Addressing Wind Farm Noise Concerns

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In the past several years, as wind energy development expanded from the plains and west, into rural areas with fewer working farms and ranches and higher population densities, complaints about wind turbine noise have become more common. Initially, based on experience in ranching communities where sound levels of 50dB and more were easily tolerated, noise complaints were often seen as a surrogate for broader NIMBY attitudes or as the habitual response of local complainers. But over the past year or two, as it's become clear that some residents are experiencing genuine annoyance and stress responses to "normal" wind turbine noise levels, developers have been seeking new ways of working with noise concerns. Paul Thompson, commercial director of Mitsubishi's wind turbine group, has said, "It's on the top of the minds for all manufacturers. We're all doing things to reduce the amount of noise that's generated." (Beniwal, 2011)

At the 2012 AWEA Project Siting seminar, John Anderson (AWEA Director of Siting Policy) noted that siting controversies can damage "wind's brand" and create attitudinal obstacles among citizens or political leaders. While bird and bat mortality have long been at the forefront of such challenges, concerns about wind turbine noise have rapidly ramped up in many areas where new development is proposed, to the point that in some types of communities, addressing noise concerns has become a primary consideration during planning, permitting, and operation of new wind farms. Wind farm operators are experiencing an uptick in the number of projects that trigger post-construction noise complaints in communities; often, the degree of annoyance being reported is unexpected at the distances where complainants live. Even more impactful, complaints at some wind farms have spurred a widespread rise in community resistance to many new projects. (It's important to stress that post-construction noise issues arise in only a small minority of wind farms overall; such problems seem to occur more often around projects in areas with a significant population within earshot.)

Within this context, most project developers have moved past earlier assumptions (and public assurances) that turbines will be inaudible at nearby homes, or will always be masked by nearby wind-driven ambient noise in leaves, bushes, or ears. Efforts are increasing to better understand, predict, and communicate the variability in turbine noise output, as well as to reduce the noise generated by turbines. In addition, ongoing research is investigating the ways that turbine audibility may be experienced by nearby residents (how far, how often, the quality of the sound, annoyance rates). This paper summarizes current research aimed at reducing the community noise impacts of wind farms, including:

- Passive noise reduction blade design
- Active aerodynamic load control
- Noise-reduced operation protocols
- Conditional curtailments
- New research on inflow turbulence and turbine wakes
- Low-noise brake linings
- Cooling fan noise mufflers

- Adapting to variable levels of noise sensitivity in different types of communities

An extensive list of references will provide access to more detail on each of these ways that wind farm noise concerns are currently being addressed.

Turbine noise reduction as primary goal

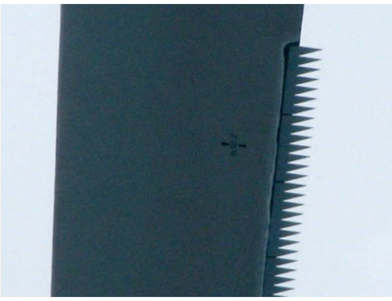
Reducing the source level of the sounds made by wind turbines is the area in which the greatest strides have been made to date. The two primary lines of research and implementation have been in the evolution of equipment design to reduce mechanical noise and trailing-edge aerodynamic noise during normal turbine operation, and in the development of Noise Reduced Operation (NRO) protocols for use in situations where local noise standards cannot be met during full power operations.

Mechanical noise

Mechanical noise, primarily from gears and fans in the nacelle, has been largely addressed in the past two decades, to the point that it is rarely the source of noise complaints or siting limitations. However, continued improvement is always the name of the game, especially when siting relatively close to homes. A recent example is this past summer's addition of noise-muffling louvers on the 23 turbines at the Pinnacle Wind Farm in Keyser, WV, after several neighbors along the road below the ridgeline complained of excessive noise. Likewise, several brake manufacturers are developing new linings that are being designed specifically for noise reduction in comparison with standard linings.

Aerodynamic blade noise

Aerodynamic noise from the trailing edge of turbine blades is the primary noise source of most modern turbines. This is generally a broadband noise, though most notable at frequencies of 700Hz to 2kHz. A range of design modifications are being developed by most turbine manufacturers, including shape of the airfoil, tip modifications, vortex generators along the fin's crest, and porous or serrated trailing edges. Serrated edges appear to be the most widely studied, with overall noise reductions of 3-8dB being reported (Barrone, 2011). However, many studies have found that these reductions are frequency-dependent, with reductions in low-frequency noise and increases at higher frequencies (over 2kHz). Serrations may be less effective at low or moderate wind speeds; in some situations, this can be when neighbors find turbine noise most audible.



During its first summer in operation, the three Fox Islands Wind turbines on the island of Vinalhaven, ME, were retrofitted with serrated edges as part of an effort to reduce noise impacts on neighbors (photos above by Charlotte Goodhue). No formal study of the effects has yet been released, though neighbors report that the serrations seemed to moderate the lower-frequency thumping element of the sound, while slightly increasing the overall whooshing aspects, as the studies summarized in Barrone might suggest (personal communications, 2012).

Operational adjustments

In some situations, turbines operating at full power either cannot quite meet local noise criteria, or continue to trigger complaints even while in compliance. To address these cases, wind farm manufacturers have developed Noise Reduced Operations (NRO) or Noise Reduction Systems (NRS), which are software-driven operational protocols that aim to reduce noise with minimal reductions in power output. These systems typically combine changes in the pitch angle of the blades and reduction in RPMs, and can be set to achieve the desired noise reduction, often from 1dB to 4dB. Power losses are modest at moderate wind speeds when aiming for 2dB noise reduction, and increase with additional noise reduction and at higher wind speeds (Leloudas, 2007; see images below from NRO applied on a 2.3MW turbine). Such settings are often used to meet reduced nighttime noise criteria, or to adjust a few turbines within a larger wind farm that are closer to neighbors (for example, one of the three Fox Islands Wind turbines routinely operates in NRO 1dB mode).

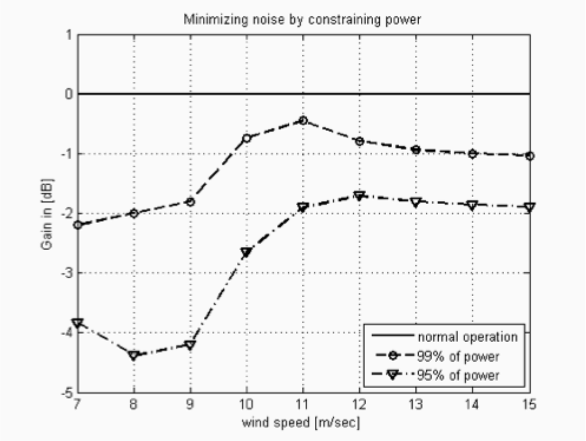


Figure 8: Noise reduction in dB(A) as a result of optimization at different wind speeds.

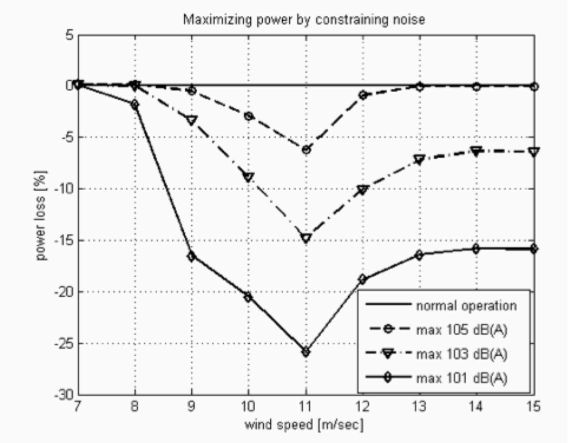


Figure 9: optimized (minimum) power losses for different noise constraints at different wind speeds. The stricter the constraint, the lower the power production. The maximum losses are at 11 m/s.

During 2011, Fox Islands Wind experimented with NRO in addition to the serrated blades. A Lawrence Berkeley National Laboratory study of the relationship between NRO, noise levels, and neighbor annoyance is still being finalized; a preliminary analysis suggests a small but not statistically significant reduction in annoyance during NRO. During the summer and fall of 2012, Iberdrola's Hardscrabble Wind Farm in upstate New York began experimenting with a new software package from Gamesa, the turbine manufacturer, in order to reduce instances of noise peaking over the local noise limit.

NRO can be applied in several ways: all the time, only at night, or only in certain meteorological conditions (e.g. particular wind speeds or directions that either increase noise output or direct sound to nearby homes). In practice, most use of NRO operates in one of the first two situations; research is ongoing to better understand specific conditions in which NRO could be effective in reducing the noise footprint of projects (see Bockstael 2012 for some of this research).

Conditional curtailments

Some projects have faced the more challenging prospect of full curtailment in particular situations. The town-owned turbines in Falmouth, MA, have been shut down at night for several months after several dozen neighbors raised issues about sleep disruption; prior to this, the Falmouth turbines were shut down in winds over 22mph (10m/s). However, to my knowledge no such noise-related full curtailments have been imposed on North American commercial wind farms.

Turbine noise reduction as secondary benefit

Increased cut-in speeds as bat mortality mitigation

One high-profile type of conditional curtailment may provide some degree of noise relief for neighbors: seasonal night-time operational adjustments designed to reduce bat mortality. As with conditional NRO, research is ongoing to better understand the conditions in which bat mortality may be most effectively reduced. So far, an increase in turbine cut-in speed appears to be the most likely path forward in areas with high concentrations of bats. Bats tend not to fly in high winds, so keeping turbines shut down (or fully feathered and freewheeling slowly) in light winds can reduce mortality to half or even a fifth of the rates measured under normal operations (Arnett et al, 2011). Since relatively little power is generated at the low end of operational wind speeds, an increase of the cut-in speed from 3-4m/s to 5m/s results in a reduction in total power output of only 1-3%. An earlier study (Baerwald, 2009) of similar moderate increases in cut-in speeds reduced total turbine operating time by 42% (in a season with a generally lower wind speeds, so this reduction would likely be less at other times). This was obviously great for bats, though it could be a worthy area of further research in community noise/annoyance mitigation (while turbines create less noise at these low wind speeds, it could be worth investigating whether such a noticeable reduction in turbine operations reduces the stress/annoyance that underlie many noise complaints).

Inflow turbulence, directional shear, and turbine wake research

More far-reaching and promising is a large body of ongoing research at the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and within the wind industry aimed at reducing turbine blade loads caused by turbulence. The primary goal of this line of research is to lower the overall cost of energy (COE) by both avoiding power output losses in turbulent conditions, and reducing structural stress enough to allow the use of longer blades that can capture more energy from the wind. Cost reductions are also achieved by reducing wear and tear caused by sudden, shifting blade loads; these stresses take their toll not just on blades, but on all turbine components.

However, blade load research may well turn out to be as effective in reducing community noise impacts as the explicit noise-reduction approaches that are already being pursued. Worn or damaged blades are not just less effective at capturing the wind's energy – the loss of coherent laminar flow and increase in trailing-edge turbulence also creates more noise. Likewise, worn bearings and gears are often louder, or emit tonal noise. *Note: Such noise benefits will of course be minimal if design innovations remain focused increasing size while maintaining current noise levels and/or stress tolerance; and, even if quieter, larger turbines are developed, increasing size may exacerbate amplitude modulation triggered by wind speed differentials between the top and bottom of the rotor diameter, and may be associated with increased sound levels at low frequencies, which can be the primary noise annoyance at greater distances, especially indoors (Moller and Pedersen, 2011)*

Other aspects of this new research, especially the development of adaptive blade designs and incorporation of new insights about wake and other flow dynamics into wind farm layouts, offer even more promising possibilities for creating unexpected benefits in terms of community noise, because of the likelihood that turbulence in the blade-swept area is a key factor in the most problematic aspect of wind turbine noise: its extreme variability, in both amplitude (with peaks of up to 20dB above daylong averages) and in sound quality and intrusiveness.

While many of us think of wind turbine noise as a gentle whooshing, wind farm neighbors often speak about knocking, banging, and tumbling sounds that are especially disruptive, and of deep rumbling low-frequency sounds that, even when barely audible, intrude into their bedrooms. These are just the sorts of noises that are often associated with blades operating in the presence of inflow turbulence.

Research efforts are aimed at innovative new blade designs that can reduce the physical stress on blades and mechanical components that is caused by rapid variations in wind speed or direction along the length of the blade. A Sandia NL paper summarized the situation thusly (Wilson et al, quoting Kelly, 2005):

> "…greatest structural fatigue damage tends to occur during nighttime hours from coherent turbulence that develops in the stable, nocturnal atmospheric boundary layer. Under such conditions, intense vertical wind shear and temperature gradients create resonant flow fields capable of imparting short-period loading and vibrational energy as wind turbine rotor blades pass through regions of organized or coherent turbulence. This energy is subsequently propagated throughout the remainder of the structure…"

The leading-edge research now underway aims to reduce these load stresses in two ways (Zayas presentation). First is "passive load mitigation," including innovative materials (such as carbon fiber as a component in various places within the blade core) and blade geometries (one design reduces loads through a geometric sweep that allows "bend twist coupling"). This is a step forward from simply trying to reduce stress by adjusting the pitch angle (which can only respond to average loads along the blade), but such passive mitigations cannot respond to local load variations as the blade sweeps through turbulent air.

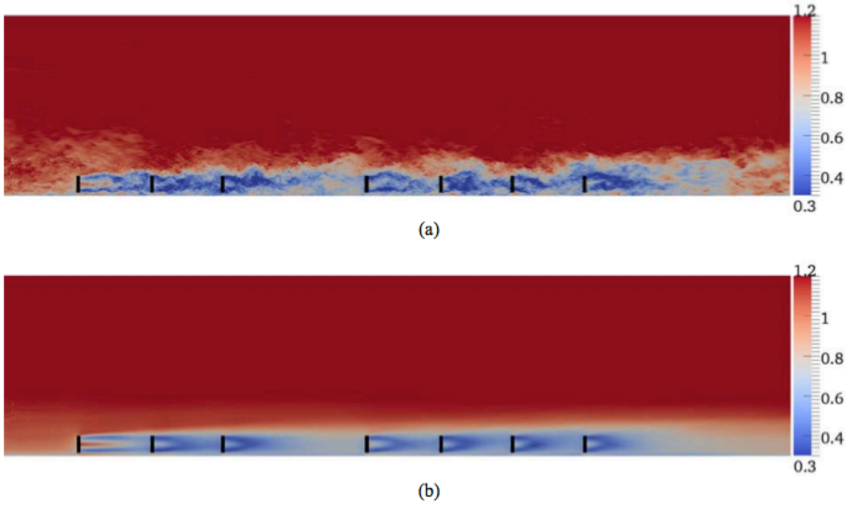
That’s where Active Aerodynamic Load Control (AALC) comes in: sensors along the blade that can instantaneously trigger small flaps along the trailing edge of the blade to relieve transient pressures.

Sandia’s Structural and Mechanical Adaptive Rotor Technology (SMART) blades are in an intermediate R&D stage, with 30-foot blades currently being tested (image left). Other active blade control approaches being studied include wings whose trailing edge can deflect either way, and flexing microtabs with the height of the boundary layer (Wilson et al 2009; Zipp 2012).

Sandia National Lab is also on the leading edge of wake research. Their Scaled Wind Farm Technology Facility (SWiFT) facility, under construction near Lubbock, will feature an array of four turbines with 27m rotors to study wake interactions (Windpower Engineering, July 2012). Project lead Jon White affirms that they are expanding the original project design to perform a variety of acoustic measurements (personal communication, 8/19/12).

Researchers at NREL are also investigating wake interactions, with the goal of better assessing the power production and load effects of turbine wakes on downwind turbines. Early indications are that we have much to learn, and once again, the same power losses and physical stresses being studied here are very likely associated with some of the more troublesome turbine noise events.

One recent study found that in “perfect” worst-case, but typical average, wind conditions (wind head-on the rows in a 48 turbine wind farm of 2.3MW turbines with a spacing of 4.3 rotor diameter), there was a 60-70% decrease in power output behind the front row; their modeling matched the average power plant output well, but actually over-estimated the feeble power output of the turbines in the farthest back rows (Churchfield et al, 2012; image below shows (a) instantaneous and (b) time-averaged velocity, clearly illustrating that only the front row operates at peak efficiency). The authors note that “it will be an interesting future study to examine the structural response of the turbines in the plant.”



Another NREL research team stresses that "the enhanced turbulence in turbine wakes increases the loads on downwind turbines. Furthermore, turbines located in the center of large arrays experience more faults and damaging loads than turbines located at the edge of wind farms." (Lundquist and Clifton, 2012)

The final area of ongoing research that is likely to pay dividends in noise reduction as well as in power increases is the study of wind shear in far more detail than typically found in current wind farm modeling. As noted in a recent overview of current research, we must look beyond "the narrow definition of shear (i.e., the change in wind speed with height). Wind direction can also change with height. During the day, when there is strong mixing throughout the lower ABL (atmospheric boundary layer), this change is a few degrees throughout the typical 40m to 120m rotor plane. However, at night, as turbulent mixing decreases, directional shear can be 20-40 degrees or more, depending on how much temperature increases with height. Directional shear also has an impact on the power derived from the wind and can impart considerable stress on turbine infrastructure…" (Freedman and Moore, 2012) Indeed, while vertical shear (which is more apt to be relatively consistent) can increase power output, directional shear (which can change rapidly) generally leads to power losses and increased stresses (Wharton & Lundquist, 2012)

For the latest thinking from industry, agency, and academic researchers on many of these issues, the report of this year's DOE Complex Flow Workshop is a great starting point (DOE Wind Program, 2012). Working groups summarized current knowledge, complicating factors, and desired next steps in great detail at three scales: regional atmospheric, wind-farm scale, and single-turbine scale (down to millimeter-scale wind interactions with blades!). Of special interest is this observation from their conclusion (emphasis added):

> **One of the largest obstacles to obtaining useful validation data for public use has been the inability of the research community to convince industry players to share their data.** While this is entirely understandable given the competitive nature of the wind industry, future public R&D efforts must rely on such data. As such, it will be highly important to **find ways to incentivize data owners and users to share their data and/or provide access to their assets for testing purposes**. The idea is not to simply expect that these data should and would be provided, but rather that public research institutions need to find ways to bring value to the industry participants in exchange for their openness.
>
> While several (workshop members from industry) commented that complex flow R&D is a high priority area for their respective companies, they also noted that the resources and access to data required are difficult to come by for a single company in the competitive wind industry. **There seems to be a strong desire on the part of turbine manufacturer R&D groups to work together and share data; however, the management of these companies will still require convincing.**

Mitigation of reported noise impacts (existing projects)
Reducing fear of noise impacts (proposed projects)

In addition to the physical and operational adjustments covered in the first section of this paper, several approaches have been taken to addressing homeowners directly about both existing noise complaints, and fears of noise impacts.

Home retrofits, including double-glazed windows and air conditioning systems, have sometimes been offered to mitigate intrusion from many community noise sources. Recently, residents near the Hardscrabble Wind Farm were offered white-noise machines to help mask turbine sounds (initial press reports suggest they did not fully mask the troublesome noise, perhaps because the turbine sounds, especially inside the house, were weighted heavily toward the audible low-frequency range and sometimes have a pulsing quality).

Very occasionally, homes of nearby residents are purchased by wind developers. Most often, this occurs prior to construction, and involves homes that are simply too close to the project site for noise standards to be met; for example, one such house was purchased in Vinalhaven, ME prior to Fox Islands Wind becoming operational. Rarely, homes are bought after complaints arise, and are generally then resold or used by the wind farm operator. Records are spotty on this, though it clearly happens in some situations (two Ontario projects are the best documented; see aeinews.org/archives/350 and aeinews.org/archives/1344).

The most constructive approach, and one pursued by many developers with varying degrees of commitment, transparency, and success, is engaging in open dialogue with community members. A leading player in such efforts has been the Cambridge, MA, based Consensus Building Institute (Raab and Suskind, 2009; Suskind, 1990), which stresses, among other things, developing trust and keeping multiple project siting options open. AWEA's Siting Handbook also includes suggestions to help shape community outreach efforts, including fostering a sense of local ownership and empowerment along with proactively engaging allies in the local dialogue.

Once problems arise, things get more difficult, and all too often wind up in the courts (again, Ontario provides an instructive example: aeinews.org/archives/1432). The most intensive and constructive community engagement process to take place after noise issues cropped up seems to be the ongoing Falmouth, MA, Wind Turbine Options Analysis Process (WTOP), which includes a variety of local stakeholders including town officials, wind advocates, and affected neighbor who have been meeting since June and plan to offer the town a set of options for reducing the noise impacts of the two town-owned turbines in time for the spring Town Meeting. For records of this process, see cbuilding.org/falmouthwind

Bigger-picture considerations

My work over the past four years has largely been about developing an understanding of the points of view and experiences that underlie both the current project design and siting of wind energy in America, and the ways that the resultant changes in local soundscapes have spurred a push-back in some areas. I am a member of both AWEA and the American Society for Acoustic Ecology. While this has involved a great deal of research, reading, listening, meeting, and talking about a wide variety of specific and detailed information, it has also helped me to come to some larger framings that are clearly relevant to moving forward constructively in a way that fosters the continued expansion of wind energy while being empathetic and respectful of the varied character of host communities.

So I'd like to close with a couple of bigger-picture considerations that might help everyone involved to understand each other's point of view a bit better, one technical and one sociological: first, a look at how the use of average sound levels can be confusing, and second, a consideration of place identity as a clue about why wind farms are more easily accepted in some areas than in others.

Average and peak sound levels

We all know that it can be hard for people to really know what a particular decibel level will sound like. Yet even once a noise limit has been agreed upon, the necessary use of averaging sound levels over time only adds to the confusion. Of course, wind farm sound emissions vary greatly, as do background sounds, with transient noises moving through as well; this is why we need to use time-averaged sound metrics. Yet it is often far less clear to community members that this is how it works. In my work monitoring contentious local situations, it's increasingly common to hear wind farm operators struggling to communicate the fact that they are operating within compliance conditions even though sound levels occasionally exceed the stated limit. For example, the Pinnacle Wind Farm in Keyser, WV, operates under a state noise limit of 55dBA Ldn – the noise is averaged over a full 24-hour period. Thus, it's not surprising that neighbors may occasionally record sounds of 65dB or even more; such peaks alarm residents, while being a natural consequence of a project operating in compliance.

As David Hessler stresses in a recent "Best Practices" report prepared under the auspices of the National Association of Regulatory Utility Commissioners:

> It is important to note that the…suggested sound level targets discussed above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that **short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed** (emphasis added) when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

Hessler observes that "the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level that falls in a gray area ranging from about 35 to 45 dBA (Ldn). Below that range the project is so quiet in absolute terms that almost no adverse reaction is usually observed and when the mean project sound level exceeds 45 dBA a certain number of complaints are almost inevitable." Citing the classic

Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. He thus currently recommends a mean (Ldn) sound level of 40dB at residences in most cases, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.” He stresses, “It is important to note that a project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors. “ (Hessler, 2011)

While Hessler’s recent work seems to point to a lower noise standard than has been typically used in projects up until now, we must bear in mind that he is working with the full day-night average, rather than an hourly or ten-minute average threshold. The lower long-term average takes into consideration the likelihood of frequent periods of 5dB higher (and lower) sound, fairly regular peaks of 10dB higher, and rare peaks of 15-20dB higher.

It appears that project managers are increasingly aware of the divergence between expectations based on averages and experiences based on peak sound levels; several projects have implemented noise-reduction efforts over the past couple of years, even when operating in compliance with the time-averaged standards. As Charley Parnell, vice president of Public Affairs for Edison Mission Group, owners of the Pinnacle Wind Farm, said in regards to the addition of noise-muffling louvres, “We believe Pinnacle is operating in a manner that meets the requirements of our permits, but taking additional steps to mitigate noise is an important part of our commitment to be a responsible corporate citizen of the communities in which we operate. We look forward to many years of providing clean energy generated by Pinnacle, and we intend to work in good faith to address local concerns.” Likewise, at the Hardscrabble Wind Farm, where new NRO software is being tested, Paul Copleman, Iberdrola Communications Manager concurred: “While our studies do not show turbine sound levels by themselves exceeding the permit limit, we do acknowledge we have received complaints from some of the residents and we are working diligently to address the situation."

Hessler’s 40dB Ldn recommendation, coming from a stalwart of mainstream acoustics assessment, is moving closer to the recommendations of the more cautionary acousticians, who have been recommending targets of 30-35dB in some types of communities, in order to reduce nearby annoyance rates to near zero (though they often are speaking of shorter-term averages). Both approaches acknowledge that whatever averaging period is used, there will be peak events above the perceived “limit.” This crucial point needs to be more clearly communicated, in order to better manage expectations.

Place Identity and Expectations Regarding Local Soundscapes

Over the past five years, the wind industry has been faced with more widespread questions about noise impacts than it had been used to. For many years, wind farms built in either remote locations in the west, or in farming and ranching communities in the great plains, had been operating with virtually no noise problems. Suddenly, in Wisconsin, Maine, Ontario, New York, and Massachusetts, among other places, small local communities were in an uproar about perceived noise intrusions. Initially, industrny representatives were taken aback, assuming the noise complaints were rooted in simple NIMBY sentiments, since we “knew” from experience that 50-60dB wind turbine noise was easily accommodated in other places. Over time, though, it's become more clear that different types of communities have different noise tolerances.

Many rural communities have begun seeking a balance that represents their self-perceived willingness to live with wind farm noise, adopting a wide range of noise and setback standards, ranging from the effectively exclusionary (1 mile is often impossible, 2 miles nearly always is), to attempts to find a happy medium, such as nighttime noise limits of 35 or 40dB and setbacks of 2500-4000ft. Other communities have adopted more familiar and accommodating standards, such as 45-50dB daytime average sound levels, or setbacks of 1200-1800ft. The era of "one size fits all" siting (which was commonly in the 900-1200 feet/50-60dB ballpark) is clearly coming to a close.

The best assessment of what is going on here comes from the Scandinavian team responsible for the only in-depth, peer-reviewed community annoyance research to date. In one of the most fascinating side studies from that body of research, Eja Pedersen and her collaborators dug more deeply into the paradoxical polarization of responses to very similar noise levels. They conducted in-depth interviews with survey subjects who rated their annoyance at the opposite extremes of the scale, and the results shed some much-needed light on what we've been seeing in communities over the past few years (Pedersen et al, 2007). It applies both to varied responses in any given community, and to the larger differences between types of communities.

They found that annoyance levels tracked closely with two very different ways of viewing the rural lifestyle and landscape, a differentiation that they termed "place identity." For some, the countryside is a place for economic activity and technological development/experimentation. These people like new machines and technology, are glad to see a new use for the land (and wind!), and easily accept local disturbances (flies, odors, sounds). They let others use their land as they see fit, and consider turbine sounds as both relatively insignificant compared to the machinery they use every day, and also as outside their territory. Conversely, many other rural residents see the countryside as a place for peace and restoration, a tranquil refuge (or retirement) from their busy life of work in town. For them, turbine sound, especially at the times when it's the loudest element in their soundscape, intrudes on what they see as their space and privacy, disrupting their enjoyment of their backyards, porches, and living rooms (see Cummings, 2010, for an overview of community response studies, including the full body of Pedersen et al research).

It's not hard to see that in farm and ranch communities, the "economic activity" place identity will dominate, and that in the northeast and upper midwest, there is a higher proportion of residents who live in pastoral landscapes with a "peace and restoration" approach to place and home. A broad-brush look at projects around the country certainly can fit this framework: In Texas and Iowa ranch country, very few problems arise even in sprawling wind farm complexes such as those around Sweetwater, TX. In Wisconsin and New York state, though, some wind projects in farmland where there is a mix of these place identities, such as Blue Sky Green Field (WI) and Tug Hill (NY), revealed a vocal minority that is very clear about the disruption of their sense of place that wind farms created. At the other end of the spectrum, a few wind farms placed in areas with virtually no working farms, and where landowners are predominantly seeking peace and quiet, ran into substantial local uproar (e.g., Mars Hill, ME), as have some municipally-owned turbines placed in towns with higher population densities, such as Falmouth and Fairhaven, Massachusetts. In Falmouth, 45 residents, about a quarter of homeowners within a half-mile downwind of the three turbines, have filed formal complaints with local authorities, a remarkably high number.

Still, it's not as simple as this brief sketch may imply. Many wind farms in relatively rural, non-farming country don't seem to trigger an outcry. The Massachusetts Clean Energy Center has conducted some preliminary studies, attempting to discern what the differences may be between places where projects go online with little fuss, and places where significant community reaction occurs (personal communication, June 2012). Much more needs to be done along these lines, in order to help clarify the factors that contribute to project success or a rocky road.

It could be, as Hessler suggests, as simple as population density; it's quite likely that some version of place identity and expectations about natural quiet play into it; generic psychological noise sensitivity could be a factor (with the likelihood that fewer noise sensitive people are ranchers, and more noise sensitive people choose to live outside of towns in search of relative tranquility). There's much to learn, and a few well-designed, comprehensive surveys in a well-selected variety of types of communities would go a long way toward helping the industry to plan future projects in ways that will be in synch with differences in local sense of place.

Paths Forward

Looking a decade or so down the line, we can expect that current research efforts will lead to the development of new blade designs and wind farm layouts that greatly reduce the significant impacts of chaotic air flow on the intrusive sorts of noises that underlie many of the noise issues among the more noise-sensitive neighbors of wind farms. We can also hope and imagine that more new development efforts will be located offshore, including deep-water floating offshore installations in relative proximity to coastal urban centers, taking some development pressure off the "nearby" rural landscapes in the more densely-populated states of the east and upper midwest.

In the meantime, though, current and near-future project planning will occur in three rather distinct paths, each of which is likely to be pursued vigorously. Perhaps some companies will choose to focus on one or another of these paths, though most will likely make do as they can with projects in all three as needed and as possible.

- Continue current siting practices (e.g. 1200-1800 feet; 45-55dB). Be prepared to spend the time/money to engage in proactive pre-proposal work in communities, and in some cases, to respond to heated resistance. Even when there is little pre-construction resistance, be prepared to apply post-construction mitigations in response to noise complaints at the margins of the regulatory criteria.
  Examples: BP has been planning the Cape Vincent Wind Farm (NY) for several years, in the face of strong local resistance; this fall, they began the process of seeking state-regulated "Article X" approval. Previous examples at Pinnacle and Hardscrabble wind

farms illustrate willing application post-construction mitigation after noise concerns arose post-construction.

- Continue current siting practices, and focus efforts only or mainly in communities where there is little or no objection, as well as low population densities (to minimize risk of post-construction surprises).
  Examples: The majority of current new wind farm construction, taking place as it always has in the great plains and intermountain west. As Clipper Windpower Vice President told wind historian Robert Righter, "If people don't want it, we'll go someplace else." (Righter, 2011)
- Avoid community conflict and reduce noise impacts by prioritizing sites with few non-participating homes within a mile, and/or by working with communities or states that adopt larger standard setbacks to minimize or nearly eliminate audible noise at homes (e.g., 35-40dB, half-mile or mile setbacks,), along with easy-to-obtain waivers or easements for closer siting to willing neighbors.
  Examples: Most wind project in the State of Oregon are developed under a 36dB standard with easements available for construction closer to willing neighbors, which has minimized neighbor noise problems (and when they occur, issues tend to be moderate, with noise levels of under 40dB, far less likely to cause the severely distressing reactions that are sometimes reported with 45dB or louder noise). The site of the Record Hill Wind Farm in Roxbury, ME, was selected because there were only a handful of homes within a mile; these became project participants, while concentrations of homes at a mile and a quarter to mile and a half report they can hear turbines regularly when it's very still, but that their lives are not disrupted by the sound (though some do still resent the lights reflecting in the lake and/or the ridgetop construction). The project developer was careful to not promise the turbines would be inaudible even at those distances, which helped manage expectations.

In conclusion, I'd like to recommend Robert W. Righter's recent history of wind energy in America (Righter, 2011). Within a context of full support of the increasing role of wind in our energy future (and his longtime work on NIMBY reactions), he makes a strong case for pursuing the second two options above. He's unusually sensitive to noise concerns, while affirming that not everyone will be pleased with any public infrastructure development. He notes, "When I first started studying the NIMBY response to turbines I was convinced that viewshed issues were at the heart of people's response. Now I realize that the noise effects are more significant, particularly because residents do not anticipate such strong reactions until the turbines are up and running – by which time, of course, it is almost impossible to perform meaningful mitigation….Good corporate citizens must identify potential problems and take action."

Righter's conclusion offers a ready path forward: "Most developers understand that it is in their best interest to operate openly and in good faith with the local community. More problematical is the question of landscape….Wind developers should take to heart geographer Martin Pasqualetti's advice: 'If developers are to cultivate the promise of wind power, they should not intrude on favored (or even conspicuous) landscapes, regardless of the technical temptations these spots may offer.' The nation is large. Wind turbines do not have to go up where they are not wanted. We can expand the grid and put them where they are welcome."

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Note: the Powerpoint version of this paper, presented at Renewable Energy World North America, 12/12/2012, included a slide referencing content (re: surveys of noise annoyance near wind farms) not included in this text. This content is covered, with references, in part in Cummings (2010) below, and also in AEI's Wind Farm Noise 2012 annual report.
In addition, the Powerpoint version includes a Kalisky 2010 graph of noise levels over a year that is discussed in more detail, and referenced, in AEI's Wind Farm Noise 2011 annual report (the interpretation here is more accurate; previous interpretation did not account for hours in the year turbines are not operating)
See http://www.acousticecology.org/wind/ for these and other AEI documents

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