Wind Farm Noise
Public Perception and Annoyance

Experiential reports of
wind farm neighbors

Research findings:
annoyance surveys and noise sensitivity

Jim Cummings cummings@acousticecology.org

The heart of our challenge:

Sound models tell us they'll be quiet enough to live with

Hundreds of wind farms worldwide without many complaints

Not as loud as many other industrial/infrastructure noise sources

Reassuring research / real human responses

As wind farms proliferate, especially in farm and commuter country rather than ranchlands, far more noise complaints than expected

Are these rare exceptions, or weak spots
in our models and policies that need to be addressed?

The Big Picture
Based on our current knowledge: 2 key points

#1
Noise issues are the exception
rather than the rule

Vast majority of noise issues occur within a half mile or a bit more
Even in this area, half to two-thirds of residents are either totally or usually unbothered

Very few noise issues beyond three quarters of a mile
Many wind farms are this remote and generally free of incidents

We need to stay open and vigilant to understand what situations may trigger significant noise issues at greater distances

The Big Picture

Based on our current knowledge: 2 key points

#2

Annoyance rates to audible turbine sounds in rural areas are often over 20%

In especially quiet rural areas with many residents within a half mile or so, noise issues often become more than rare exceptions, and fairly often affect ***a third to half of this nearby population***

Noise issues increase notably when sound levels rise above 40dB
Most of those who hear turbines are receiving sound levels of 25-40dB
Relatively few (those closest) experience sound levels over 40dB

A higher proportion will hear 40dB in wind farms sited relatively close to homes

Bridging the Quantitative/Qualitative Divide

What are the some of the recurring experiential reports that seem to conflict with expectations?

How common are these negative experiences?

Making sense of divergent annoyance responses to similar sounds

What are the recurring qualitative responses?

Research is ongoing to investigate each of these

Seems very loud or intrusive, even at 40-45dB

Pulsing nature of the sound: Amplitude Modulation

Sleep deprivation affects daily life

Physical “pressure waves”

Many different sounds: knocking, airplane, clatter, whistles
(no getting used to it)

Health concerns/concentration/stress

Seems very loud or intrusive, even at 40-45dB

"I think the worst is the foggy, raining nights when you get the banging, the thumping. It brings you straight out of bed…
"We were told, 'you'll never know they're back there.'"
Berlin Pennsylvania (1400-1500 ft)

“The noise sounds like and feels like a giant truck idling in our driveway.”
Jutland Denmark (4700 ft)

“We have found that the 45 decibel limit that is designated as ‘quiet’ in Maine is truly a cruel joke. On our quiet cove, we now know that 45 decibels is loud.”
Vinalhaven Maine (just under a half mile)

Many different sounds: knocking, airplane, clatter, whistles

Turbine #29 sounded like I had never heard, like a chopping blade noise coming through a distorted speaker…turbine #30 is whistling again…They can sound like a light swishing, babbling brook (or) a refrigerator as you claim...but most of the time they sound like jet plane engines.
DeKalb County Illinois

The clock read 11:45, then 1:10, then 3:35, then 5:45 each time the Wind Turbine woke me last night; it has a rhythm all its own.
Wind at different knots brings different sounds from the turbine.
Last night's sound was like the afterburner of a jet that just won't leave the air space. Yesterday during the day it was more like the thud of a marching army on parade.
Right now as I write it is quiet almost like a whisper being repeated.
Falmouth Massachusetts (1200 feet)

For many, the qualitative response is "it's no big deal," though clearly audible

"They don't bother me at all…It doesn't sound any different than when you've got the dishwasher running in your house."
Vinalhaven (2300 feet)

"If you've got the TV running, or something like that, you don't hear it all. (It's like an airplane off in the distance.) It doesn't bother me."
Vinalhaven (1500 feet)

"It is a change. You can't sit and wait for the future to be the same as the past — it isn't going to happen."
Byron Wisconsin

Note that these and most (though not all) of the preceding issues are from people within a half mile

How common are these negative reactions?

Very limited solid survey data

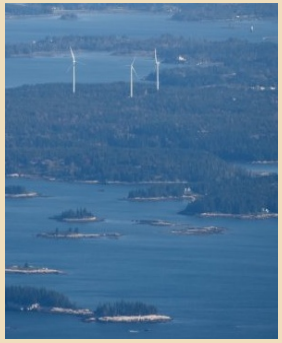
Industry reports tend to suggest issues are rare: 5-10% max
(and that those who complain about noise are more generally against the wind farm)

Community advocates imply that nearly everyone who can hear turbines is disturbed
(and those who don't speak up are under gag orders or afraid to cause waves in town)

Informal reports and the few in-depth studies of annoyance suggest the reality is between these extremes
(with plenty of ambiguity for each side to play with as they present the results)

Recent widely reported issues in New England

About a third of nearby families struggling with noise



Vinalhaven Maine

3 turbines, 15 year-round homes within ½ mile or so

5 of these have formally complained about noise and impact on quality of rural lifestyle
Several more speak of moderate annoyance while working to accept it

Extremely quiet natural background sound level here
"can hear a dog bark a mile away in the cove"
"can hear a radio at the turbine site from our house"

Falmouth Massachusetts

120 families within a mile of new turbine

45 have expressed problems with the noise
12 formal complaints, all within a half mile
Now being shut down when wind is >22mph

Our clearest picture of the extent of noise issues is a series of large surveys around wind farms in Scandinavia, 2000-2007:

Sweden 2000 (SWE-00)
351 people / rural area

Sweden 2005 (SWE-05)
754 people / mostly suburban
Both surveying residents within 1.5km (almost a mile)

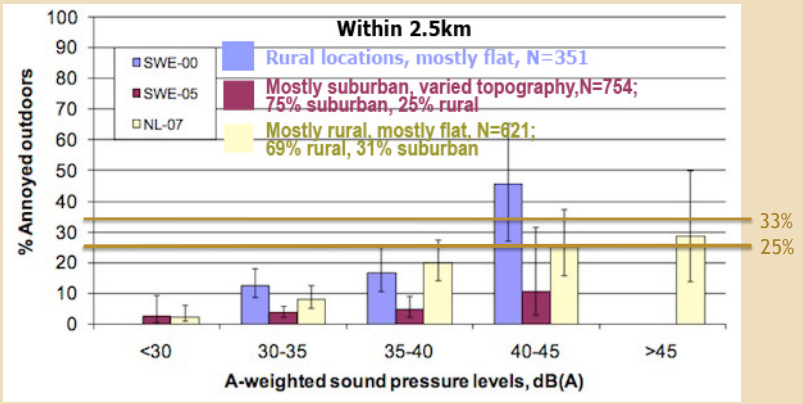
Netherlands 2007 (NL-07)
725 people / mostly rural
Survey of population out to 2.5km (1.5 miles)

Generally smaller turbines: 500-800 kW, 40-60m
Well-designed sampling from larger population in each area

Ongoing analyses published by several researchers over past few years
Lead authors: Pederson, Waye, Janssen, van den Berg

All charts in this presentation are from these studies
(see citations at end of this presentation for sources of all data and quotes)

Charting the results of all three Scandinavian studies:



One clear pattern: annoyance is notably higher in rural settings than in more built up areas

Rural areas: Purple bars Mostly rural: yellow bars

Above 40dB: "very" or "rather" annoyed tops a quarter of the rural population

At 35-40dB (far more people hear this level): annoyance of 15-20%

(These bars do not include "slightly" annoyed, which at 30-40dB generally doubles the charted percentages)

SWE-00 and SWE-05 1095 people, virtually 50/50 rural/suburban

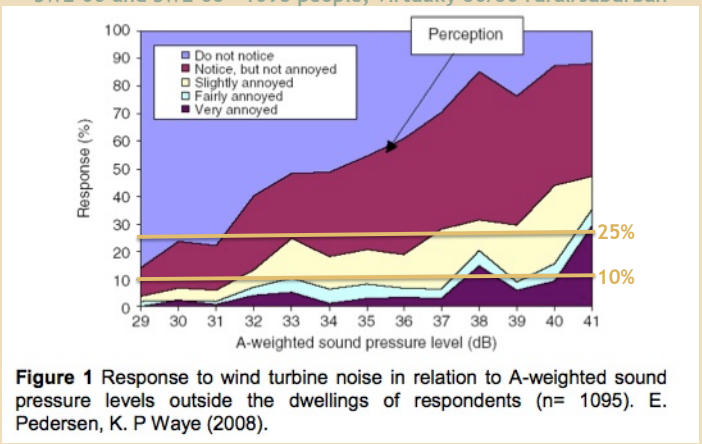
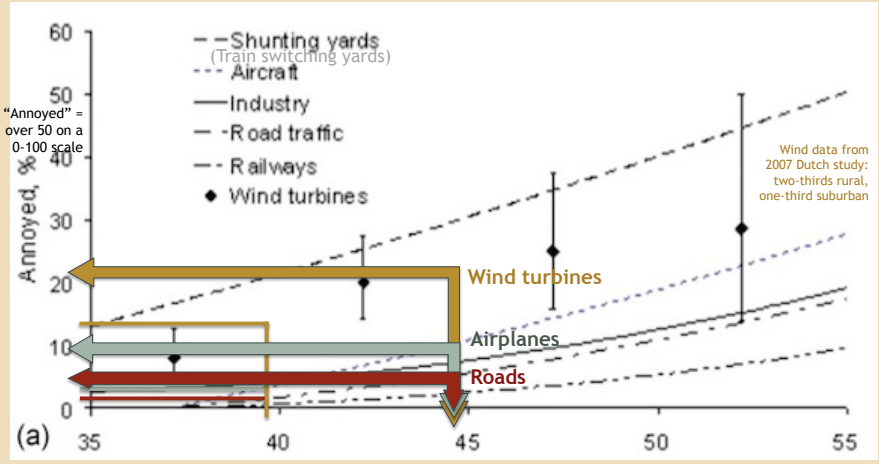


Figure 1 Response to wind turbine noise in relation to A-weighted sound pressure levels outside the dwellings of respondents (n= 1095). E. Pedersen, K. P Waye (2008).

"Very annoyed" spikes to over 25% as sound passes 40dB **(purple)**

"Slightly annoyed" is significant proportion above 33dB (yellow)
(generally doubling the numbers rated as "annoyed" in the main charts)

Also note large section of audible but not annoyed **(red)**



Moderate wind farm noise seems to trigger more than twice the annoyance caused by other typical noise sources

Even when it meets statutory noise limits for wind farms:
State/local US limits: 50dB 45dB 40dB 36dB

Factors to consider in these annoyance trends

Annoyance does not imply constant plague

For many, annoyance is occasional and temporary

Of the 5-40% who report annoyance at various sound exposures:

Half are disturbed just once or twice a week A quarter are disturbed daily or nearly daily

Roughly half are only bothered outside, the other half also bothered inside

A third or less *of those annoyed* report physical/health effects including sleep disruption

Tendency to be more annoyed when you can see turbines

This is partly a natural consequence
(more sound transmission and variety of sounds in line of sight)

Also a moderate synergistic effect: seeing turbine draws attention to its sounds

Partial overlap between those who don't like seeing turbines and those who don't like hearing them

Annoyance is strongly associated with negative attitude toward turbines

However, attitudes are *current*, rather than pre-construction, so causality is murky

Again, this is a partial correlation; does not explain away most noise issues

Factors to consider in these annoyance trends

High proportions of annoyance are mainly when ***over*** 40dB

28% in all 3 studies combined 30% in rural-dominated studies 44% in most rural study

Most of the nearby population received lower levels

Scandinavian studies included homes within 0.9 or 1.5 miles of turbines
87-97% of residents did not experience 40dB

NOTE: Some US wind farms (especially when spread amongst existing farms and homes) are sited based on sound models that predict peak exposures at many homes to come in just under local limits of 45dB or 50dB, with many or most homes within about a half mile of one or more turbines. In these situations, a much higher proportion of the population may regularly hear sound levels of 40dB or more

Overall annoyance figures in Scandinavian studies:

All three studies: 9%
Rural-dominated studies (SWE-00, NL-07): 13%
35-40% of those studied (mostly those at greatest distances) never hear turbines (purple, p16)
A similar proportion (more among those closer) hear them and don't mind the sound (red, p16)

Annoyance among those who *do* hear turbines
All three studies: 15%
Rural-dominated studies: 22%

Making sense of these annoyance rates

Why are some people so annoyed, while many others hearing the same sound aren't particularly bothered?

Variability in annoyance

Rural lifestyles and "place identity"

In 2007, some researchers from the Scandinavian research team dug deeper with a study in which they did in-depth and repeated interviews with a few participants from their earlier Swedish annoyance studies that heard turbine sound and were either not annoyed at all or very annoyed.

Similar noise exposures

e.g., among people exposed to turbine sound at 37-40dB

↓

Polarized annoyance responses

15% don't notice it; 35% hear it but not annoyed
(1 and 2 on the 5-point scale)

20% "very annoyed" by this sound level
(5 on the 5-point scale)

Rural lifestyles and "place identity"

They found that annoyance tracked closely with two ways of viewing the rural lifestyle and landscape:

"Countryside is a place for economic activity and technical developments/experimentation"

Like new machines and technologies

Indifferent to sound exposures:
turbines sound perceived as outside their territory

Accept local disturbances (flies, odors, sounds);
let others use their land as they see fit

"Countryside is a place for peace and restoration"

Sound and flicker are disruptive

Turbine noise intrudes into their space and privacy

A perhaps related personal quality: **Noise Sensitivity**

Research since the 1970's

Innate personality characteristic, not something we control or can change

Many proposed causes and correlations with other personality types, yet all find a generally consist split in the population:

Noise Sensitive
20% of the population
Good chance any audible sound will be attention-grabbing and bothersome

Noise Tolerant
50% of the population
Doesn't particularly attend to sounds
Moderate noise levels rarely noticed; rarely perturbed even by loud noise

Moderately Noise Sensitive
30% of the population
Notices most sounds, reactions are sound- and situation-dependent

And some factors that may inform understanding of annoyance responses to wind farms:

The differences between the responses of Noise Sensitive and Noise Tolerant people are most striking at soft and moderate noise levels

At high noise levels and clearly aversive sounds (e.g., jackhammer) annoyance is more similar

And in particular,
Noise sensitive people experience more arousals during sleep
Especially at low sound exposures

And perhaps most interesting:

Both Noise Sensitivity and Place Identity researchers note a strong tendency for people on opposite ends of the spectrum to have a hard time understanding the other type

Noise Sensitive find it hard to imagine anyone could be Noise Tolerant, & vice versa

"Work the land" folks can't understand the extreme reactions of "restorative" identity neighbors, while "restorative" have a hard time imagining how anyone could *not* be bothered by noise intrusions

Both rural **place identity** and **noise sensitivity** research are surprisingly well-aligned with wind farm annoyance rates:

Half or more don't notice or aren't bothered by wind farm noise below 45dB

Noise Tolerant accounts for about half the population

Likely to be a similarly large proportion of farmland population sharing the rural identity of economic activity and technological experimentation

Some residents begin to be bothered as soon as sound is audible (25-35dB)

Noise Sensitive accounts for about 20% of population

Many "restorative" place identity folks annoyed at any audible technological sound

At moderate noise levels, annoyance rises to 20-45% in rural areas (35-45dB)

Moderately Noise Sensitive begin to be bothered as noise becomes more notably audible or intrudes on core activities (sleeping, outdoor activities)

More of those with a "restorative" rural identity
find their quality of life being impacted as noise levels increase

Conclusions

Assessment of place identity patterns could help customize noise standards to the location

More negative reaction in areas with
substantial population seeking restorative qualities
Iowa, Texas seem to tolerate low and moderate noise better than
Wisconsin, New York, Ontario

Pressing need for better analysis of annoyance in existing wind farms, in a variety of settings

Are there common qualities of wind farms sites with
lower-than-average — or higher-than-average — noise complaints?
Replicate successes ; avoid areas likely to spur problems

Conclusions

Expectations are key

Especially: acknowledge they'll be audible, to a mile in some conditions
Surprise at hearing them is at root of much distress

Putting noise concerns in perspective
Acknowledge some annoyance and stress will result from audibility,
while being moderate and manageable for most people

Local engagement and respect

Some communities may want lower noise exposure levels than others

Listening — and responding — to qualitative reports and experiences

Proactive mitigation plans in place to address rare but foreseeable issues
Can reassure communities to know there is a willingness to reduce noise if needed

Fundamental social question we need to answer:

What proportion of those close to wind farms is it OK to bother?

5%? 10%? 20%? 40%?

And how often?

Ten bad nights a year? Thirty-five? (10% of nights)

Difficult to assess, challenging to answer, hard to ignore

Wordle version of: Wind Farm Noise 2009: Research, public concerns, industry trends
http://acousticecology.org/spotlight_windfarmnoise2009.html

References

Slide 2: Photo Allegheny Ridge Wind Farm, PA Source: http://farm2.static.flickr.com/1222/1223167815_26c726043a.jpg

Slide 3: Photo Cohocton, Centerville, NY http://api.ning.com/files/cXwKpFMM8QqcizoZT6n6Xr8e-aH1kKFDiqXmGqm-e9zyxJYGJbbskTYRmWintHC3E6XNds6xnnyzwFlKFxp0hiVuQEVnzFqM/Centerville_Rd_Eagle_NY_1.jpg?width=540&height=405

Slide 6: Photo Tug Hill NY: Andy McEvoy; Source: http://www.windaction.org/?module=images&func=display&fileId=L2hvbWUvbGlub2ovd3d3L3d3dy53aW5kYWN0aW9uLm9yZy9odG1sL2ZpbGVzL2ltYWdlc2l6ZWQvZTFlZGE4ZTUwZWI4ZDViZWE5NjY2ZTg3MGU2OGVkMjgtanBnNDAweDQwMC5qcGc=

Slide 8: Intense Pennsylvania: http://www.altoonamirror.com/page/content.detail/id/517600.html?nav=742
Denmark: http://windconcernsontario.wordpress.com/2010/01/12/vindmøller-letters-from-denmark/
Maine: Working Waterfront, quoted at http://aeinews.org/archives/592

Slide 9: Many different sounds.Illinois: http://lifewithdekalbturbines.blogspot.com/ Massachusetts: email

Slide 10: No big deal. Altoona: http://www.tribune-democrat.com/archivesearch/local_story_343235353.html Vinalheven: http://www.workingwaterfront.com/articles/As-electric-co-op-conducts-sound-experiment-Vinalhaven-residents-debate-solution-to-turbine-noise-issue/13674/ Illinois: http://articles.chicagotribune.com/2009-06-19/news/0906170534_1_wind-turbine-green-energy-neighbors Byron WI: http://www.bccrwe.com/index.php?option=com_content&view=article&id=66%3Apressarticle1&catid=3%3Anews&Itemid=54&showall=1

Slide 12: New England towns. Vinalhaven: Total year-round residents and number complaining drawn from personal communications with both Fox Island Wind officials and local citizens. Quotes from email correspondence. Falmouth: Number of homes and number of formal complaints from news coverage; number of informal complaints from email correspondence with a local citizen who has collected names of local citizens who are at least somewhat disturbed.

Slide 13: Scandinavian studies. Information on this slide taken from primary papers on each of the three studies:
SWE-00: Eja Pederon and Kerstin Persson Waye. Perception and annoyance due to wind turbine noise—a dose-response relationship. J. Acous.Soc.Am. 116(6), December 2004.
SWE-05: Pederson and Waye. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 2007;64;480-486
NL-07: Pederson, van den Berg, Bakker, Bouma. Response to noise from modern wind farms in the Netherlands. J. Acous.Soc. Am. 126 (2), August 2009

References

Slide 14: Annoyance graph, all studies. From Kerstin Persson Waye. Perception and environmental impact of wind turbine noise. Internoise 2009. Annotation added by me: 25% and 33% lines.
Regarding rural/suburban figures in annotation, added by the current author (Cummings 2010):
Swedish 2005 study, as published in 2007 (Pederson and Waye. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 2007;64;480-486), includes a chart (p484) in which the numbers of suburban and rural residents are clearly stated; the totals are 569 suburban and 185 rural, from which the percentages added are calculated.
Similar data used as basis for calculations on the Swedish 2000 study, as published in: Eja Pederon and Kerstin Persson Waye. Perception and annoyance due to wind turbine noise—a dose-response relationship. J. Acous.Soc.Am. 116(6), December 2004.

The 2007 Dutch study, as published in 2009 (Pederson, van den Berg, Bakker, Bouma. Response to noise from modern wind farms in the Netherlands. J. Acous.Soc. Am. 126 (2), August 2009) included a chart (p637) listing percentages of the 725 total respondents that lived in "built-up", "rural", and "rural with roads" areas. Simple proportional math reveals 198 suburban and 527 rural (282 no road, 245 with road) respondents (this would be 73% rural and 27% suburban). However, the Persson Waye 2009 paper from which this graph is drawn noted that the Dutch annoyance figures were for only those who did not benefit economically, so these numbers need to be reduced, especially on the rural side. Pederson et al 2009 (JASA, cited just above here) says (p638) that 100 of the 725 benefitted economically, and that 19% of the rural respondents benefitted, while 2% of the built-up area respondents benefitted; using these percentages, this leaves 427 rural and 194 suburban (621 total—an anomaly, in that it's 104 less than we started with). These are the numbers used in my annotation percentages, lowering the rural percentages a bit from the full 725 respondent set.
NOTE: There is some inconsistency in knowing for sure how many of the 725 respondents in the Dutch study were included in this annoyance graph; Persson Waye did not specify, noting only the full 725 when referencing the study, and another Pederson paper from 2009 (Eja Pederson. Effects of wind turbine noise on humans. Third International Meeting on Wind Turbine Noise, 2009) reproduces a similar graph suggesting a total of 593 non-benefitting respondents, and elsewhere in the same paper mentions an N of 586, suggesting more like 132-139 respondents omitted due to benefit. Thus, it is possible that the rural percentage should be slightly less, and the suburban slightly higher; assuming 1 of the extra omitted came from the built up respondents, and 34 from rural areas, the percentages would become 67% rural, 33% suburban (193 rural, 393 suburban, for 586 total, the lowest number cited anywhere).

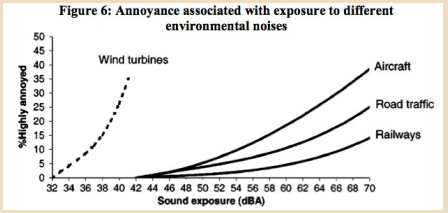
Slide 15: All annoyances graph, two Swedish studies: each of the annoyance rating groups (1=do not hear to 5=very annoyed). This graph combines the total annoyance data from the two Swedish studies (2000 and 2005). Annotation added by me: 10% and 25% lines. Graph from Hunt and Hannah, The Use of Noise Perception Index (NPI) For Setting Wind Farm Noise Limits. Third International Meeting on Wind Turbine Noise, 2009. Originally from Pedersen E, Waye K. (2008) Wind turbines—low level noise sources interfering with restoration experience? Environmental Research Letters 3 (2008) 015002

References

Slide 16:Annoyance related to other infrastructure sources. Annoyance graph from Pederson, van den Berg, Bakker, Bouma. Response to noise from modern wind farms in the Netherlands. J. Acous.Soc. Am. 126 (2), August 2009. Annotations added by me: arrows and their labels. This graph includes ALL respondents in this survey, including over a hundred that receive economic benefit from the turbines, and who nearly unanimously reported no annoyance; these respondents were omitted from further analysis in the original and subsequent papers, which generally analyzed the responses of respondents with no economic benefit from the wind farms. This is why the annoyance rates shown here are lower than the yellow bars on the "3 studies" graph on Slide 14.

NOTE: A different graph showing increased annoyance from wind farms, widely reprinted in online and even some published articles (including MN Dept of Health 2009), was used by Pederson and Waye in 2004, though it was meant for illustrative purposes only, not as data. The scales of the wind and other sources are not the same, and it is not a valid comparison (see below for the older, illustrative-only graph).
Pederson (personal communication, June 2010) recommends the more recent graph used on Slides 16 and 34 as an accurate representation; papers in process now will examine these comparisons more closely.

This is the inappropriate chart:
See Slides 16 and 34 for proper comparison chart



Source: from MN Dept of Health report 2009, reprinted from Pederson and Waye 2004. Perception and annoyance due to wind turbine noise, JASA 116:3460
Meant for illustrative purposes only, not as data

References

Slides 17, 18: All factors considered here are drawn from the three primary papers listed in note to Slide 13 and the later papers noted in notes to slides 14 and 15. Some of the interpretations of the factors are mine (Slide 17, first sentences following the headings regarding annoyance and seeing turbines and annoyance and dislike of turbines; and Slide 18, the "note" regarding siting of some US wind farms); all other information here is from the published papers.
Slide 19: Image: Cohocton; source: http://www.the-leader.com/archive/x1098988966/g13c0002403c438f261198cebf4154dd10db7d8e61ff879.jpg
Slides 20,21: Place identity: E. Pederson, LR-M. Hallberg, K.P. Waye. Living in the Vicinity of Wind Turbines — A Grounded Theory Study. Qualitative Research in Psychology, 4:49-63, 2007. DOI: 10.1080/14780880701473409
Slide 22: Noise sensitivity. Largely from : George Luz, Alerting individuals about their Noise-Sensitivity before the move into a noise-impacted neighborhood. Noise-Con 2004. With additional insights drawn from Stephen Stansfield (quoted by Luz),
Slide 23: Noise sensitivity and place identity analysis. From Luz 2004 and Pederson 2007 (as cited in the preceding notes)
Slides 24-27: My summation and suggestions
SUPPLEMENTAL SLIDES:
Slide 32: Pressure waves. Maine: New York: http://www.wind-watch.org/news/?p=26248 Vermont: http://caledonianrecord.com/main.asp?SectionID=3&SubSectionID=19&ArticleID=48177&TM=49190.16
Slide 33: Final reflections: regrets: http://www.windaction.org/news/22193 Not annoyed yet: http://www.youtube.com/watch?v=X6SaRLYbnhA&eurl=http%3A%2F%2Fwww%2Ewindaction%2Eorg%2Fvideos%2F22835&feature=player_embedded#t=420&fmt=18
Image: Cohocton, out window of person quoted at top of this page; source: http://www.the-leader.com/archive/x1098988966/g13c0002403c438f261198cebf4154dd10db7d8e61ff879.jpg
Slide 34: Annoyance related to other infrastructure sources. Annoyance graph from Pederson, van den Berg, Bakker, Bouma. Response to noise from modern wind farms in the Netherlands. J. Acous.Soc. Am. 126 (2), August 2009. Annotations added by me: arrows and circles/stars as highlights. This graph includes ALL respondents, including over a hundred that receive economic benefit from the turbines, and who nearly unanimously reported no annoyance; this is why the annoyance rates shown here are lower than the yellow bars on the "3 studies" graph on the slides to come in the middle section of the presentations. **See also additional note, above, for Slide 16, regarding the use of this updated comparison chart.**
Slide 35: Referring to a wide variety of ongoing research as presented at the biannual Wind Turbine Noise conferences and annual Internoise conference, among others. For example: regarding low ambient noise conditions, work by Clif Schneider; regarding Amplitude Modulation, work by Stefan Oerlemans and Gerard Schepers as well as Werner Richarz and Harrison Richarz; regarding low-frequency and infrasound, work by GP van den Berg as well as Rick James, and studies by Kerstin Persson Waye.
Slide 36: Turbine sound dominant at night. van den Berg thesis, p55. G.P. van den Berg.
The sounds of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise (thesis, Rijkesuniversiteit Groningen)
Slide 37: Noise sensitivity observations.
Qualities of noise sensitive people: George Luz, Alerting individuals about their Noise-Sensitivity before the move into a noise-impacted neighborhood. Noise-Con 2004.
Sound not all around: E. Öhrström, , A. Skånberg, H. Svensson and A. Gidlöf-Gunnarsson.Effects of road traffic noise and the benefit of access to quietness. Journal of Sound and Vibration, Volume 295, Issues 1-2, 8 August 2006, Pages 40-59 doi:10.1016/j.jsv.2005.11.03

What are the recurring qualitative responses?

Physical "pressure waves"

"I can *feel* this sound. It's going right through me. I thought, 'Is this what's it's going to be like for the rest of my life?'"
Vinalhaven Maine (half mile)

When the blades sped up, they did so with such a forceful whump of air that I almost took a step back.
Tug Hill New York (1500 feet)

When one stands at a spot ½-mile to over 2 miles away, the sound is a low, dull, penetrating, throbbing series of never-ending pressure waves - hour after hour, day and night, sometimes for days on end, like Chinese water torture.
Mendon Vermont

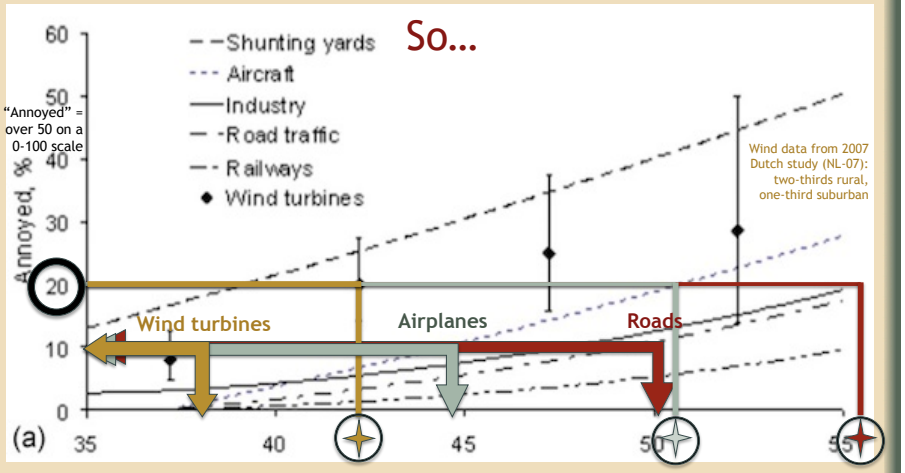
This may have less to do with sound, than with air-pressure differentials created by the huge turbine blades

What are the recurring qualitative responses?

A couple final reflections

"(The noise) has been a disaster…If we knew what would happen, never would we have signed a contract that puts our friends and neighbors through this."
Cohocton, NY

"Is it loud? It's not very loud. Am I annoyed? I'm not annoyed yet. But then I'm only going to be here for ten or fifteen minutes, then I'll get in my car and go home where it's very, very quiet. If I lived here and had to listen to it all the time, I think I'd find it extremely annoying."
A visitor to Mars Hill Maine



So…

10% annoyance reached at much lower dB levels than other noises

20% annoyance at 40-45dB
Airplanes and roads reach 20% at 50-60dB
Regulations often permit these exposures: limits of 55-65dB are common

Why do wind turbines seem to trigger annoyance at lower sound levels than other industrial or infrastructure noises?

Many researchers are taking the qualitative reports of noise problems at face value, and doing research aimed at understanding some of the possible annoyance factors.

Very quiet rural ambient background sound levels, especially at night
(so turbines at even 35-40dB become very noticeable)

Some sound monitoring procedures can over-estimate background sound levels of quietest times of night

Not uncommon to find sound levels at 25dB or lower, sometimes below 20dB threshold of equipment

Amplitude Modulation: sources and directivity of the pulsing quality of the sound

Appears to be loudest to the sides of turbines, in the area where the sounds are otherwise the lowest

Wind shear across height of turbine rotors may be a factor (higher wind at top than bottom)
This could explain why there seems to be more AM reported as turbines get bigger

Pulses at about once per second: our auditory system is especially attentive to this timescale, since it is at about the rhythm that speech sounds occur

Low Frequency and Infrasound

Wind turbine sound is heavy in audible lower frequencies, which may contribute to annoyance levels
Infrasound levels are generally well below audible, but may at times be perceptible to most sensitive people

Refinements and inevitable limitations of sound models

While sound models are being continually refined to incorporate ever more factors, they are not perfect
There are some atmospheric or topographic conditions that create higher sound levels than predicted
Researchers are doing in-the-field measurements of audible and infrasound to clarify what's going on in trouble spots

A perhaps related personal quality: **Noise Sensitivity**

Some interesting and important observations from this 40-year body of research

Qualities seen in Noise Sensitive people:

Do not generally hear any better

Sound is important to them
May find new sounds more threatening
(and may appreciate more sounds as pleasurable)

An active "orienting response"
Notices and assesses sounds;
harder to turn attention away and concentrate on something else

Sometimes experience more sense of threat,
and difficulty releasing the feeling of noise being beyond their control

More arousals during sleep
Especially at low sound exposures

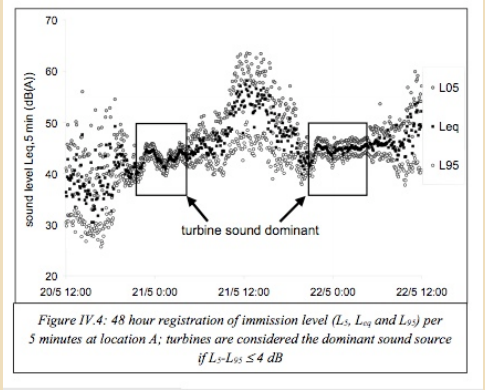


Figure IV.4: 48 hour registration of immission level (L_5, L_{eq} and L_{95}) per 5 minutes at location A; turbines are considered the dominant sound source if L_5-$L_{95} \leq 4$ dB

G.P. van den Berg.
The sounds of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise (thesis, Rijkesuniversiteit Groningen), p55

48 hours, noon to noon

Several hours each night, before and after midnight:
Variety of local sounds, including ground winds, die down

Turbine sounds are the dominant sound, in the 40-45dB range