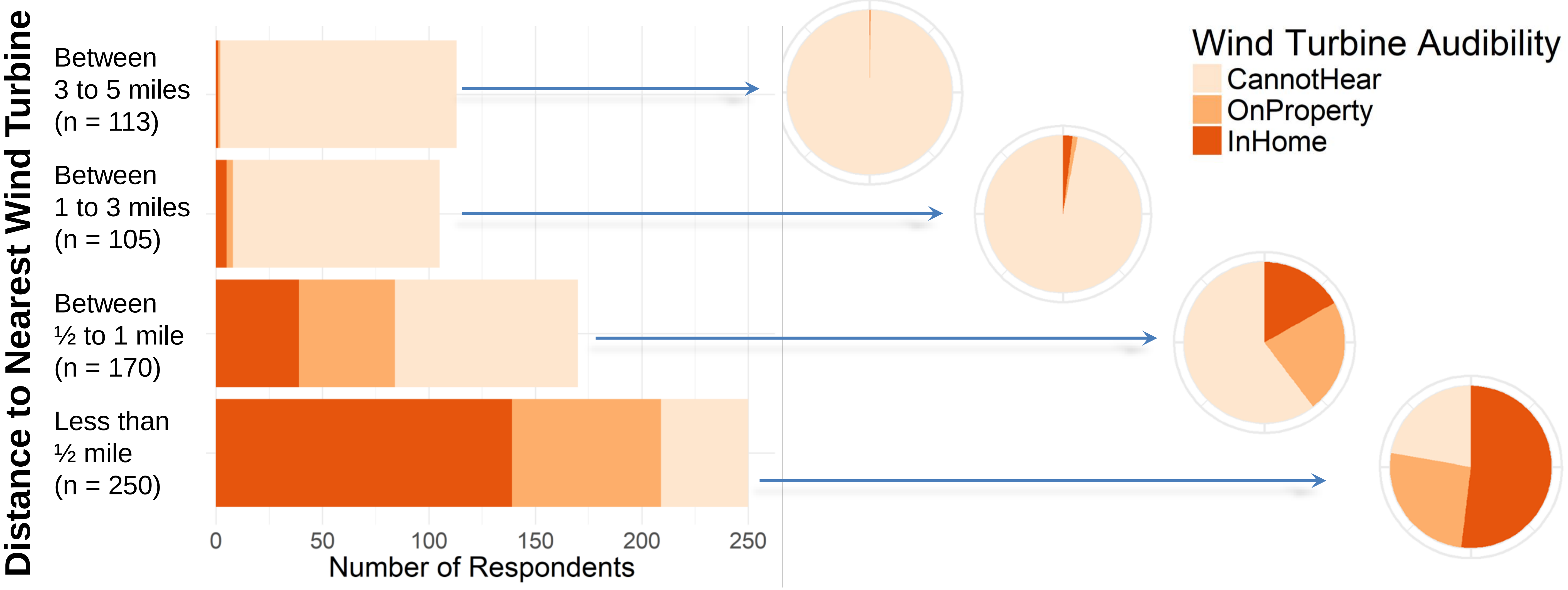
Wind Turbine Audibility in the Sample and Population

Respondent Count (Sample) / Population Proportion (Weighted)



Wind Turbine Audibility in the Surrounding Population

Population Summary

Distance to Nearest Wind Turbine

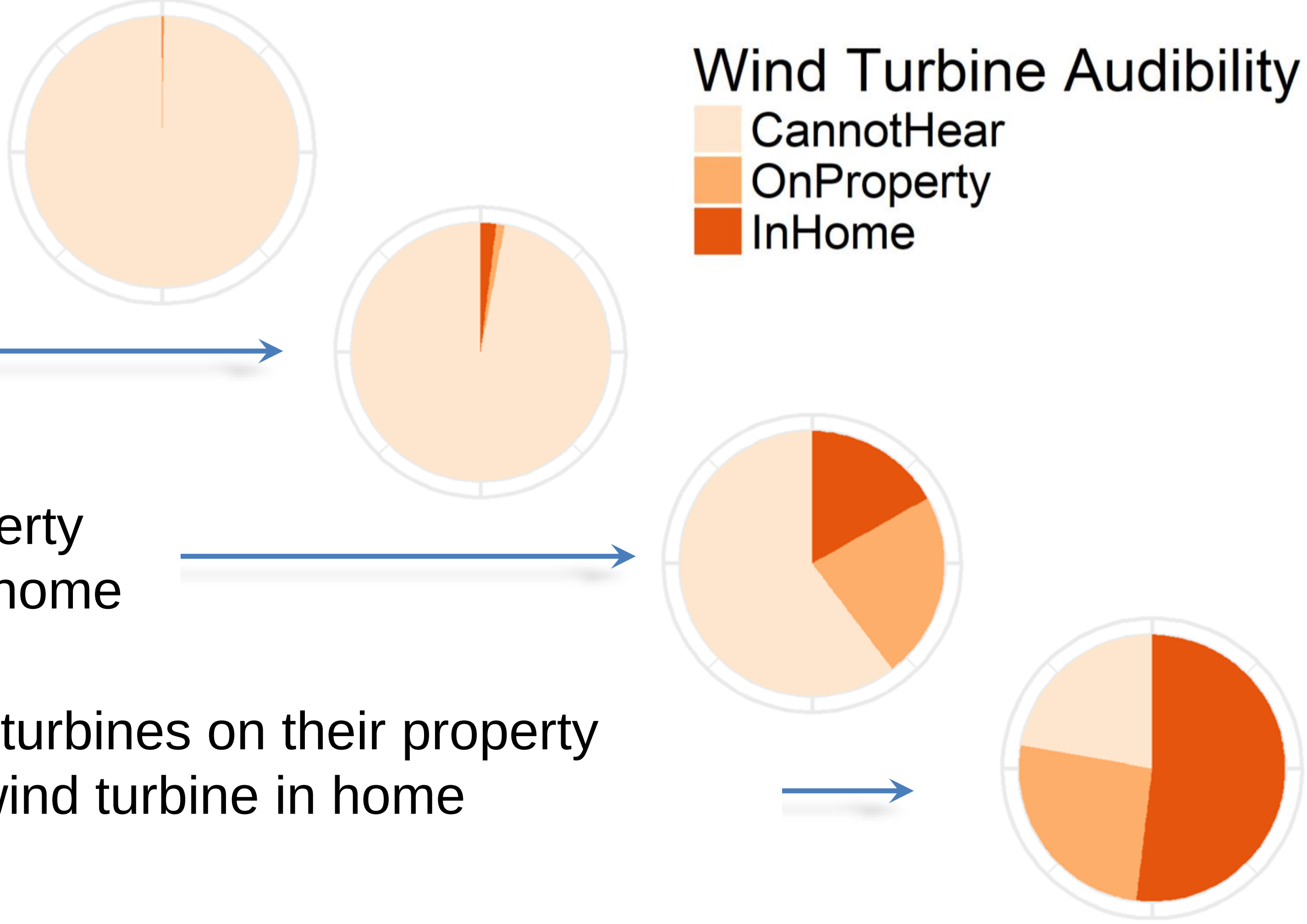
Between 3 to 5 miles (n = 113) — Almost all cannot hear wind turbines

Between 1 to 3 miles (n = 105) — Over 90% cannot hear wind turbines

Between ½ to 1 mile (n = 170) — ~40% hear wind turbines on their property
~20% can hear a wind turbine in their home

Less than ½ mile (n = 250) — ~75% of the population can hear wind turbines on their property
~50% living within ½ mile can hear a wind turbine in home

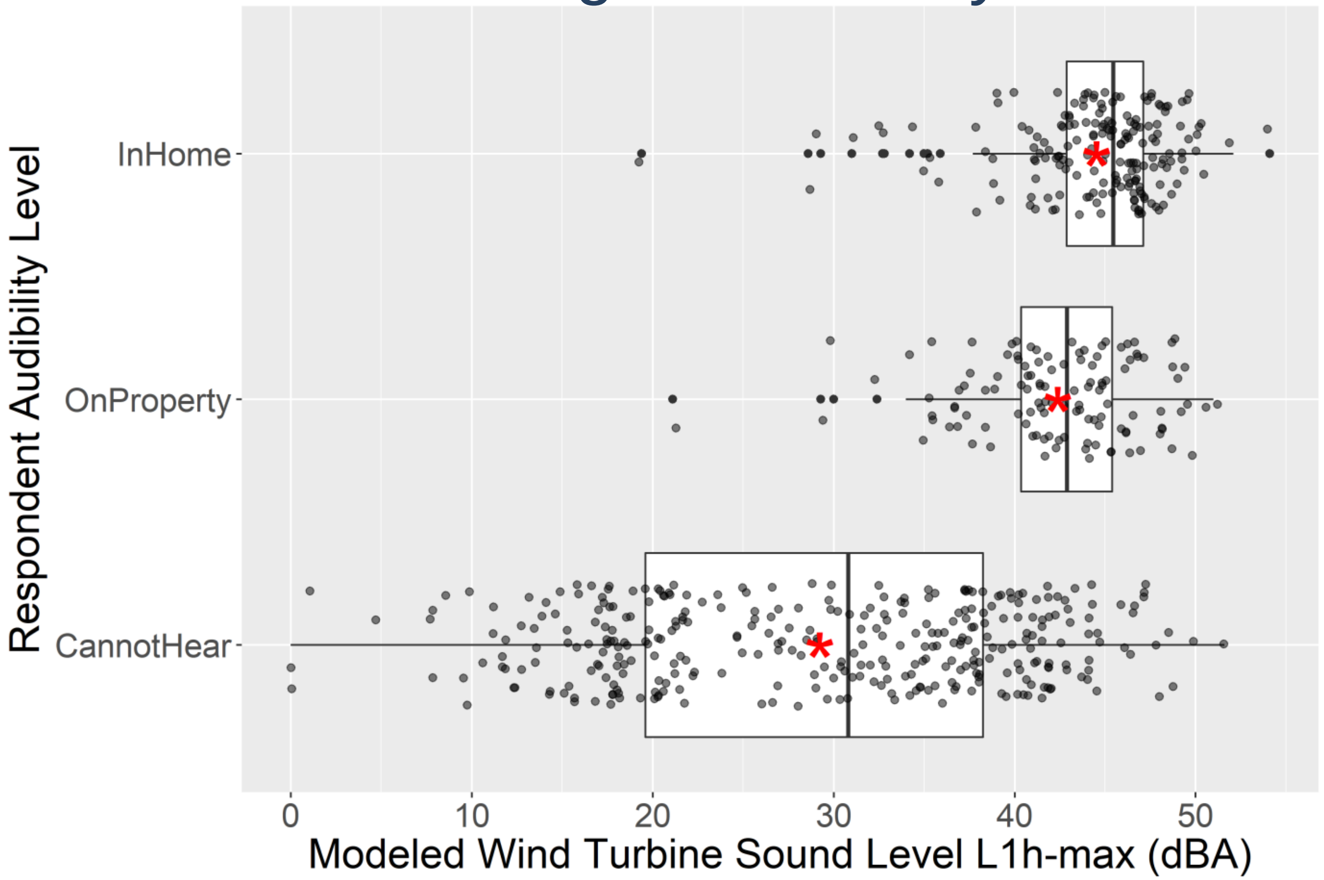
Population Proportion (Weighted)



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

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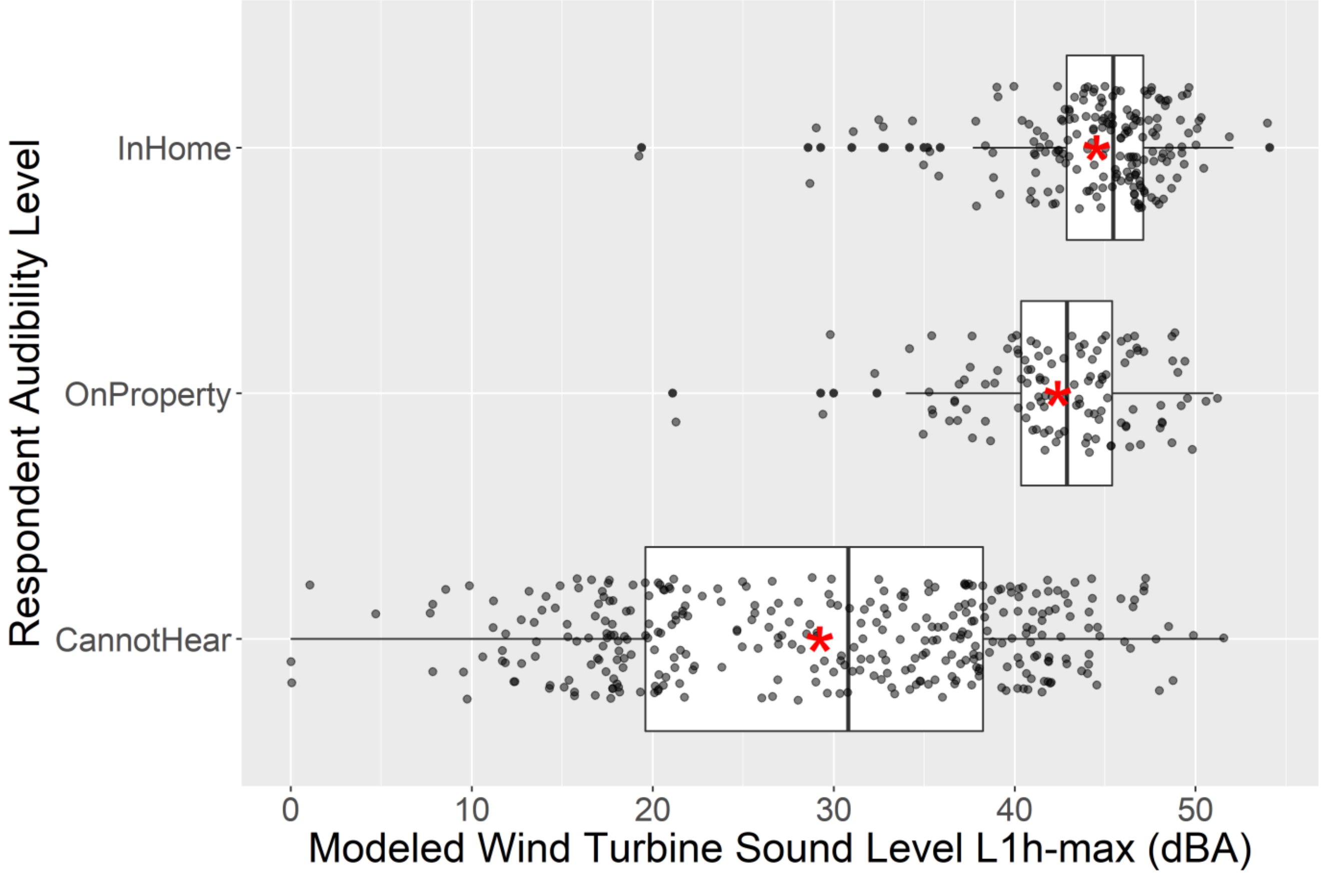
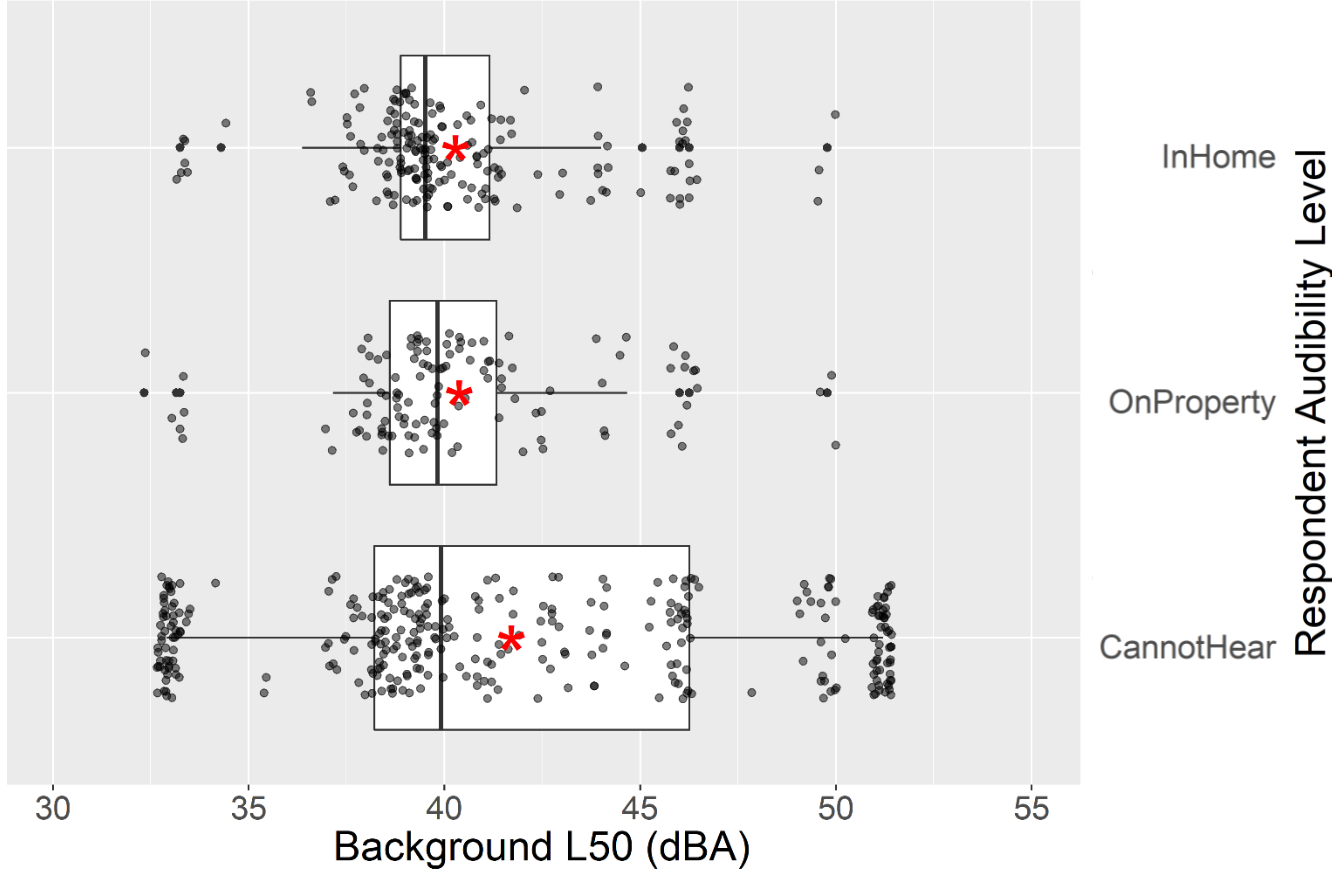


Local Background Sound Levels

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

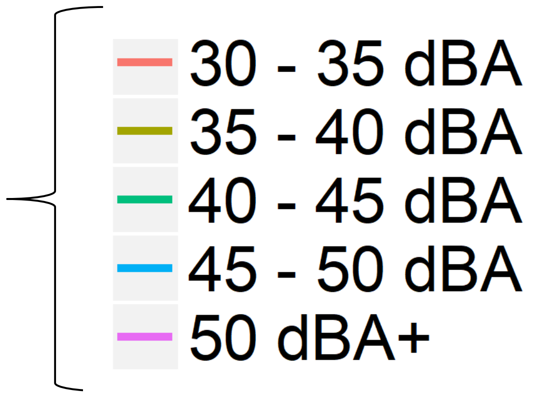
Sound Level Interaction

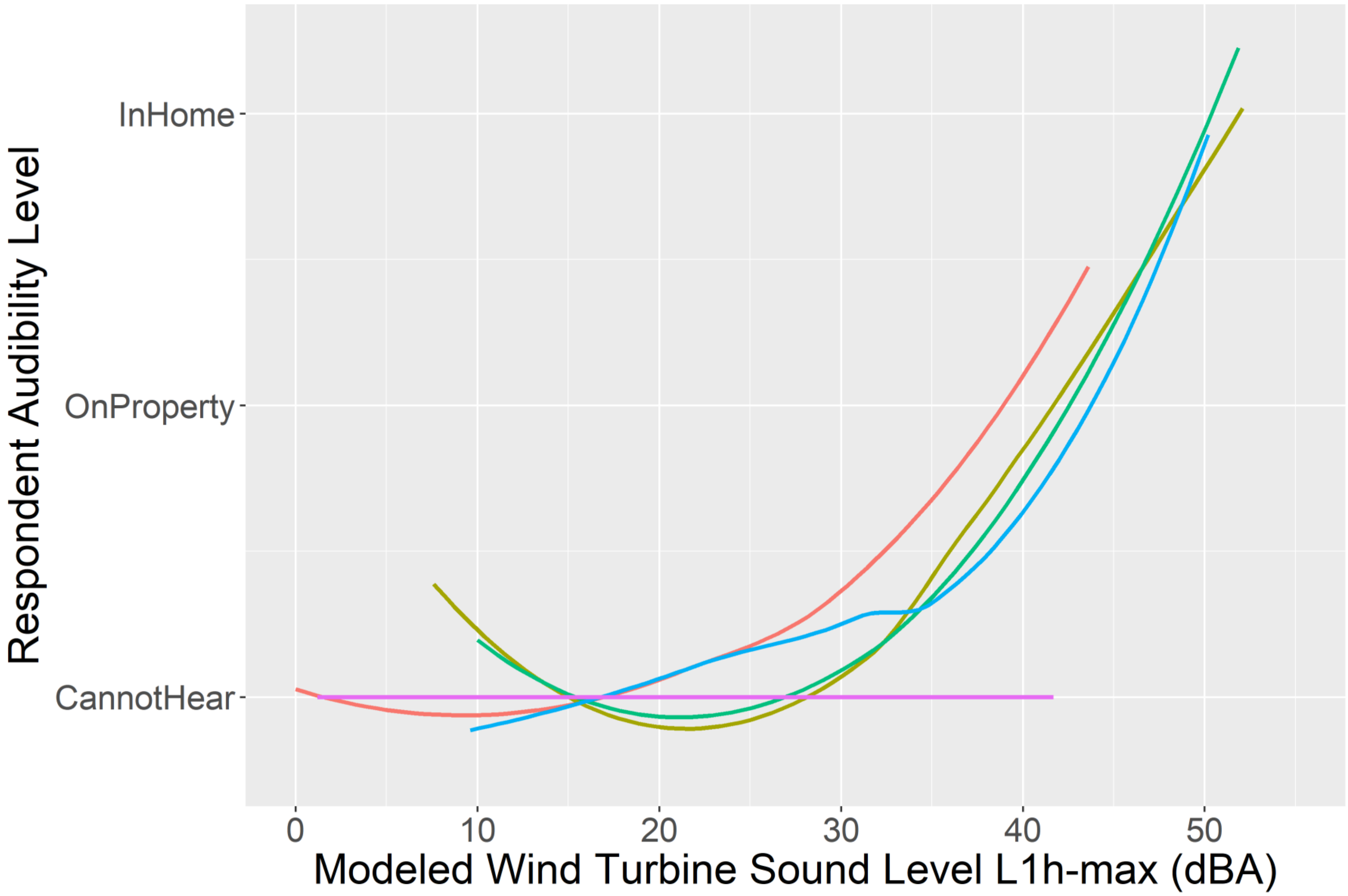
Wind turbine sound level

and

Background sound level

Background Sound Level Categories (dBA)





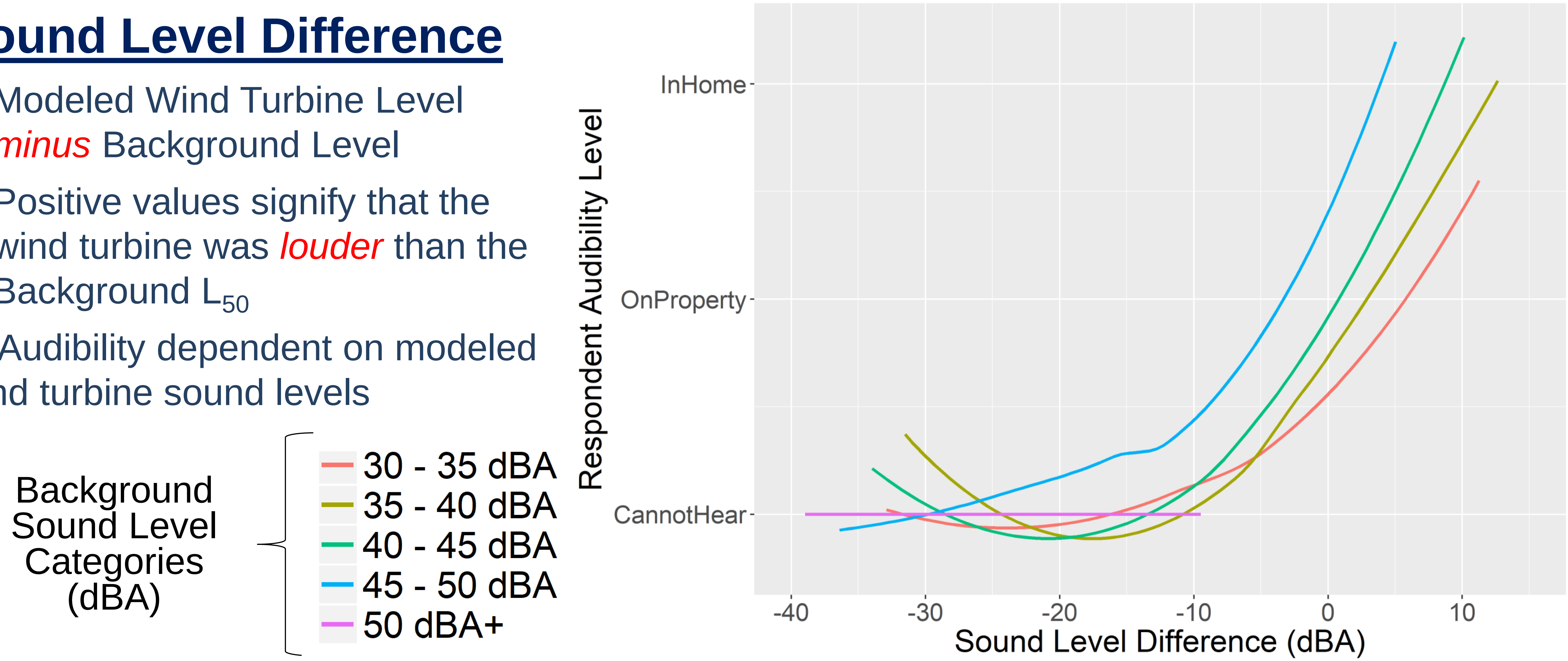
Note: Background Sound Level (Background L_{50}) is continuous; it is only categorical for plotting this relationship

Wind Turbine Audibility - Sound Level Difference Curve Fit of Survey Data by Background Sound

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



Note: Background Sound Level (Background 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
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  - Description of regression models
  - Model validation method
  - Results!
- Preliminary Conclusions and Takeaways
- Future Work

Classifying Respondent Annoyance Level

n = 656

→ *Separating annoyance from sound and wind turbine audibility*

22. Have you ever heard sound from the wind project?

- O Yes
- O No
- O 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?

- O Yes
- O No
- O 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?	**Not at All**	**Slightly**	**Somewhat**	**Moderately**	**Very**	**Don't Know**
a. Change to the landscape	1	2	3	4	5	O
b. Wind turbine lighting	1	2	3	4	5	O
c. Shadow flicker	1	2	3	4	5	O
d. Sound of the wind project	1	2	3	4	5	O

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[Image] Portland State University: Wind Energy Survey 2016

Classifying Respondent Annoyance Level

n = 656

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b. Wind turbine lighting	1	2	3	4	5	O
c. Shadow flicker	1	2	3	4	5	O
d. Sound of the wind project	1	2	3	4	5	O

Percentage of respondents in each response group

[Image] Portland State University: Wind Energy Survey 2016

Classifying Respondent Annoyance Level

n = 656

→ *Simplified classification for understanding audibility and annoyance*

22. Have you ever heard sound from the wind project?

- O Yes
- O No
- O Don't Know

Skip to #23

22a. Can you hear sound from the wind project when you are <u>on your property, but outside your home</u>?

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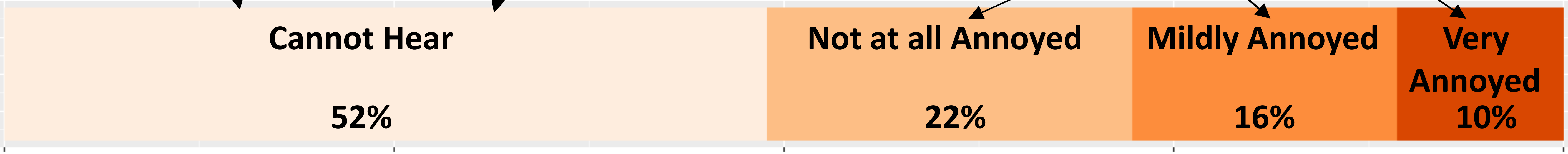
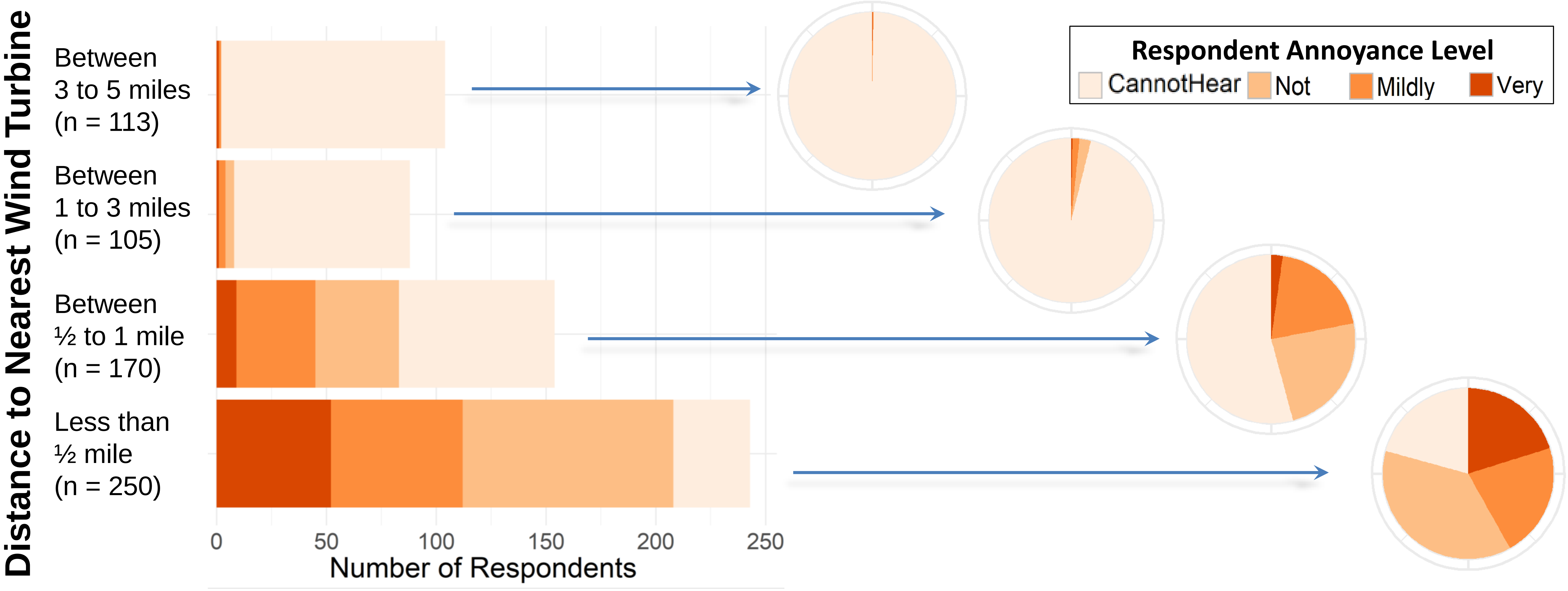


Percentage of respondents in each response group

[Image] Portland State University: Wind Energy Survey 2016

Wind Turbine Noise Annoyance – Survey Results

Respondent Count (Sample) / Population Proportion (Weighted)



Wind Turbine Noise Annoyance Summary

Respondent Count (Sample)

Population Proportion (Weighted)

Distance to Nearest Wind Turbine

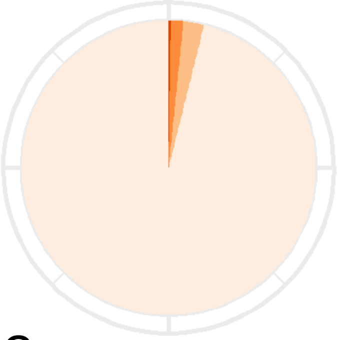
Respondent Annoyance Level
CannotHear | Not | Mildly | Very

Between 3 to 5 miles (n = 113)

Almost 100% cannot hear wind turbines

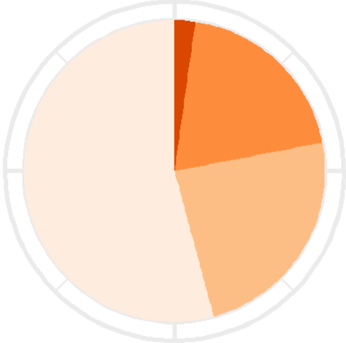
Between 1 to 3 miles (n = 105)

Over 90% cannot hear wind turbines



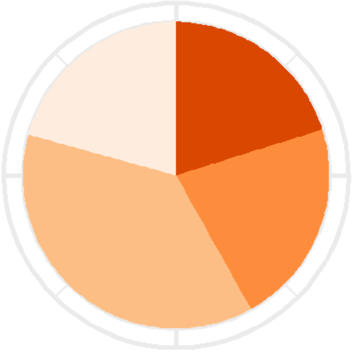
Between ½ to 1 mile (n = 170)

~75% expressed no annoyance to wind turbine noise
20% were Mildly annoyed, <3% were Very annoyed



Less than ½ mile (n = 250)

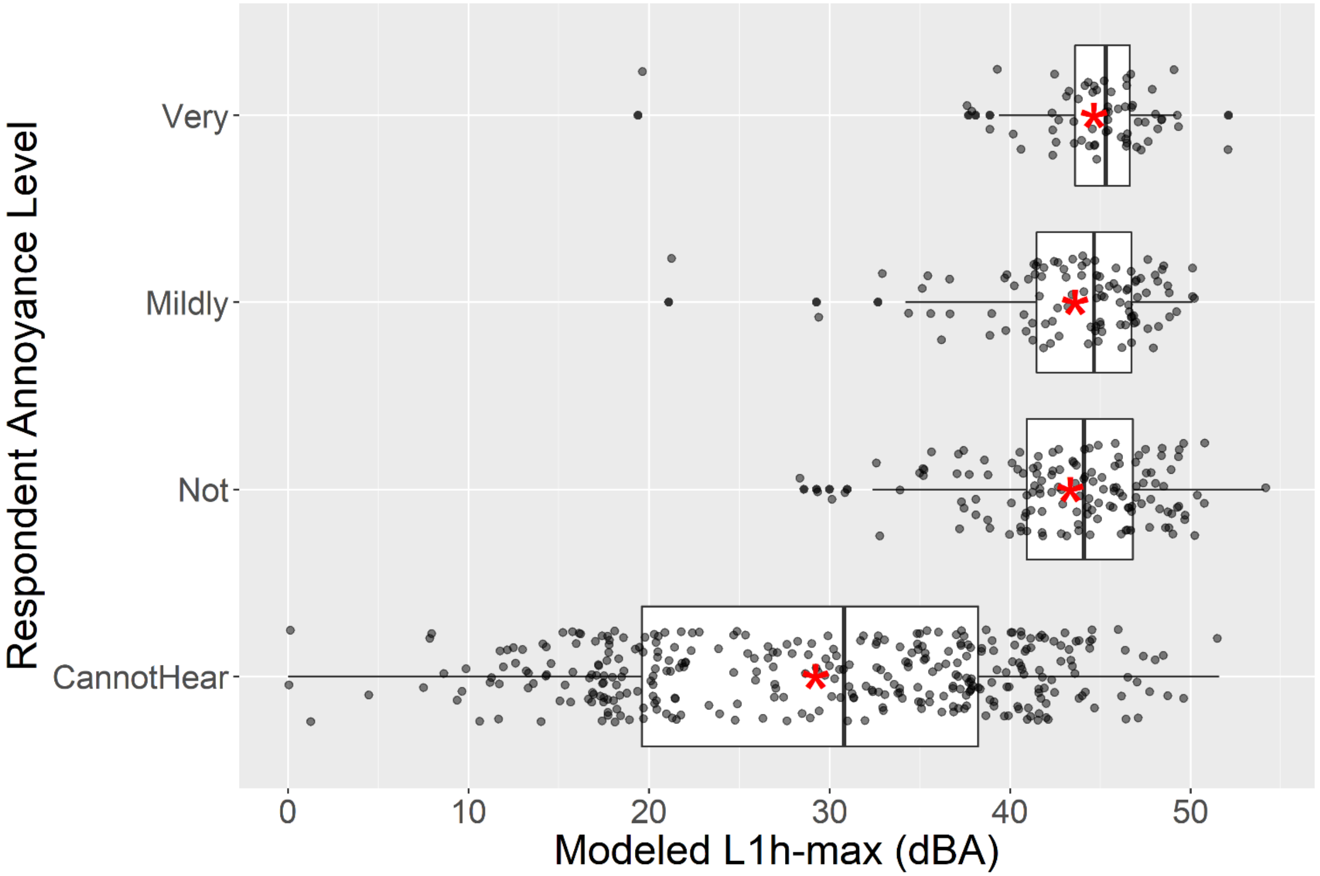
20% of the population within a half mile was Very annoyed
Same percentage of respondents Mildly annoyed as ½ to 1 mile



Sound Levels and Annoyance

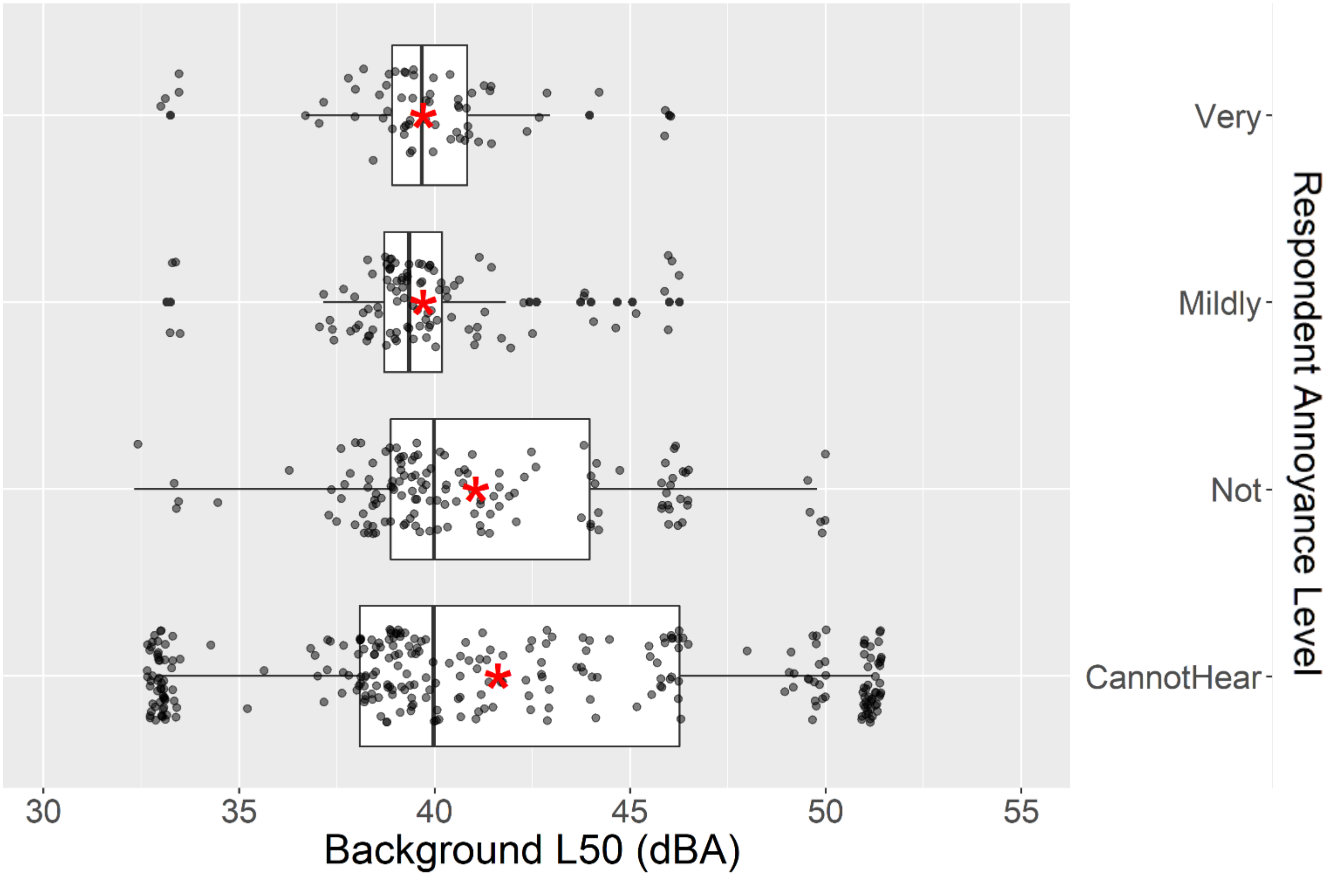
Modeled Wind Turbine Sound Levels

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

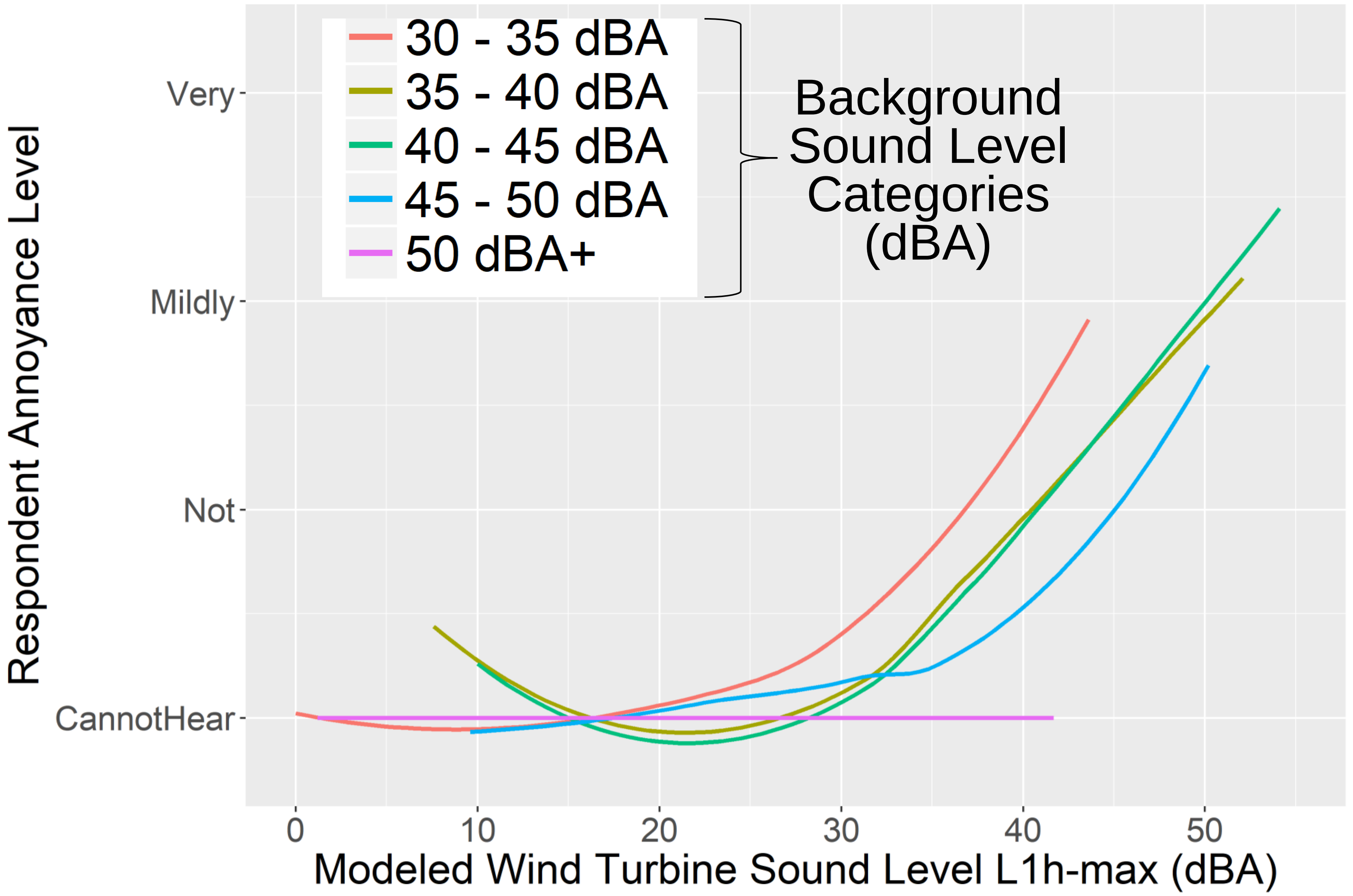
Sound Level Interaction

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 L_{50}) 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?
- O Yes
- O No
- O Don't Know

Skip to #23

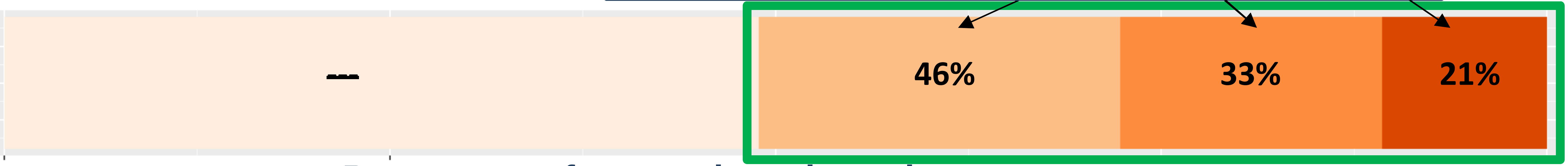
22a. Can you hear sound from the wind project when you are on your property, but outside your home?
- O Yes
- O No
- O Don't Know

Skip to #23

n = 301

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.

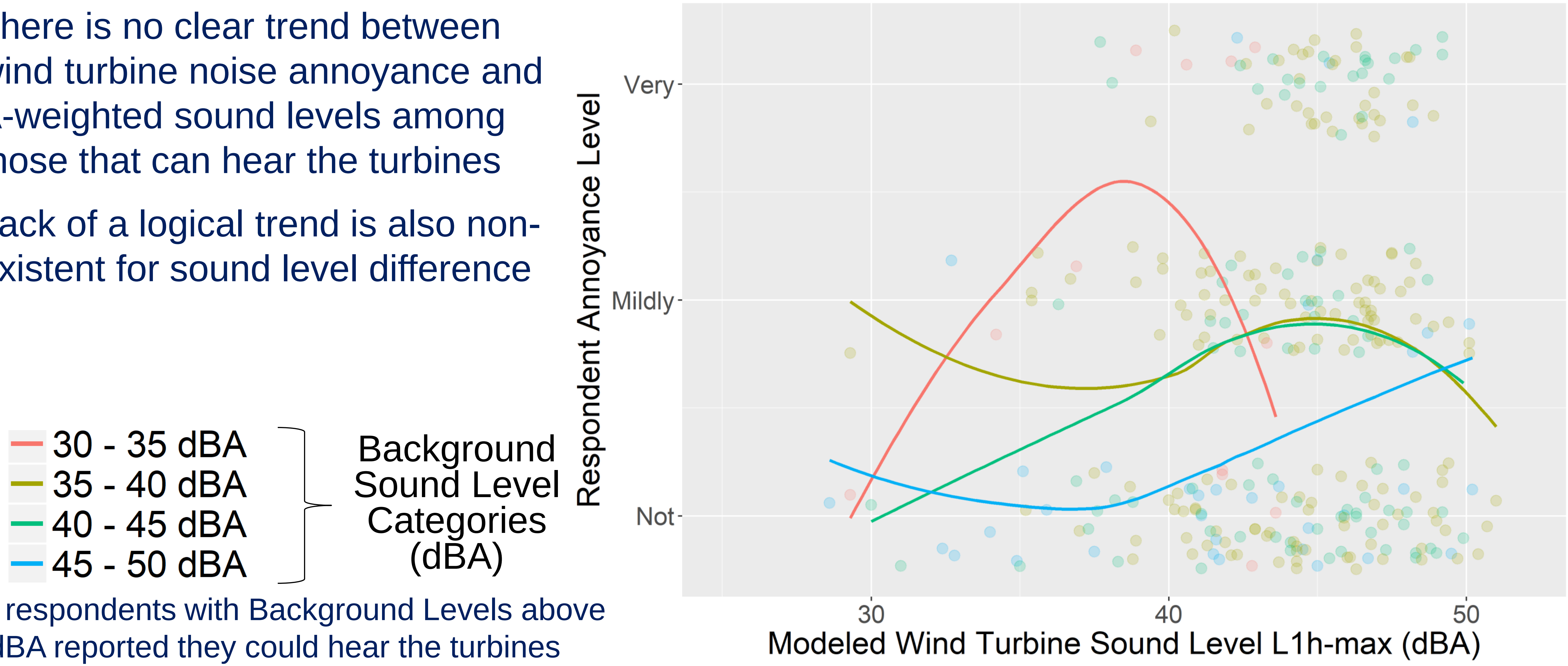
24. To what extent do you feel annoyed by each of the following effects of the local wind project?	Not at All	Slightly	Somewhat	Moderately	Very	Don't Know
a. Change to the landscape	1	2	3	4	5	O
b. Wind turbine lighting	1	2	3	4	5	O
c. Shadow flicker	1	2	3	4	5	O
d. Sound of the wind project	1	2	3	4	5	O



Percentage of respondents in each response group

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

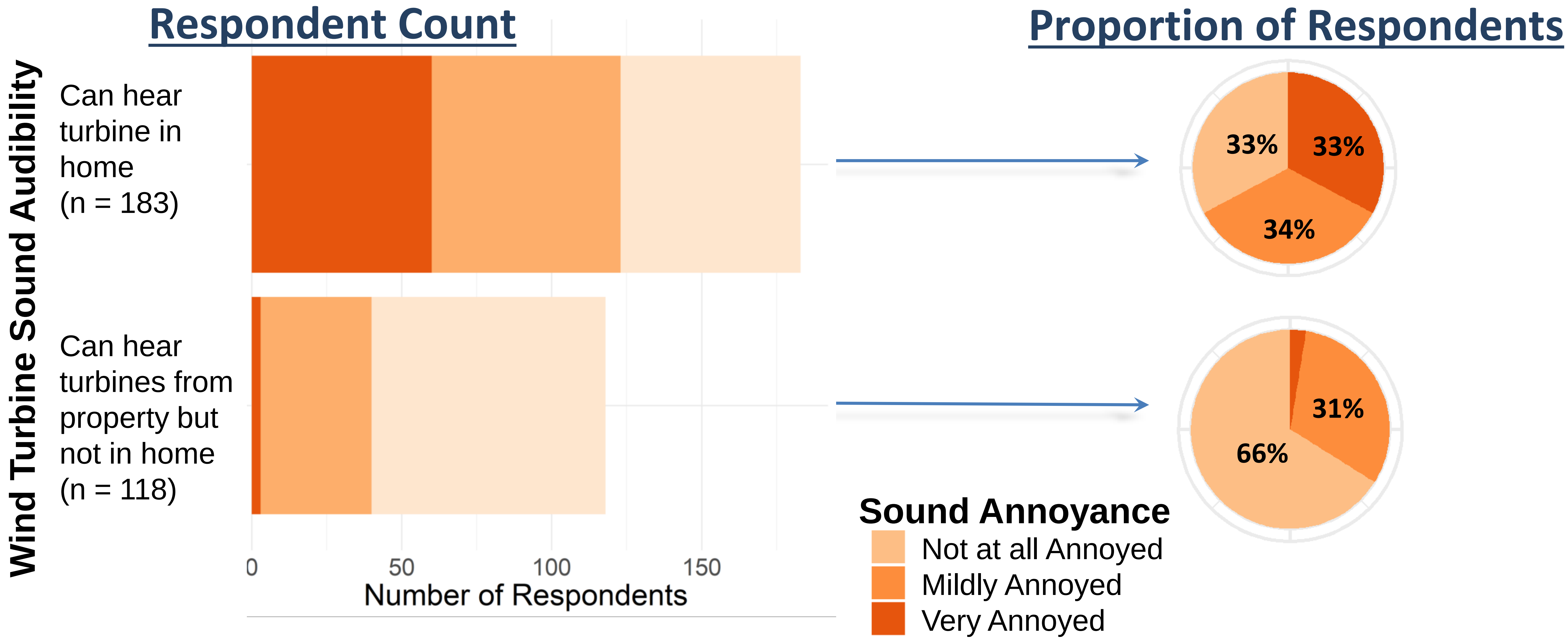
Annoyance Takeaways

- 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



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

- Sound Level and Survey Data Summary
  - Sound level overview
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  - Model validation method
  - Results!
- Preliminary Conclusions and Takeaways
- Future Work

Three Regression Models were Used to Assess Predictors of Annoyance

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

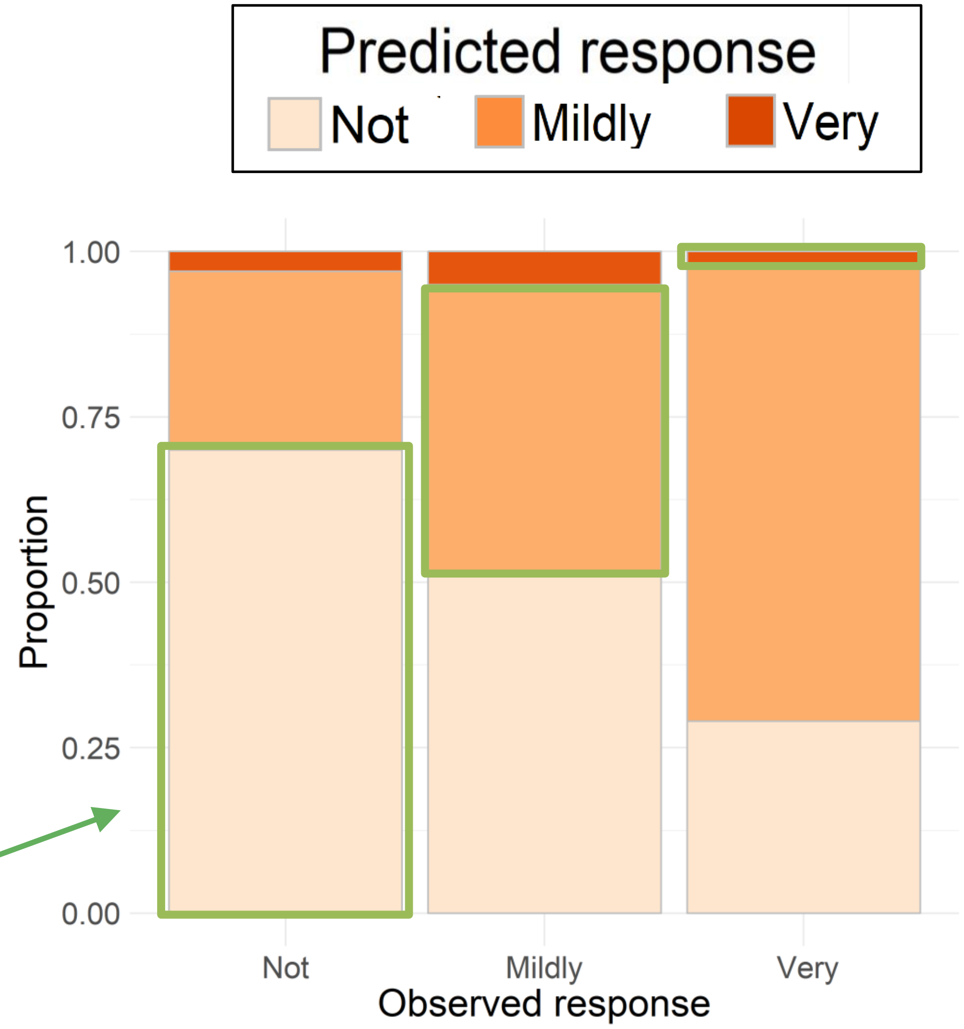
1) **Sound Level Model**
   - Modeled wind turbine $L_{1h\text{-}max}$ sound pressure level (dBA)
   - Local estimated daytime L_{50} background sound level (dBA)
2) **Objective Model**
   - All variables from Sound Level Model
   - Turbines in view from property
   - Resident prior to WT development 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.



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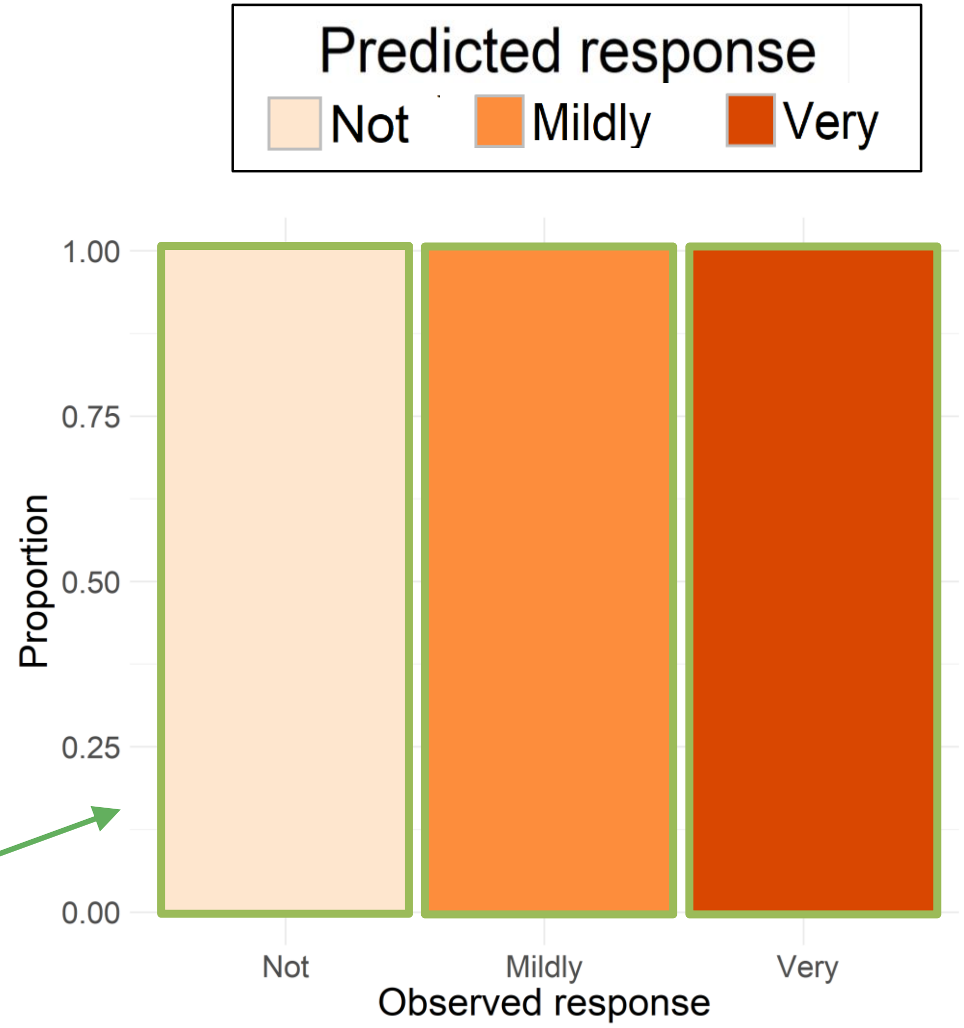
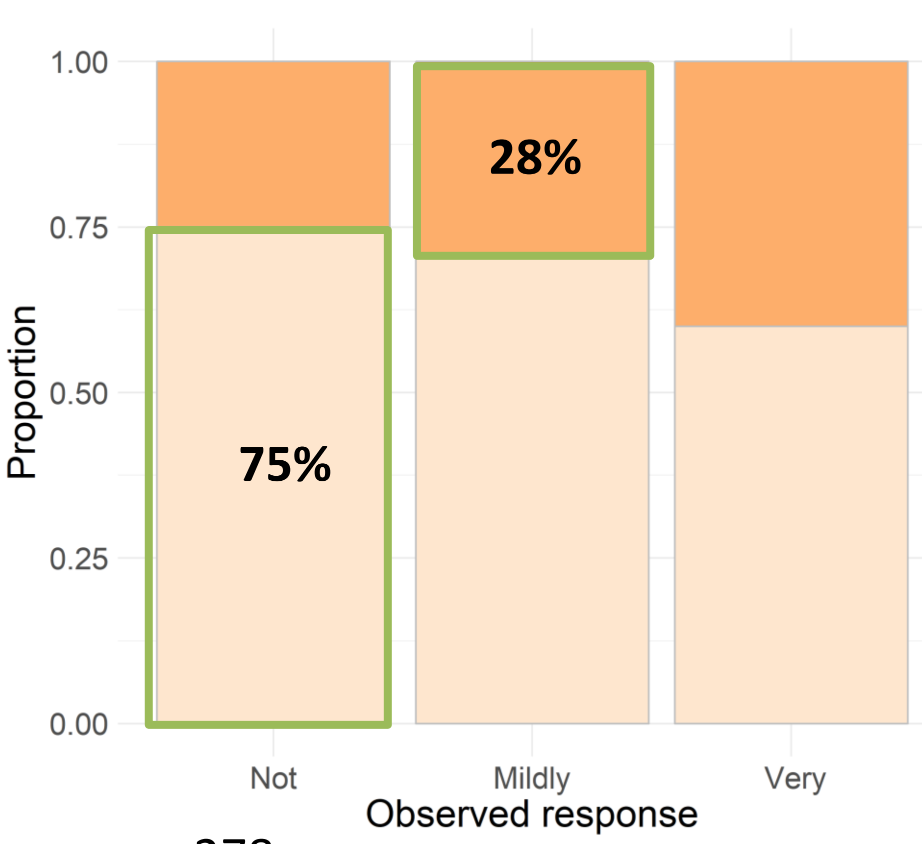


EXAMPLE: 100% PREDICTED CORRECTLY

Model Validation Results

Predicted response: Not, Mildly, Very

Sound Level Model

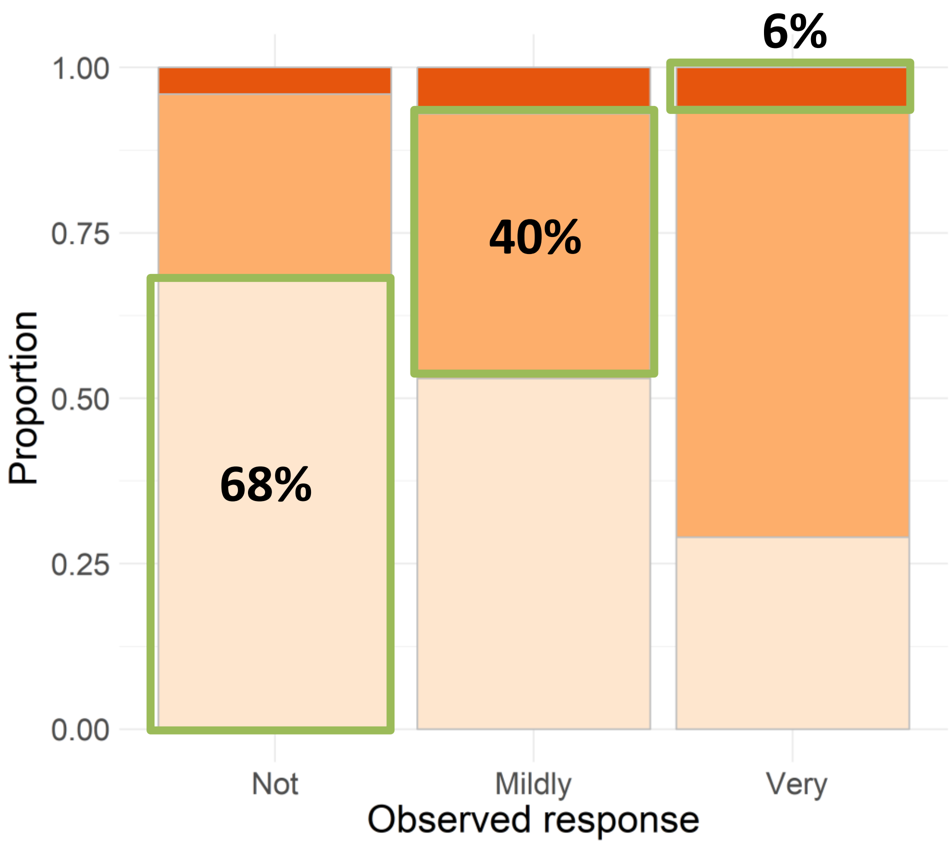


n = 278

R^2 =0.12

Correct predictions = 45%

Objective Model

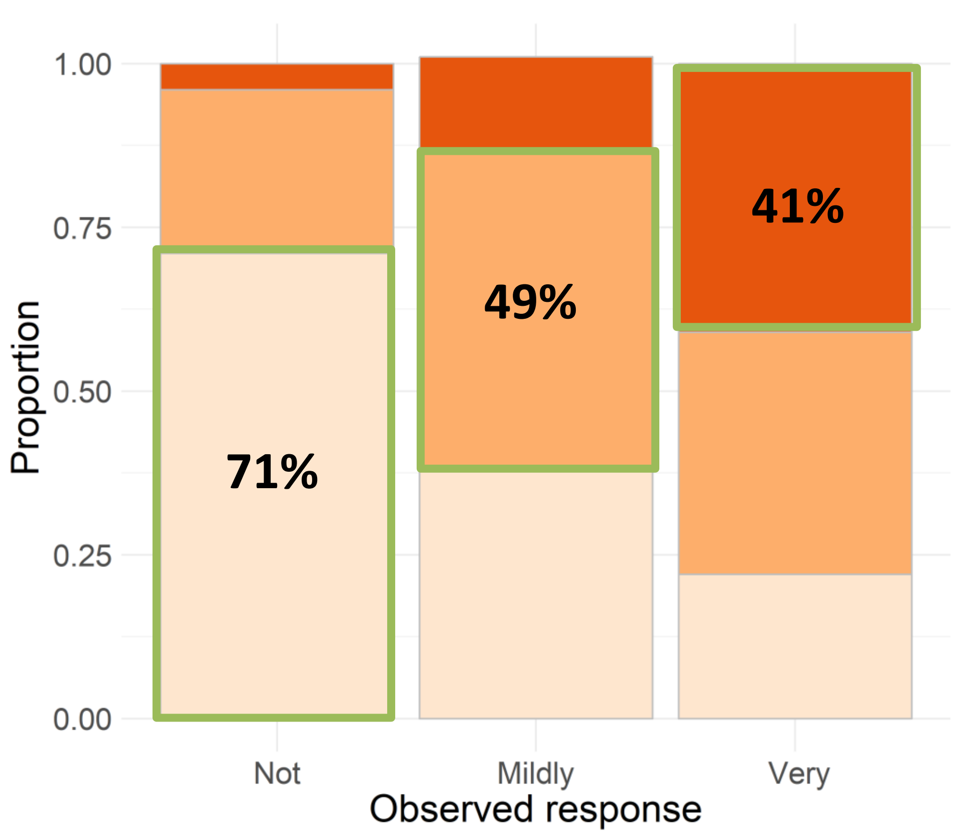


n = 265

R^2 =0.21

Correct predictions = 47%

Subjective Model



n = 264

R^2 =0.38

Correct predictions = 58%

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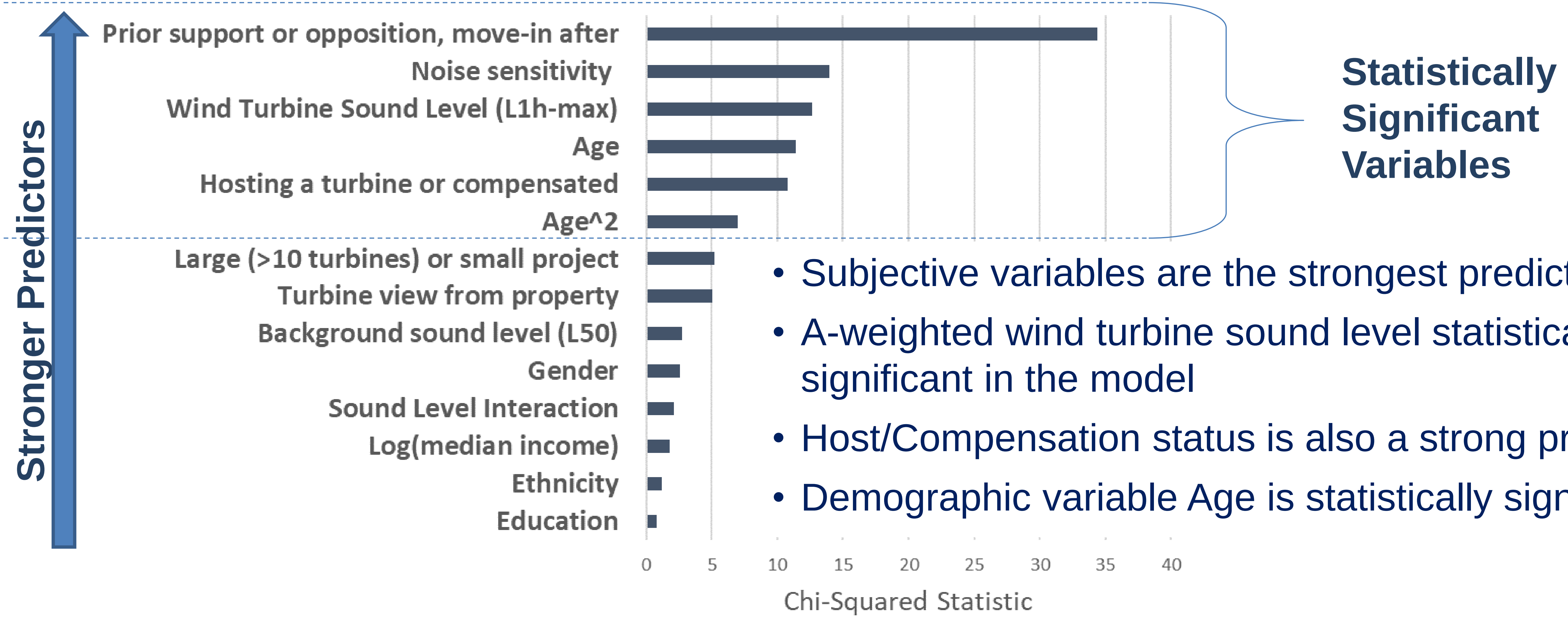
Variable Importance in the Subjective Model



- 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

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

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)

source: hingemarketing.com

Next Steps

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

Questions?

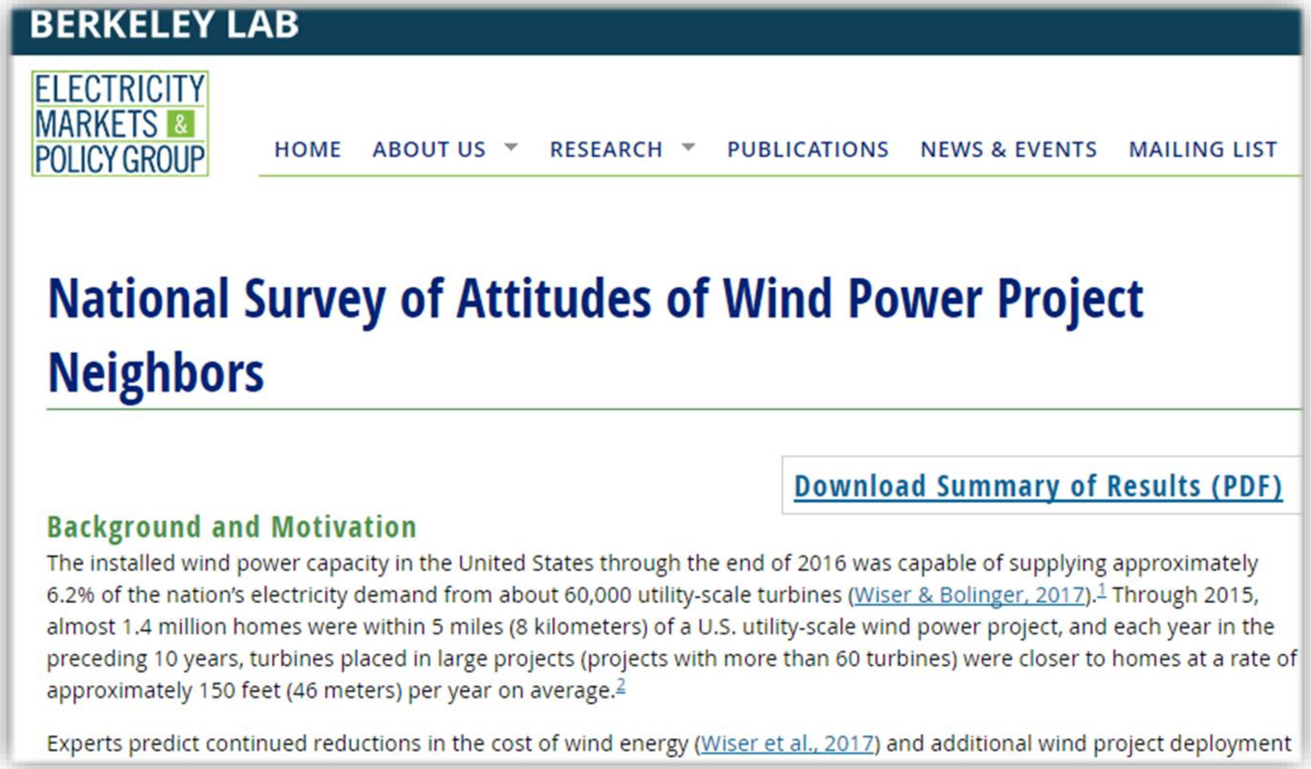
Ryan Haac: ryan.haac@rsginc.com

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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National Survey of Attitudes of Wind Power Project Neighbors

Download Summary of Results (PDF)

Background and Motivation

The installed wind power capacity in the United States through the end of 2016 was capable of supplying approximately 6.2% of the nation's electricity demand from about 60,000 utility-scale turbines (Wiser & Bolinger, 2017).[1] Through 2015, almost 1.4 million homes were within 5 miles (8 kilometers) of a U.S. utility-scale wind power project, and each year in the preceding 10 years, turbines placed in large projects (projects with more than 60 turbines) were closer to homes at a rate of approximately 150 feet (46 meters) per year on average.[2]

Experts predict continued reductions in the cost of wind energy (Wiser et al., 2017) and additional wind project deployment

If you wish to cite these results use the following:

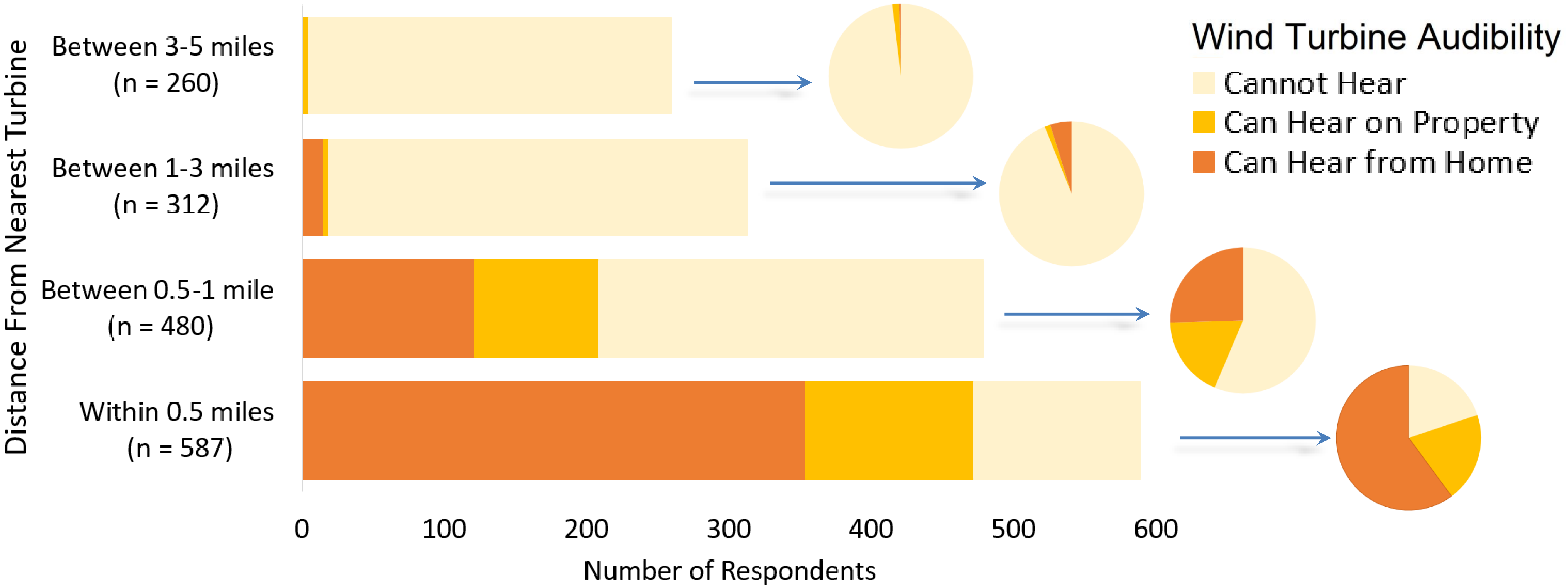
Haac, R., K. Kaliski, M. Landis, B. Hoen, J. Firestone, J. Rand, (2018) Predicting Audibility Of and Annoyance To Wind Power Project Sounds Using Modeled Sound. Lawrence Berkeley National Laboratory. Preliminary Results Webinar. February 27, 2018.

This work is supported by the US DOE Wind Energy Technologies Office

Supplemental Slides

Wind Turbine Audibility in the Surrounding <u>Full Sample</u> Population

Respondent Count (Sample) Population Proportion (Weighted)



Wind Turbine Audibility in the Surrounding <u>Full Sample</u> Population

Respondent Count (Sample)

Population Proportion (Weighted)

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

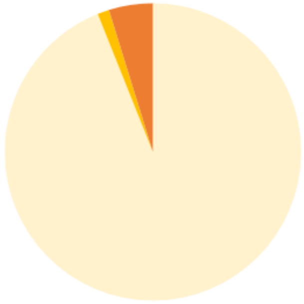
Distance From Nearest Turbine

Between 3-5 miles
(n = 260)

Almost 100% cannot hear wind turbines

Between 1-3 miles
(n = 312)

Over 90% cannot hear wind turbines

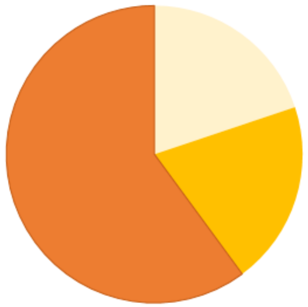


Between 0.5-1 mile
(n = 480)

~44% hear wind turbines on property
~ about 25% can hear a wind turbine in their home

Within 0.5 miles
(n = 587)

~80% hear wind turbines on property
~60% of the population within a half mile can hear a wind turbine in their home



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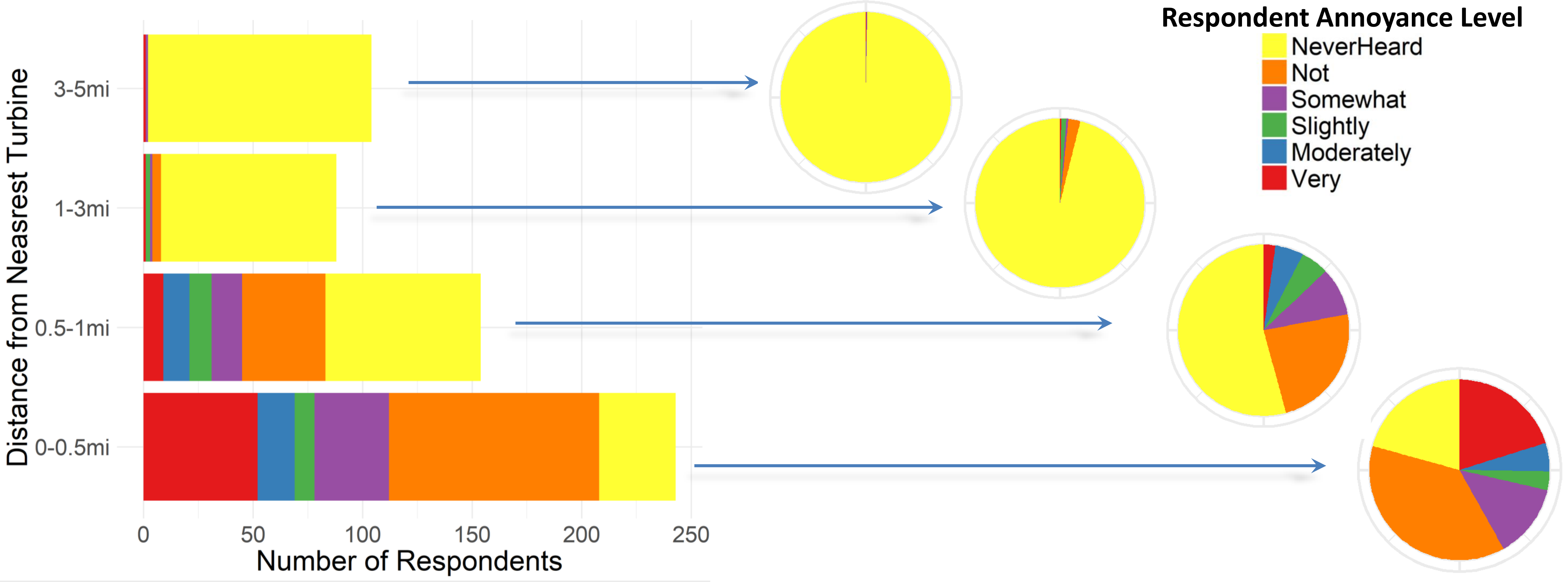
Wind Turbine Noise Annoyance – Survey Results

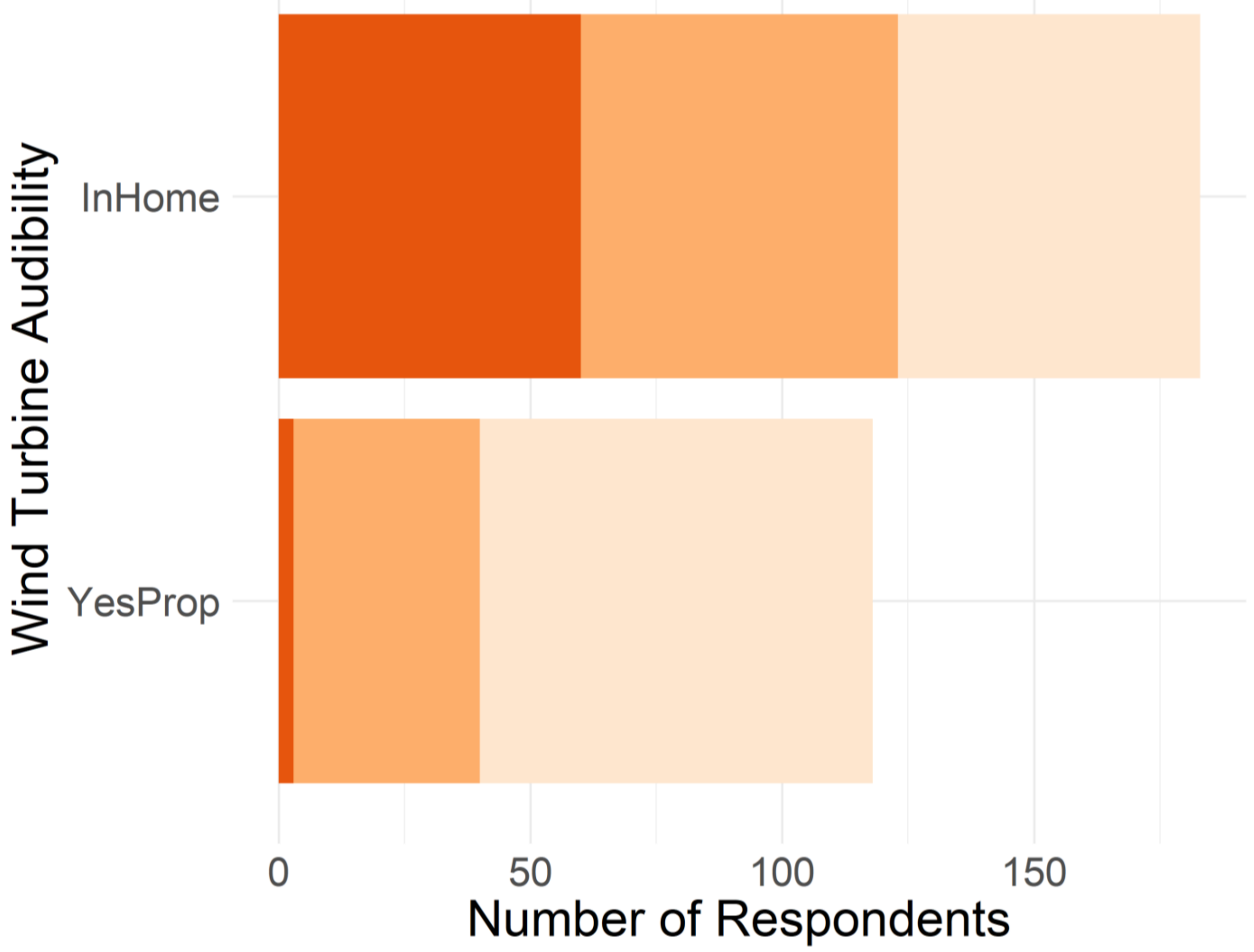
Respondent Count (Sample)

Population Proportion (Weighted)

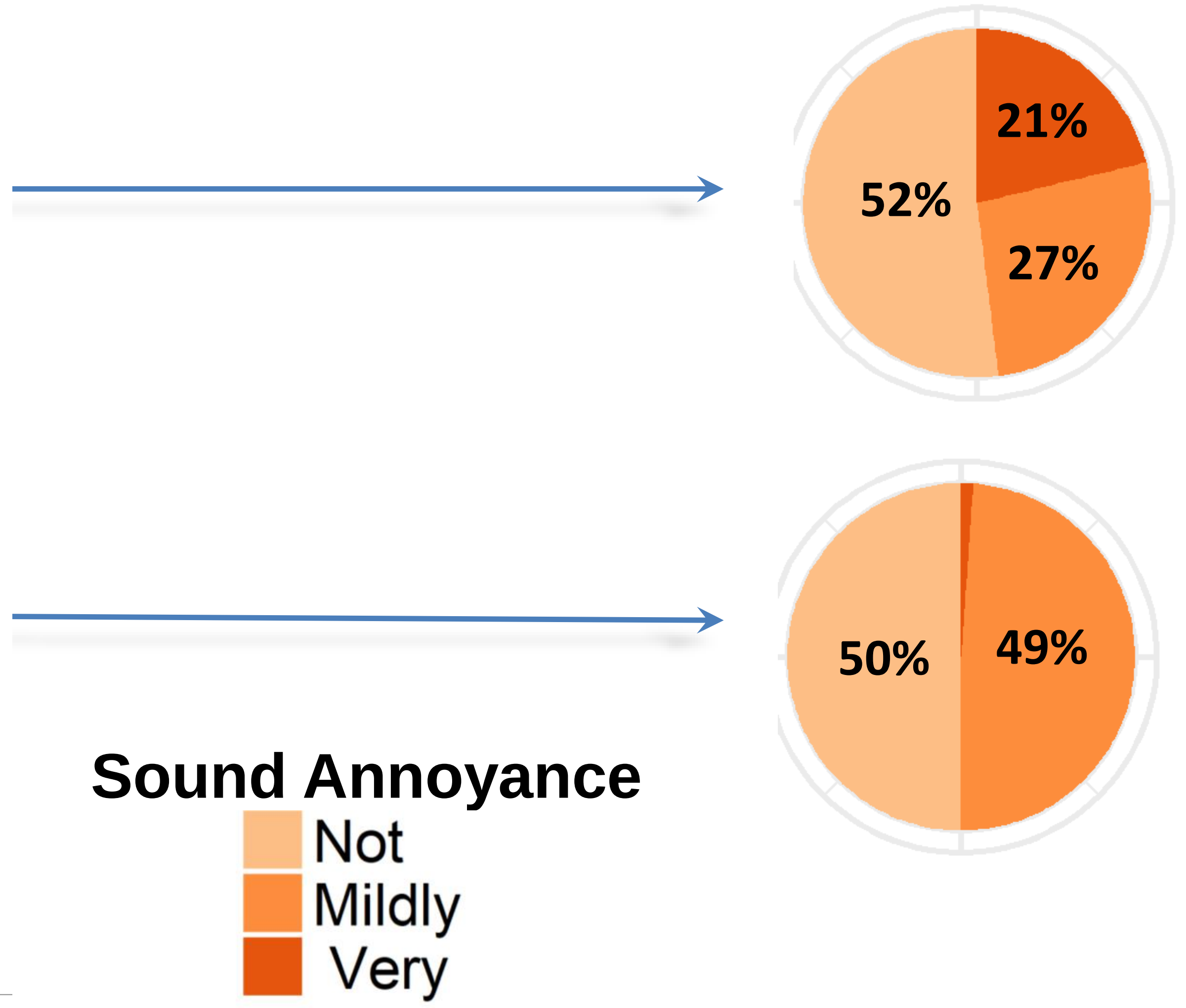


Annoyance and Audibility Inside the Home and On Property Grouped by Audibility

Respondent Count

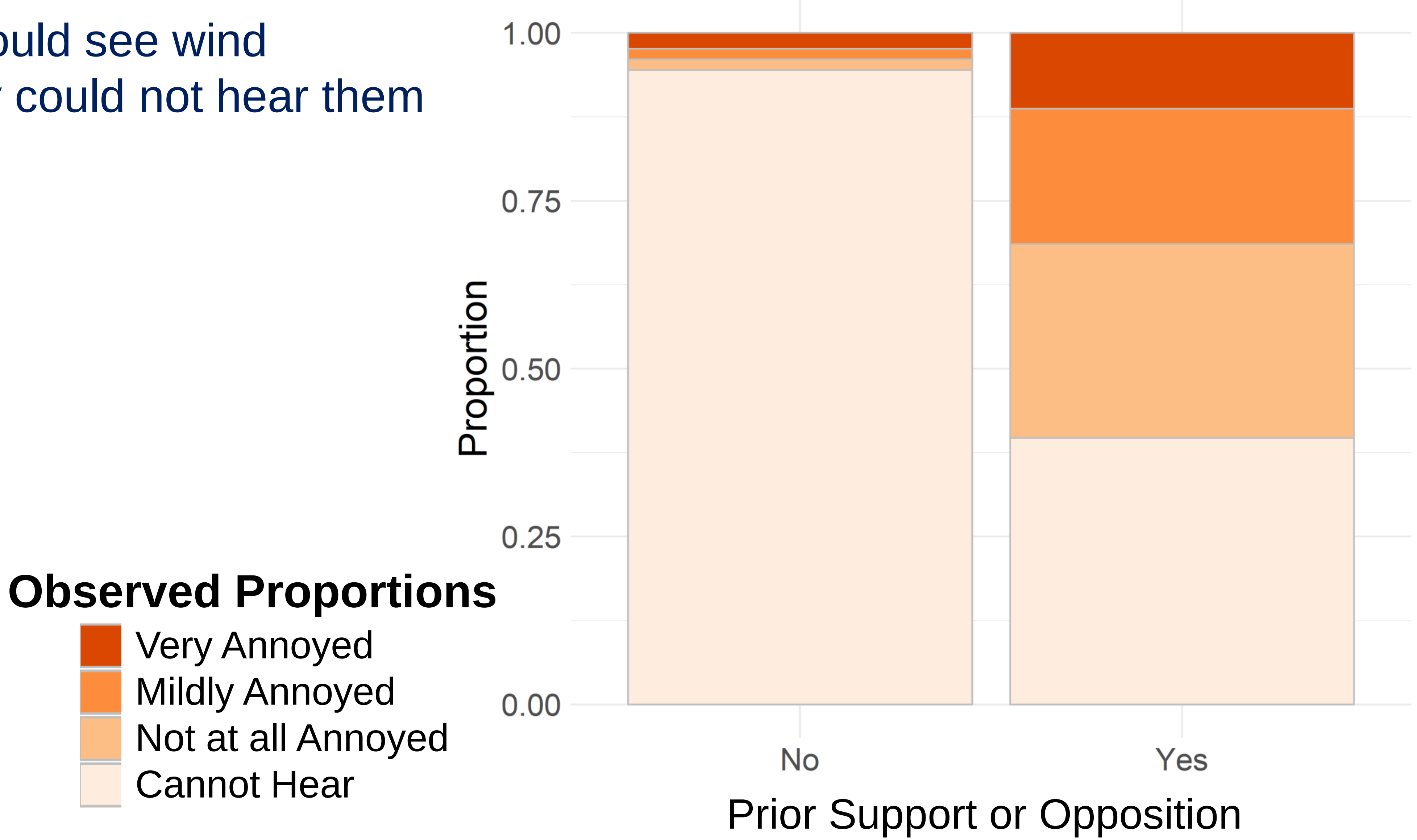


Proportion of Population (weighted data)



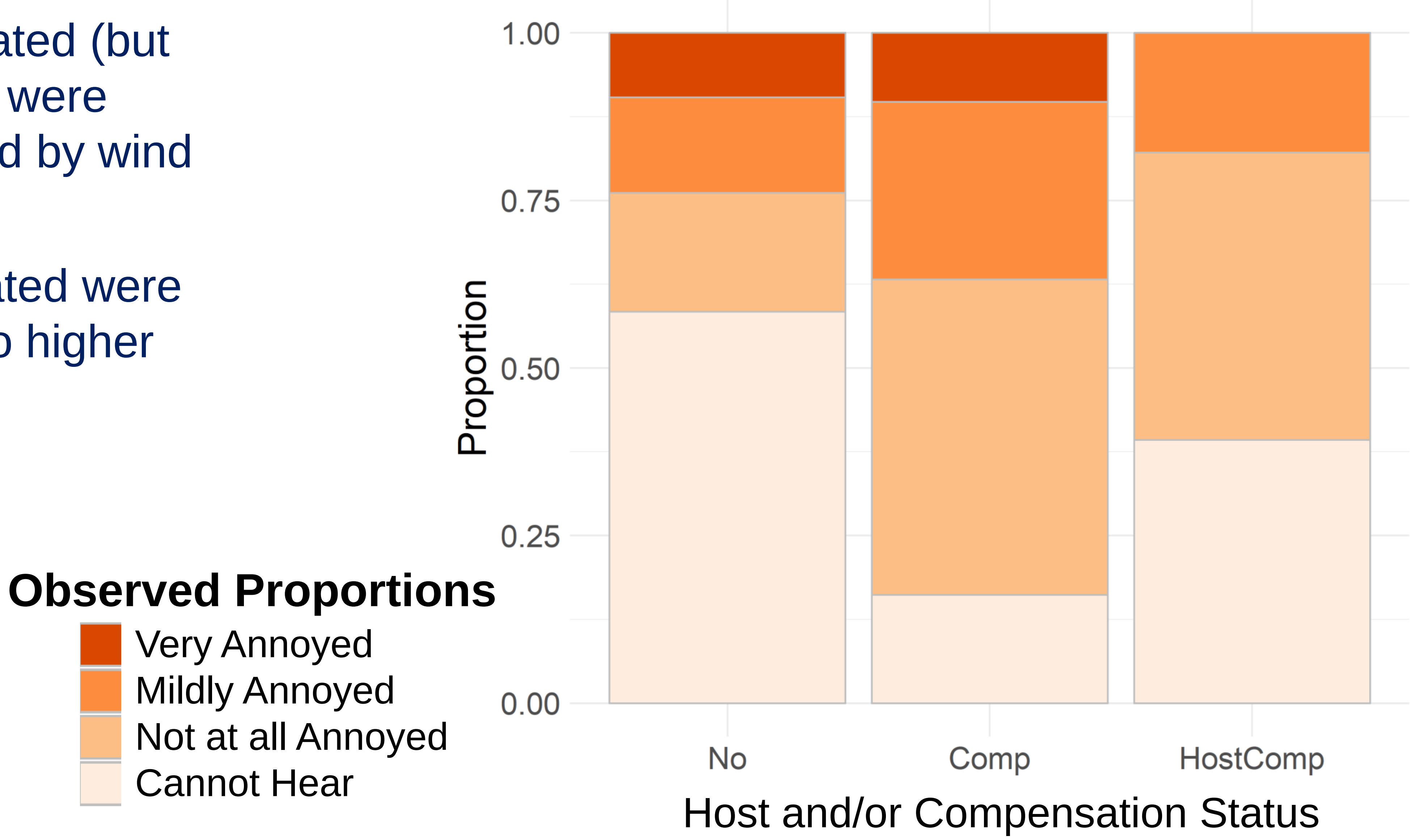
Most Respondents Who Could Not See Wind Turbines From Their Property Also Could Not Hear Them

- About 40% of those who could see wind turbines from their property could not hear them



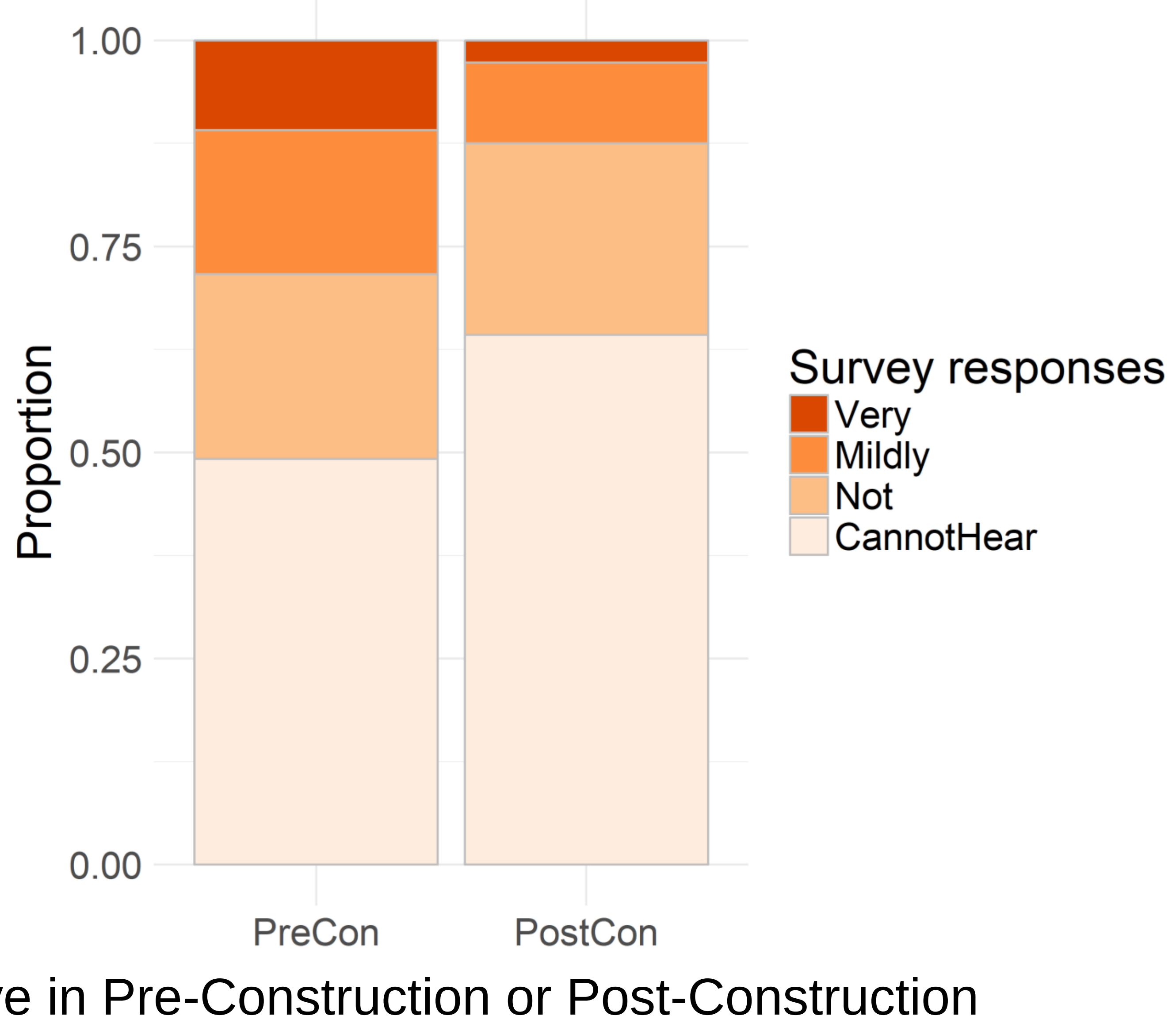
Respondents Who Were Compensated for Hosting Turbines Did Not Report Being Very Annoyed

- 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)



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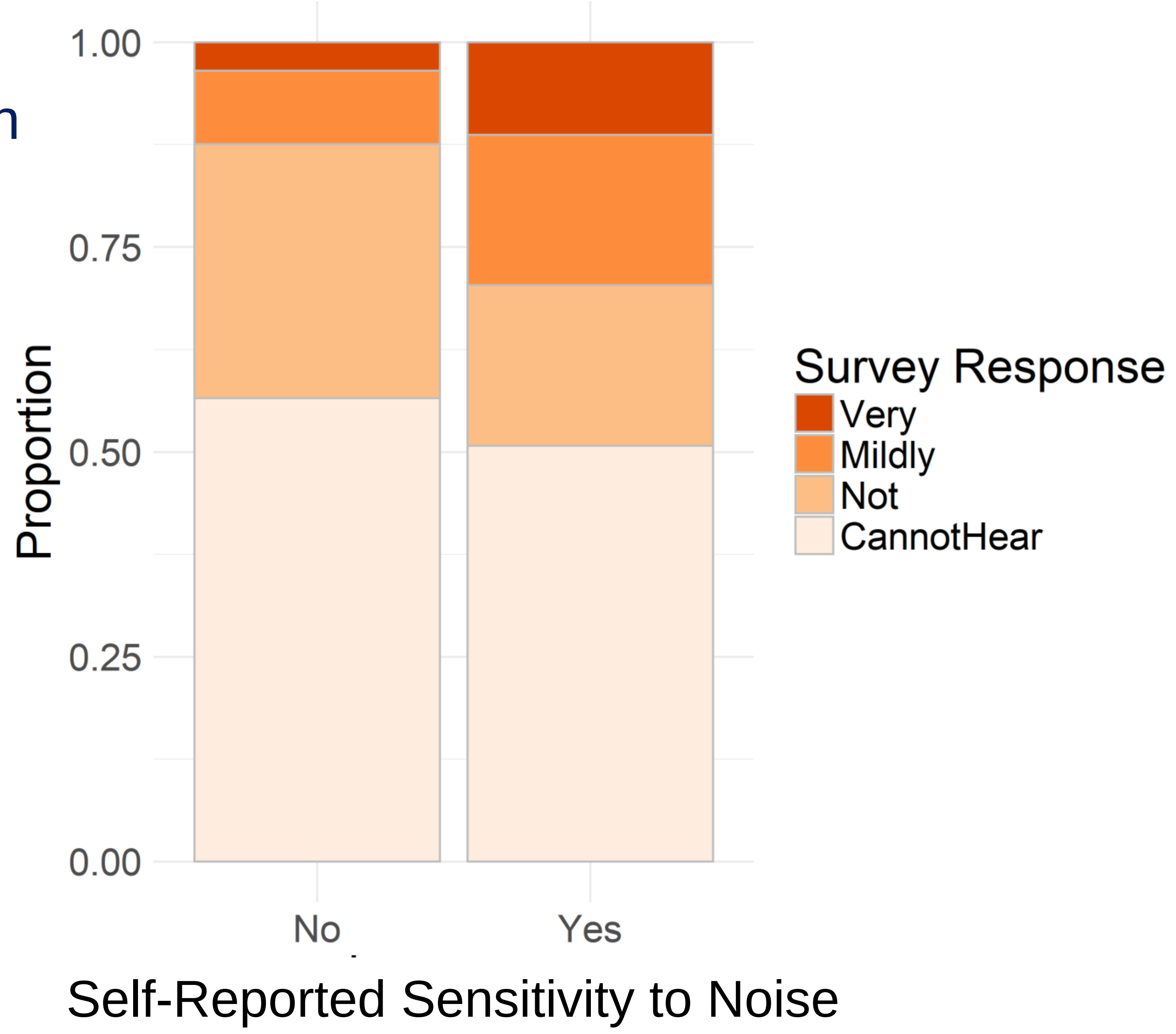
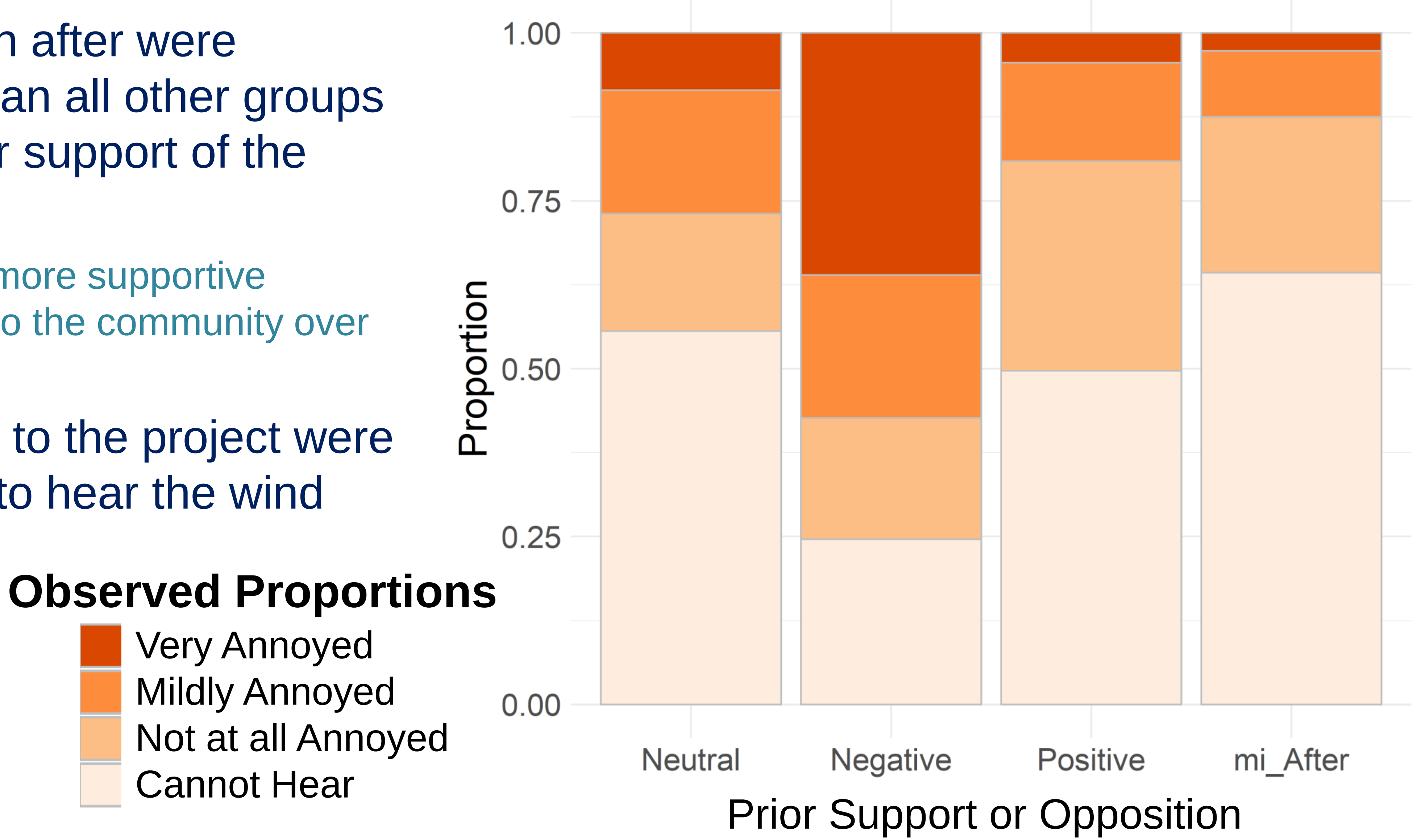
Respondents Who Reported Being Sensitive To Noise Appeared To Be Slightly More Likely to Be Annoyed By Wind Turbines

- 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



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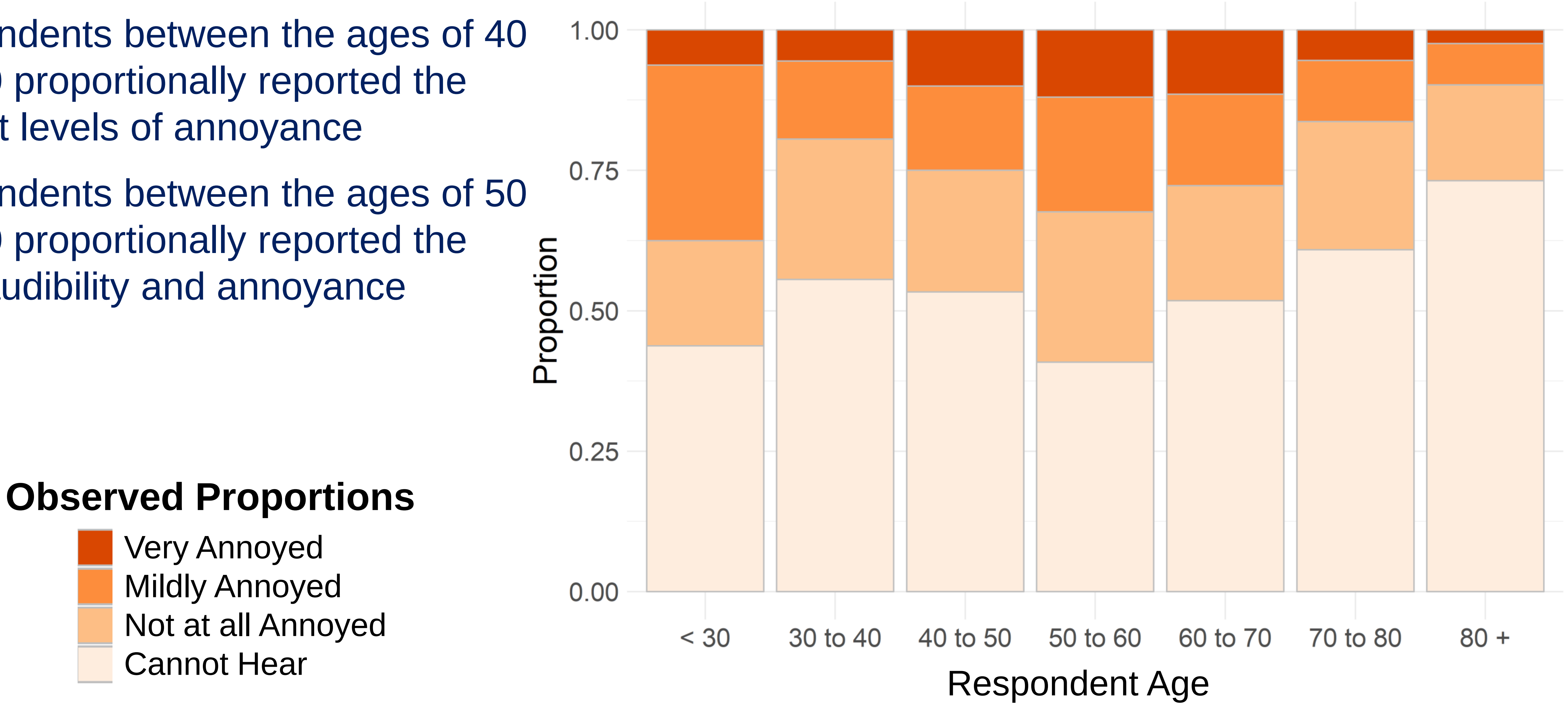
The Oldest Respondents Reported the Least Amount of Annoyance and Audibility

- 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

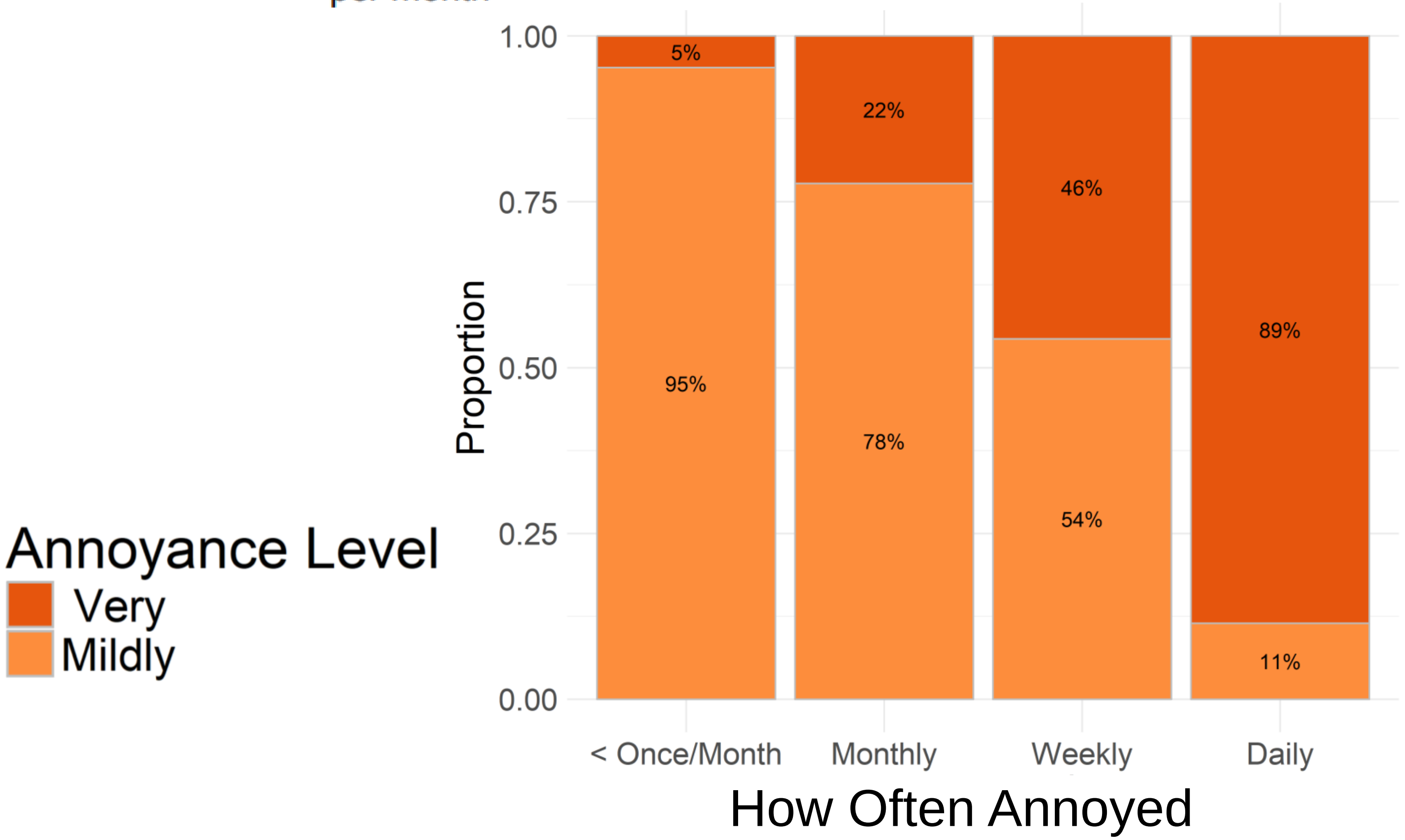


Frequency of Annoyance to Sound

25. About how often have you felt annoyed by the sound you have heard from the wind project?

○ Daily ○ Weekly ○ Monthly ○ Less than once per month ○ Don't Know

- Annoyance level increases with the frequency of annoyance
- Daily annoyance with wind turbine sounds leads to being Very Annoyed by the noise

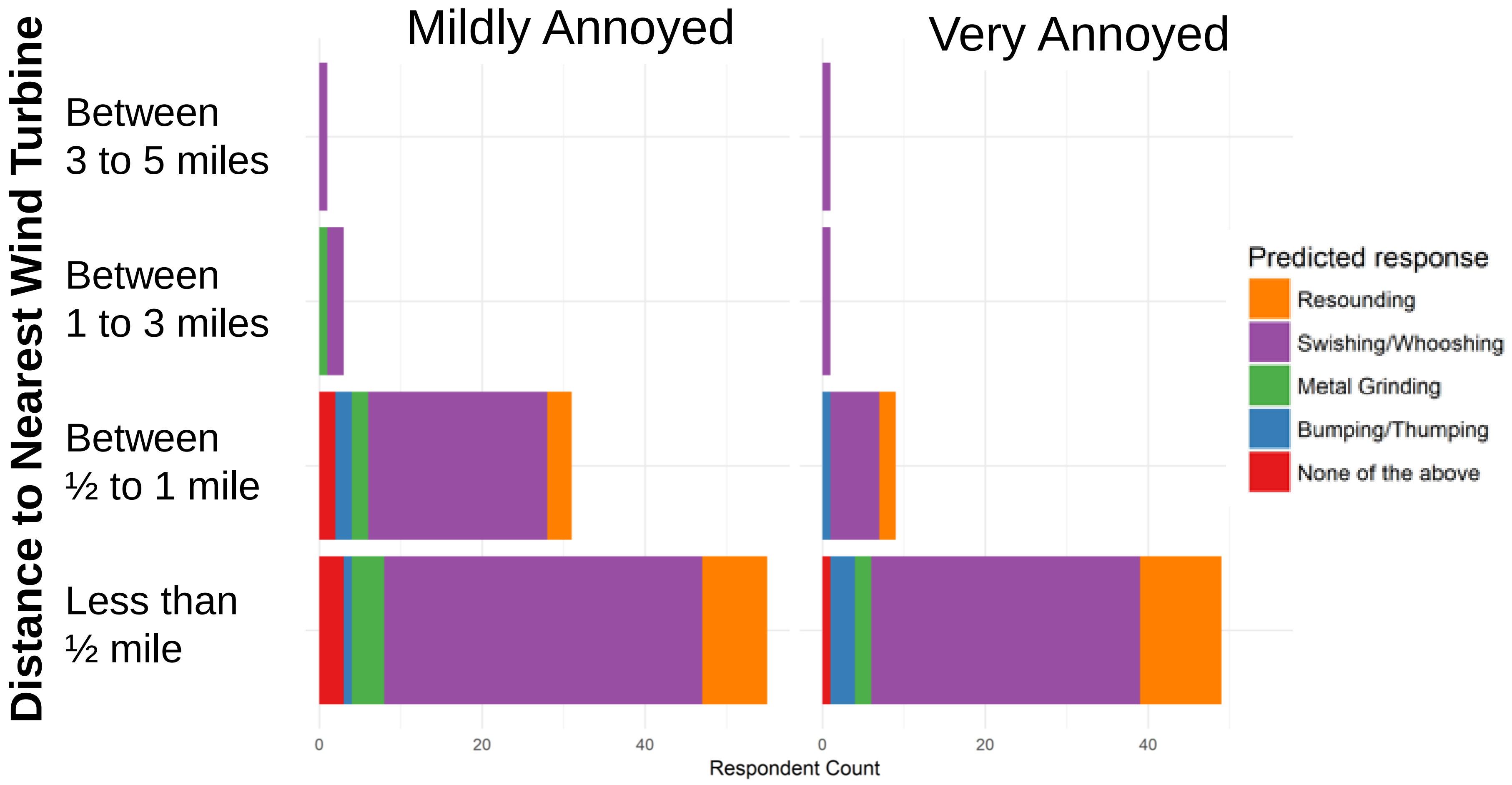


Description of Annoying Sound

26. Which best describes the turbine sound that is the most annoying to you? [Select only ONE]

- O Resounding, like a plane circling overhead
- O Swishing or whooshing, like a rhythmic sound
- O Grinding, like metal against metal
- O Bumping or thumping, like shoes in a dryer
- O None of the Above
- O Don't Know

- 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"

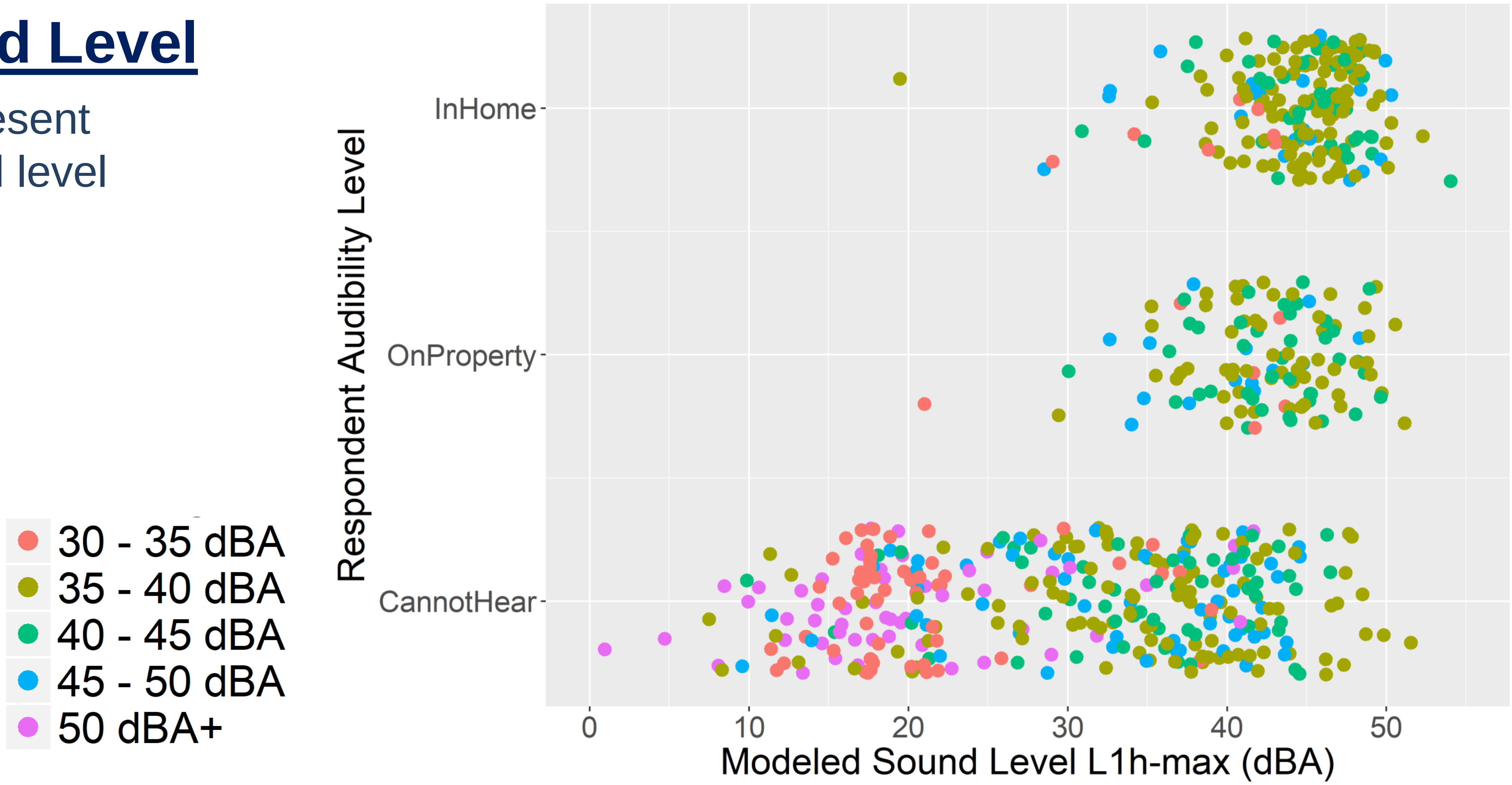


Wind Turbine Audibility - Visualize Sound Level Interaction

Modeled Sound Level

- Colored dots represent background sound level categories

Background Sound Level (dBA)



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

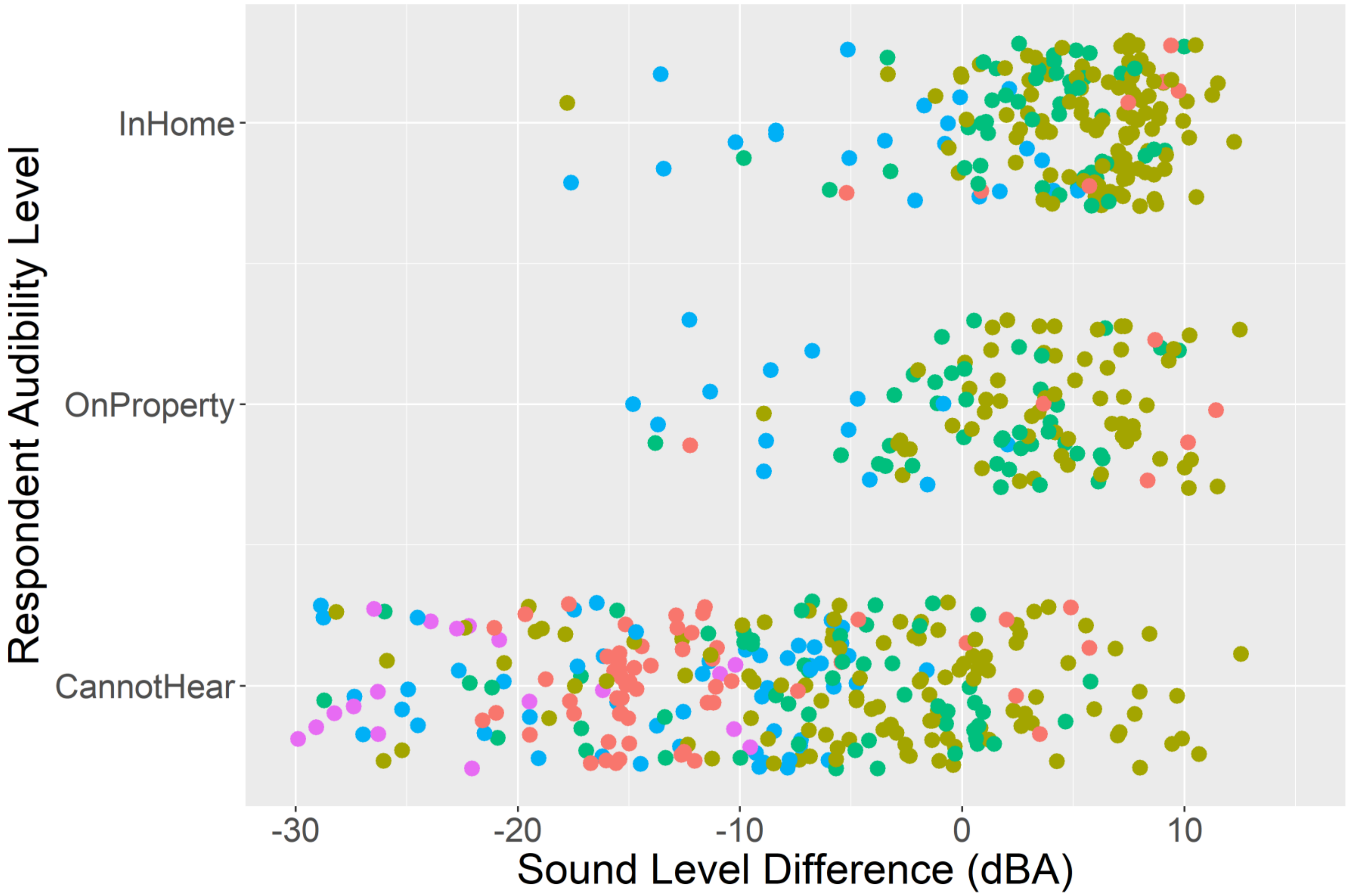
Wind Turbine Audibility - Visualize Sound Level Interaction

Sound Level Difference

- Modeled Wind Turbine Level *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+



Wind Turbine Sound Annoyance - Visualize Sound Level Interaction

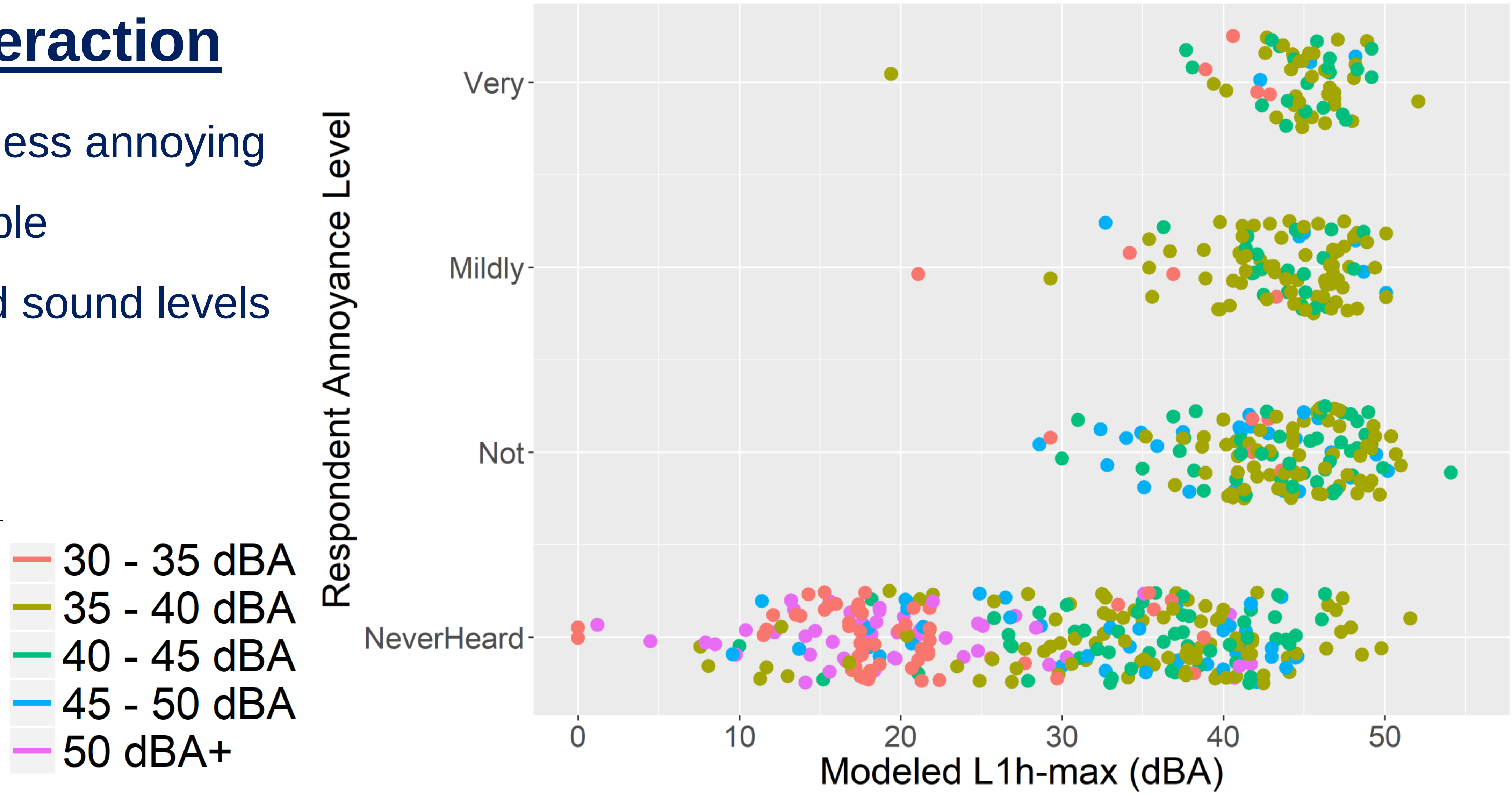
Sound Level Interaction

Turbines tended to be less annoying

and/or inaudible

with higher background sound levels

Background Sound Level Categories (dBA)



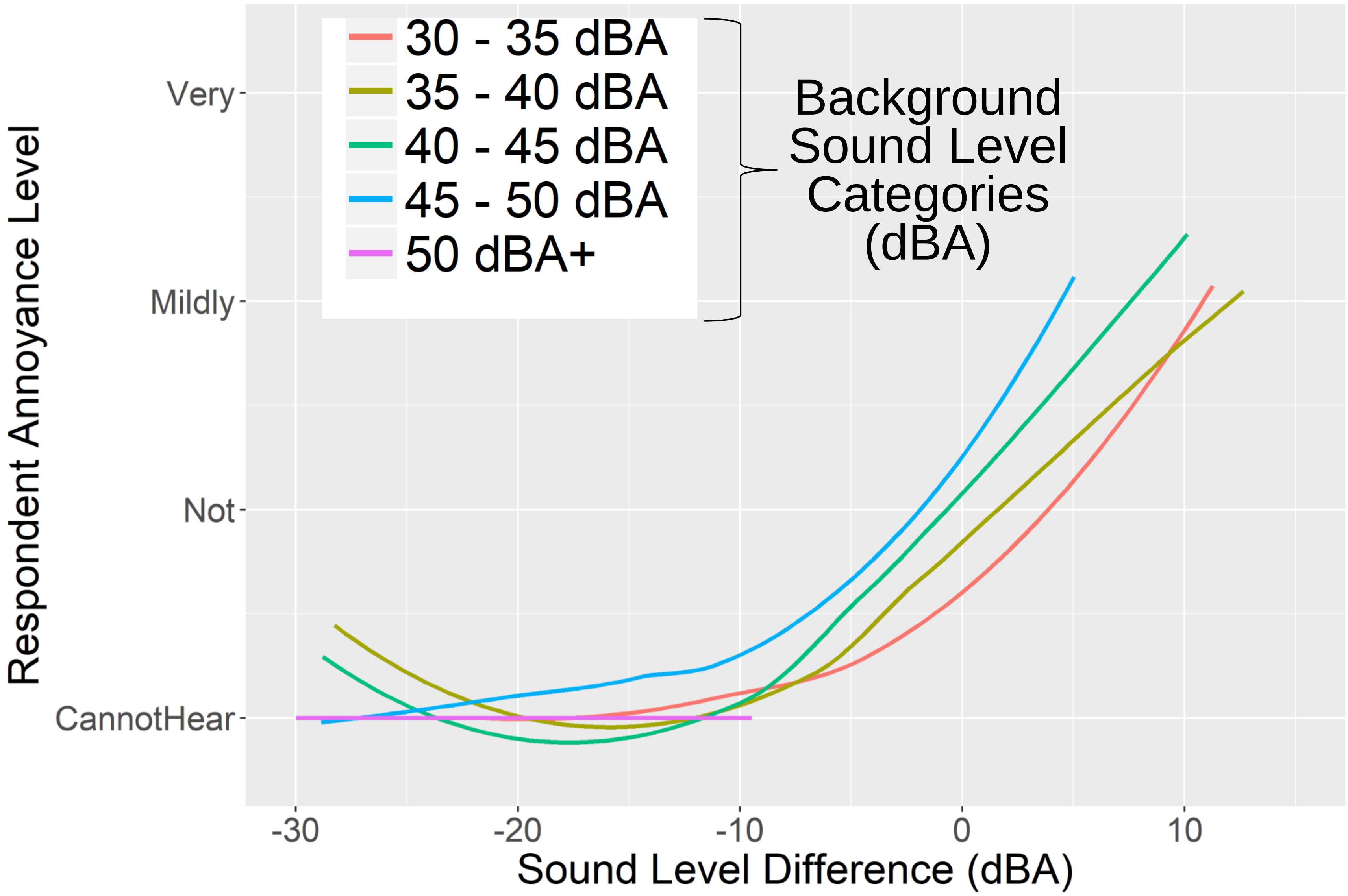
Note: Background Sound Level (Background L_{50}) is continuous; it is only categorical for plotting this relationship

Wind Turbine Sound Annoyance – Sound Level Difference

Sound Level Difference

- Modeled Wind Turbine Level *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

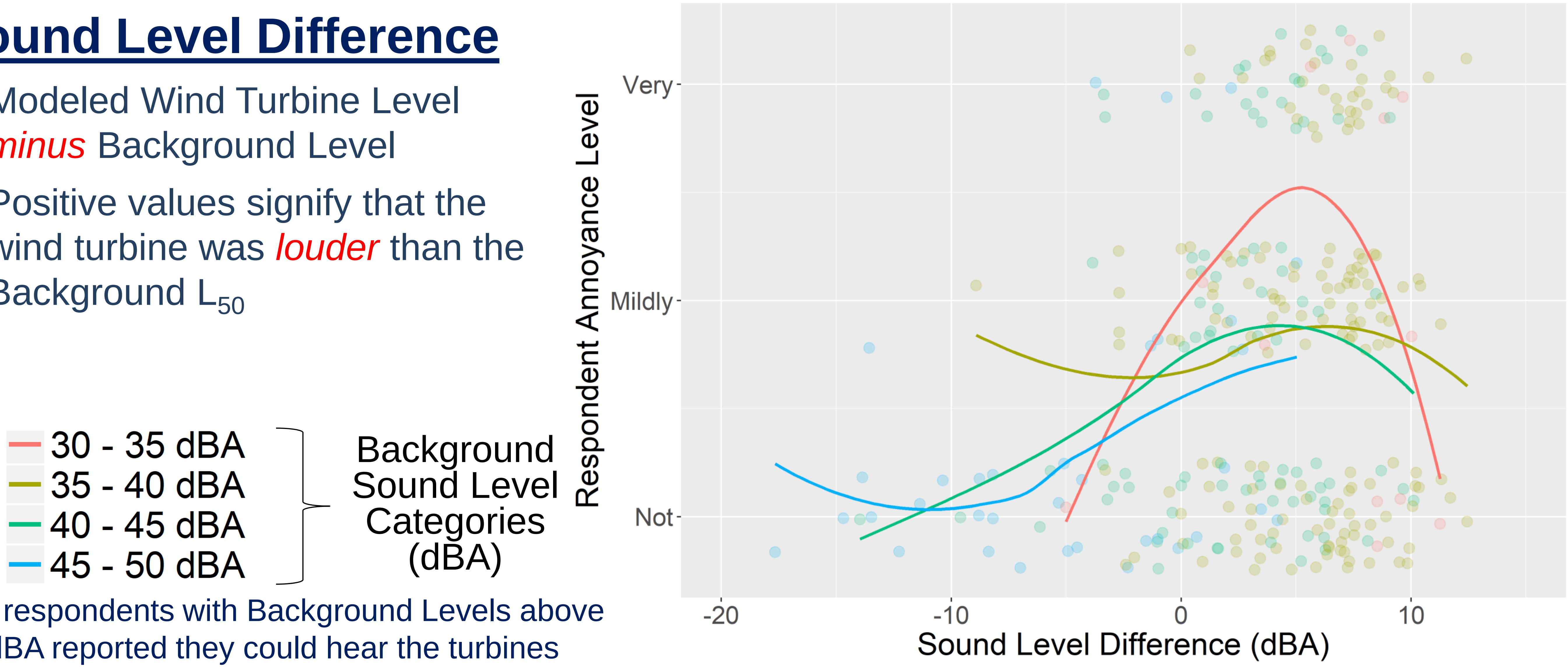


Note: Background Sound Level (Background L_{50}) is continuous; it is only categorical for plotting this relationship

Sound Level Interaction Breaks Down When We Only Consider Those Respondents That Could Hear the Turbines

Sound Level Difference

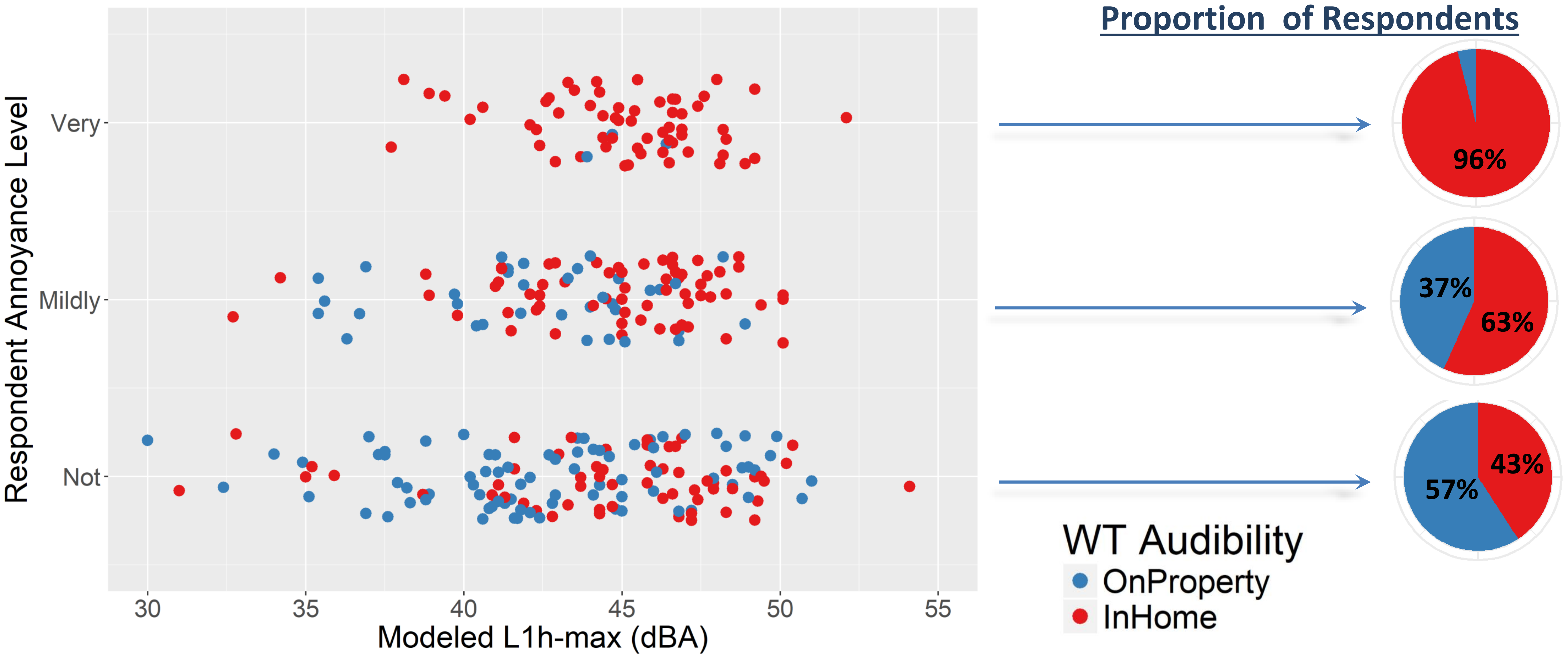
- Modeled Wind Turbine Level *minus* Background Level
- Positive values signify that the wind turbine was *louder* than the Background L_{50}



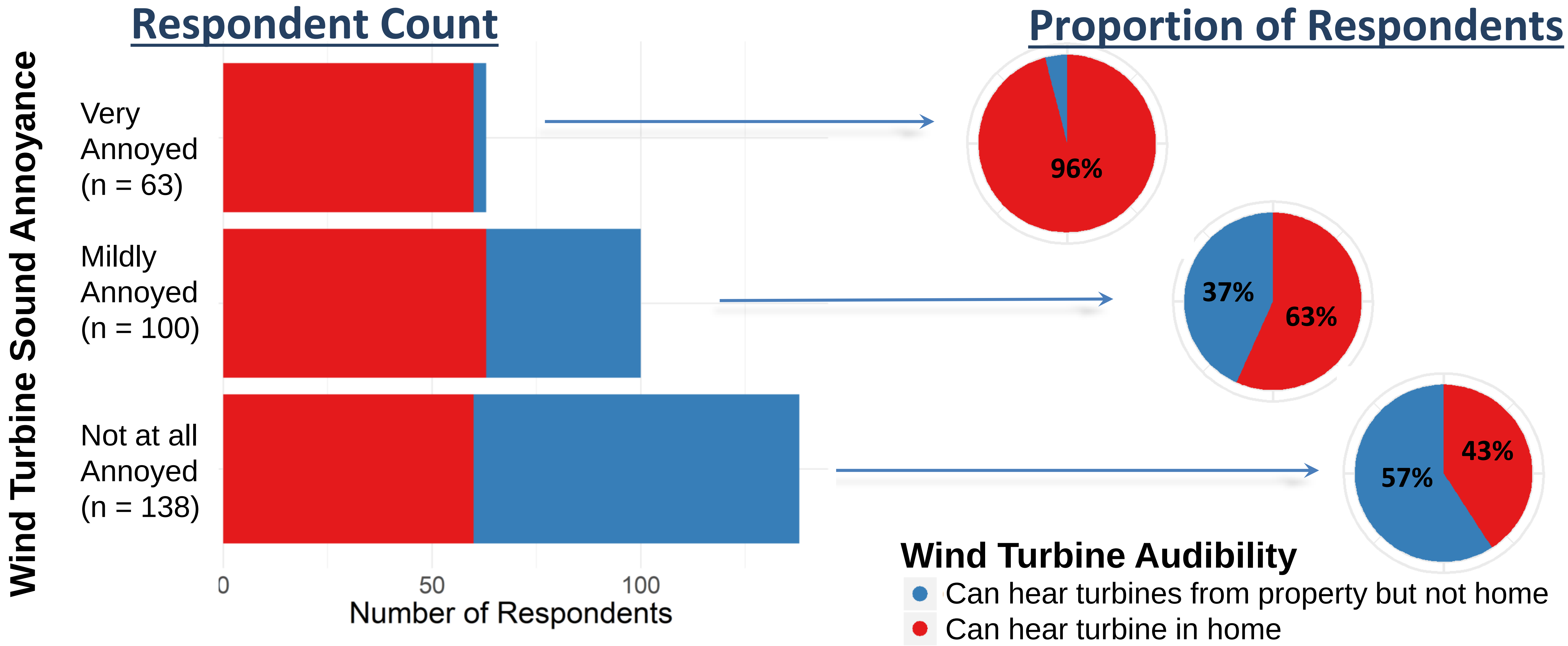
*No respondents with Background Levels above 50 dBA reported they could hear the turbines

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



Annoyance and Audibility Inside the Home and On Property Grouped by Annoyance Level



Annoyance and Audibility Inside the Home and On Property Grouped by Annoyance Level