6th International Meeting
on
Wind Turbine Noise
Glasgow 20-13 April 2015

Methods for assessing background sound levels during post-construction compliance monitoring within a community

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Summary

One of the most challenging aspects to wind turbine noise compliance measurements is the subtraction of background sound to calculate a turbine-only sound level. In the United States, a variety of methods have been used, including concurrent measurements at proxy background, using a monitor that is shielded from wind turbine noise with barriers or buildings, and shutting down the turbines. In our experience, as related in this paper, the most accurate method is shutting down turbines near to the monitoring location, so long as background wind and sound conditions are similar between the turbine-on and turbine-off periods. The shielding method can be accurate under circumstances where the building or barrier is large enough to block a substantial portion of sound, only the A-weighted level is of interest, and there are few localized sources of background sound. The shielding method increases in accuracy with increasing wind turbine sound. The proxy location method is the least accurate, especially for standards based on the equivalent average, as it is very difficult to find two locations spaced several kilometers away that have concurrently similar background sound levels.

1. Introduction

When sound levels from wind turbines are regulated by absolute limits within a community, it is important to accurately assess the background sound level during turbine operations to isolate the wind turbine sound levels and test for compliance with the absolute limits. It is typically the case that the absolute sound level limits are applicable to only sound levels generated by the wind power project since background sound levels in a community will vary greatly depending on weather conditions, transportation noise sources, other land uses, and natural sounds.

In the United States, a variety of methods are used to assess background sound levels while a project is in operation and the scientific community has not settled on favoring one specific method at this point in time. Some of these assessment methods include:

- Proxy background monitoring at distant locations with similar site conditions (proxy method),
- Shielding background monitors from wind turbine noise with barriers or buildings (shielding method),
- Shutting down the turbines (shutdown method), and
- Using pre-construction background sound level measurements as a baseline.

None of these methods are perfect in that they all have a spatial or temporal disadvantage.

In addition, some monitoring protocols do not require quantification of background sound levels, but instead rely solely on measurements conducted under a strict set of meteorological and project operational conditions meant to produce the worst-case sound propagation and noise exposure within a community. The difficulty of this type of procedure is that it is quite difficult to predict and catch the precise conditions without continuous monitoring for extended periods of time, sometimes months at a time. Complicating this type of procedure further is the requirement that when the precise conditions do arise, the collected sound data must be free of extraneous noise sources.

This paper provides an overview of the proxy, shielding, and shutdown methods, details a procedure for analysing data gathered using the shielding and shutdown methods, and provides a comparison of some results from the shielding and shutdown methods.

2. Overview of Methods to Assess Background Sound Levels

2.1 Proxy Method

One background sound level determination method involves use of a “proxy” background sound level monitoring location, located far enough away from a project that turbine noise is negligible. The proxy location should have a sound environment similar to monitoring location(s) near the turbines (without turbines operational).

To determine if a location is sufficiently similar to be used as a proxy location, the standard error is calculated between the primary and proxy locations, requiring extensive sound measurements in advance of project operations. For a location to be used as a proxy location, the standard error of sound levels between the primary and proxy locations should be within 2 dB or better. This requires matching locations for flora, fauna, meteorological conditions, nearby roadways with similar traffic, residential noise sources, and commercial/industrial noise sources. There are further descriptions of this method in the literature (Hessler 2011).

Advantages of this method include the ability to measure turbine-only sound levels at any time, with concurrent background sound levels, and without disruption of project operations. This makes the method relatively inexpensive to implement from the wind farm operator’s perspective, and capable of capturing project sound emissions at any time, making it ideal for both compliance and complaint testing.

Limitations of the proxy method are mostly due to difficulties in finding suitable proxy locations. A project where RSG implemented this method included monitoring at four primary locations, and four proxy locations. Of the four proxy locations tested, none met the 2 dB criteria, with only one even approaching sufficient similarity for use.

Matching all necessary parameters is quite difficult if the project area has many diverse soundscapes. This may not be as difficult in the Midwestern United States, or Great Plains region which have more uniform wind conditions, uniform land use, uniform flora and fauna, and flat roads that are arranged in a uniform grid. In contrast, a mountainous region, where we implemented this method, can have different meteorological conditions valley by valley, flora and fauna that change by valley and/or elevation, constantly changing land use, and roads that are not flat and not uniformly spaced. Another challenge in our case was the existence of an equivalent average sound level (Leq) standard, allowing increased influence on levels by short, loud, intermittent sounds.

To determine appropriate proxy locations, measurements need to be performed in advance of project operations, with potentially several alternate proxy locations being tested, an expensive and time consuming process since, to get a decent sample size, each test monitoring session lasts about two weeks. A further limitation is that if lower frequency sound needs to be measured, the distance from the project would need to be increased.

2.2 Shielding Method

The shielding method involves the use of two microphones at a sensitive receptor or area of compliance. One microphone is exposed to the wind power facility (open monitor), preferable with line-of-sight to the wind turbines, while the other is placed behind a shielding mechanism to block sound from the project (shielded monitor). The basic principle of the shielding method is that the open monitor is collecting sound level data that is representative of the wind power facility with background sound while the shielded monitor is only collecting sound level data that is representative of background sound. If the principle were an entirely accurate representation of the environment, then one just needs to energetically subtract the sound of the shielded monitor from the open monitor and the result would be the wind turbine sound levels.

In order for the shielding method to work, the shielding mechanism must block line-of-sight to the wind turbines and be of substantial construction to sufficiently attenuate noise from the project. This may only work on the edge of a project. For compliance areas located within a project area and surrounded by wind turbines, this method is more problematic. Some examples of potential shields include noise barriers, residences, or outbuildings. It is important that the open monitor and shielded monitor be placed close enough to one another so that the shielded monitor most accurately represents the background sound levels present at the open monitor. In addition, the open monitor and shielded monitor must be time synchronized and log the same acoustical parameters.

The benefit of the shielding method is that one is able to collect background sound levels at the same time as gathering operational sound levels. This gives the method a temporal advantage. That is, if there are extraneous sources of noise such as insects, inclement weather, traffic, airplane overflights, or farm equipment, they will theoretically be logged by both monitors. With this, compliance can be tested for any interval for a continuous monitoring period. If continuous monitors are installed for two weeks, one could look at ten minute or one hour compliance intervals for the entire monitoring period. It is also advantageous that most sites of interest for compliance have structures that can be used as a shielding mechanism.

There are, however, several clear theoretical flaws to this method. The first is that it is a difficult task finding a perfect shield to block wind turbine sound. Most structures that are available at compliance sites are sufficient in blocking high and mid frequencies, but are not typically large enough to attenuate low frequencies. Where a good portion of the A-weighted acoustical energy of wind turbines is located in low frequencies this could be problematic and may result underestimating sound levels attributable to a wind power project. As a result, the method is best used when only overall A-weighted sound levels, rather than spectral levels, are of interest.

Another issue with this method is a spatial disadvantage. It is too easy to assume that the background sound levels logged at the shielded monitor are representative of the background sound levels at the open monitor. While the shield blocks sound from the wind turbines, it may also block sound from other sources of background noise that the open monitor may be exposed to such as roadway noise or foliage noise where there is line-of-sight to the open monitor, but not to the shielded monitor. This would result in an over-estimation of sound levels attributable to a wind power project. In addition, depending on the location of the source of background sound, it may be possible for the background levels to be amplified by reflections off the shielding mechanism which would not be an accurate representation of the background sound levels at the open monitor resulting in an under-estimation of sound levels attributable to a wind power project. It may also be possible for the shielding mechanism itself to create noise with either wind blowing over the surface or breakout noise from sources located indoors if the shield is a building. It is for these reasons that careful site selection is necessary if this method is to be used, and any potential issues with the site must be documented and recognized when reporting data.

2.3 Shutdown Method

The shutdown method is one of the more common methods used to assess background sound levels at an operating wind power project. It involves just one microphone at a sensitive receptor or area of compliance. At either regularly scheduled intervals or when conditions are favourable for high sound power output and good propagation, wind turbines are shutdown to measure background sound levels for a period of time, typically 10 to 30 minutes before they are allowed to operate again. To determine the sound levels due to the wind turbines, one would then energetically subtract the sound level measured during the shutdown period from the operational periods immediately before and after the shutdown period.

There are a few procedural issues to work out when using the shutdown method. The first is determining which turbines need to be shutdown in order to get an accurate assessment of background sound levels. Depending on the location of the compliance monitor and the wind turbines, some or all of the turbines need to be shutdown. Secondly, due to potential changes in background sound level with time, it is important to determine the appropriate amount of operational time before and after a shutdown for which the measured background sound levels are valid. This will depend on site conditions and weather. Lastly, wind turbine operators typically need some advanced noticed that turbines will need to be shutdown which requires a fixed schedule or a signal from monitoring and forecasting systems that favourable conditions will occur for some period of time.

The benefit of the shutdown method is that it is spatially consistent and, for the most part, is temporally consistent provided that there are no significant changes in background sound levels between the shutdown period and the operational periods immediately before and after the shutdown period. One downside to this method, however, is that it is entirely possible for background sound levels to change between the operational periods and the shutdown periods. The entire period of analysis between the starting operational period, shutdown period, and ending operational period may be 30 minutes to 2.5 hours. In that time, it is not uncommon for wind conditions to change, rapid increases or decreases of biogenic sounds, or anthropogenic sources to fluctuate. For example, someone may decide to mow their lawn during one of the operational periods, but stop during the shutdown period. We recommend at least the concurrent measurement of wind speed to assure similarity between test periods for wind-induced background sound.

There are other negative factors with this method including the operational and financial burden it poses on the wind power operator and the potential problems of fluctuating the power supply to the grid at peak power output. To mitigate the burden on the operator, it would be ideal if it were possible for shutdowns to only occur when the operational and background sound levels exceed the applicable noise limits, but the technology to protocols to implement this have not been widely implemented at this point in time.

Perhaps the biggest flaw when compared to the shielding method is that the shutdown period does not allow for continuous compliance monitoring. Instead the shutdown method only allows for discrete compliance determinations on either side of a shutdown period. Depending on project requirements, this may or may not be acceptable.

3.0 Shielding Method: Setup and Analysis Procedure

This section describes the setup and analysis that RSG has used in implementing the shielding and shutdown methods.

3.1 Data Collection for the Shielding Method

RSG’s typical data collection setup for the shielding method includes ANSI/IEC Type 1 sound level meters at both the open and shielded monitors. Each meter is set to log 1/3 octave band sound levels at one second intervals, and the frequency range is at least 20 Hz to 10 kHz. The open monitor either has audio recording incorporated into the sound level meter, or an audio recorder is used with audio output from the sound level meter. The shielded monitor may or may not have audio recording capabilities enabled depending on whether there are privacy concerns. Microphones are installed at a height of 1.5 meters and are typically covered with 178 millimetre hydrophobic wind screens.

Weather sensors are installed at the open monitor to log average and gust wind speeds, precipitation, and temperature. If available, hub height wind speed, wind direction, and power output from the project’s SCADA system may be provided by the project’s operator.

3.2 Data Collection for the Shutdown Method

RSG’s setup for the shutdown method is typically the same setup that is used for the open monitor setup described in the previous section.

3.3 General Analysis Procedure

It is first important to recognize that the analysis procedure for any method depends to some extent on the applicable noise limits for a project. One must consider what acoustical metric is to be used, what the time interval is, and what procedural standards are recommended or required.

The first step in the analysis process for either the shutdown or shielding method is to convert the 1/3 octave band data into spectrograms which when coupled with the audio files are helpful in source identification. Developing spectrograms from 1-second 1/3 octave band sound level data rather than audio files is one reason for collecting a fine interval of acoustical data and allows one to process the spectrograms more quickly and view large quantities of data at once. Some examples of spectrograms that RSG has developed are presented in Figure 1.

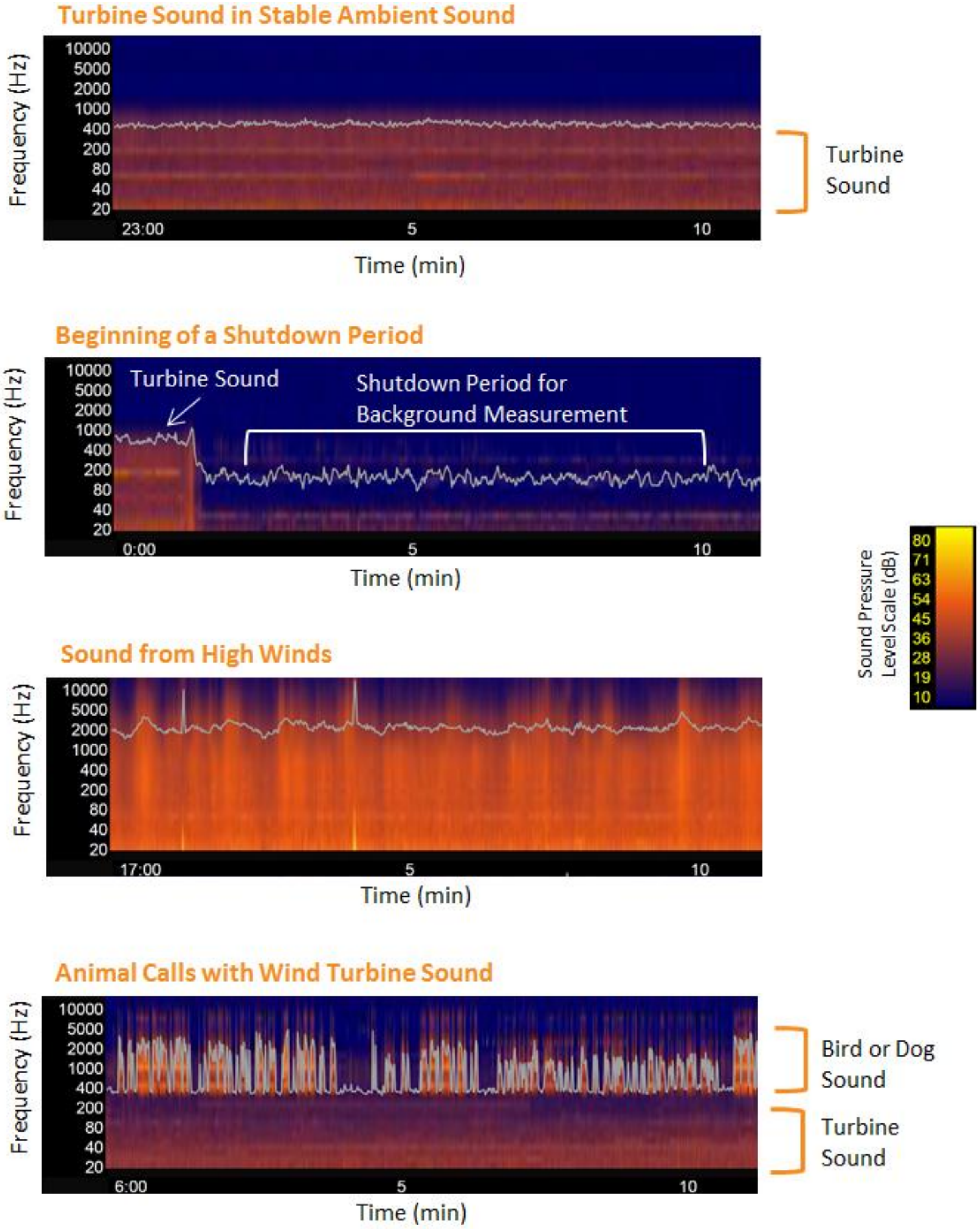


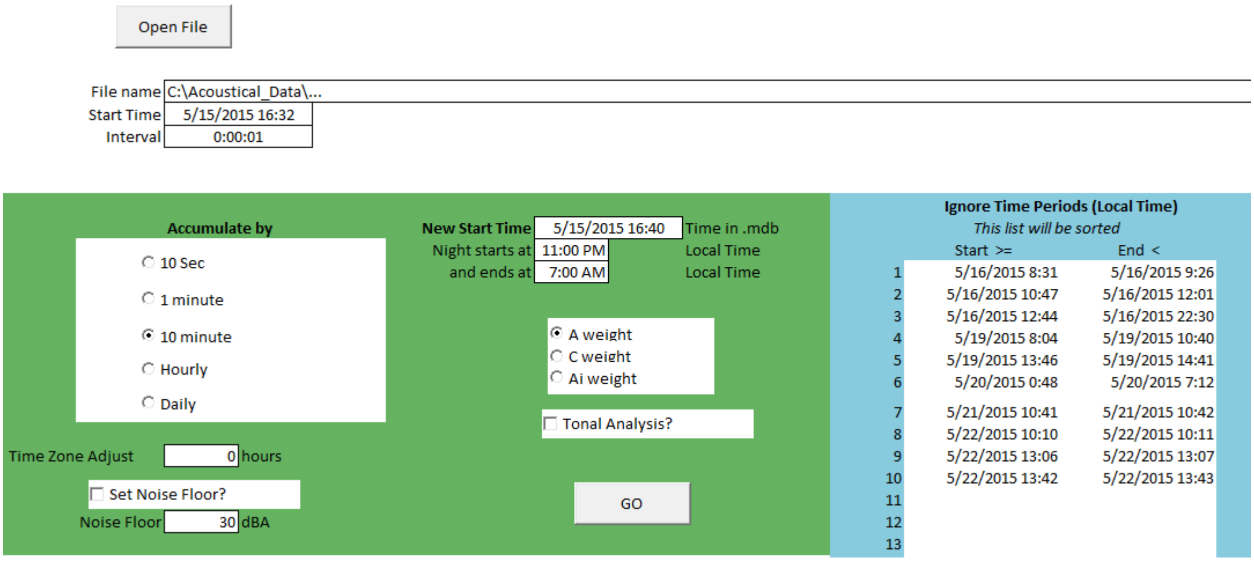
Figure 1: Sample Spectrograms with Source Identification Notations

3.4 Analysis Procedure for the Shielding Method

For the shielding method, one-second data from both the open monitor and the shielded monitor are then condensed into ten-minute periods consistent with the typical logging interval for turbine SCADA systems. Typically when the data is condensed into ten-minute periods, there is an initial data exclusion process that disregards time periods with:

- Rain,
- Wind speeds at microphone height in excess of five meters per second,
- Temperatures below instrumentation limits, and
- No wind turbine operation.

A screenshot of the tool that RSG developed and uses to condense one-second data into various time intervals and exclude invalid data is shown in Figure 2.



File name C:\Acoustical_Data\...
Start Time 5/15/2015 16:32
Interval 0:00:01

Accumulate by
○ 10 Sec
○ 1 minute
● 10 minute
○ Hourly
○ Daily

Time Zone Adjust 0 hours
☐ Set Noise Floor?
Noise Floor 30 dBA

New Start Time 5/15/2015 16:40 Time in .mdb
Night starts at 11:00 PM Local Time
and ends at 7:00 AM Local Time

● A weight
○ C weight
○ Ai weight

☐ Tonal Analysis?

Ignore Time Periods (Local Time)
This list will be sorted

	Start >=	End <
1	5/16/2015 8:31	5/16/2015 9:26
2	5/16/2015 10:47	5/16/2015 12:01
3	5/16/2015 12:44	5/16/2015 22:30
4	5/19/2015 8:04	5/19/2015 10:40
5	5/19/2015 13:46	5/19/2015 14:41
6	5/20/2015 0:48	5/20/2015 7:12
7	5/21/2015 10:41	5/21/2015 10:42
8	5/22/2015 10:10	5/22/2015 10:11
9	5/22/2015 13:06	5/22/2015 13:07
10	5/22/2015 13:42	5/22/2015 13:43
11		
12		
13		

Figure 2: Screenshot of RSG’s Data Processing Tool

Once these periods have been excluded and the data has been condensed into ten-minute periods, it is analysed to detect extraneous or anomalous sound sources that are not consistent with turbine operations. If compliance with the standard is only of interest, then only the periods that approach or exceed the standard need to be reviewed. Some examples sources that may be detected include dog barking, periodic machinery use such as chain saws, lawn mowers, or tractors, vehicle passbys, air planes, or sounds from wildlife. The time periods in which these extraneous noise sources occur are identified by looking at the spectrograms and for anomalies in the ten-minute data. When needed, the recorded audio files are used to listen to the soundscape and confirm source identification. Once all of the extraneous noise sources have been identified and time stamped, the data is reprocessed into ten-minute intervals disregarding the periods of extraneous noise. In the end some of the ten-minute intervals may represent data that is not a full ten minutes in length if less than ten minutes of data was removed from that interval due to any of the exclusions previously discussed.

With a clean dataset, the ten-minute data from the shielded monitor are energetically subtracted from the ten-minute data from the open monitor resulting in a ten-minute sound level that is attributable to the wind power project. Depending on the applicable limits, the ten-minute sound levels can then be further processed to estimate the sound level over longer periods of time such as an hourly equivalent continuous sound level ($Leq_{1\text{-}hr}$) and this could be done using a moving average to determine the sound level from 10:00 AM to 11:00 AM, from 10:10 AM to 11:10 AM, etc.

3.5 Analysis Procedure for the Shutdown Method

For the shutdown method, one is only interested in sound level data during a shutdown and the operational periods before and after the shutdown. Since these are discrete periods of some number of shutdown samples, one-second data can be used to calculate the sound level before, during, and after shutdown periods.

As shown in Figure 1, the shutdown period may be quite apparent in spectrograms, but if there is too much background sound, it may not be. To process the data, first, shutdown periods must be identified and time stamped. One can rely on spectrograms and SCADA data to determine the start and end time of the shutdown periods. The one-second data must then be processed to exclude time periods with:

- Rain,
- Wind speeds at microphone height in excess of five meters per second,
- Temperatures below instrumentation limits, and
- No wind turbine operation.

Once these periods have been excluded, a more detailed assessment of the one-second data, spectrograms, and audio files is necessary to identify and timestamp extraneous sound sources that are not consistent with turbine operations. These extraneous sound sources are then removed from the one-second data, and the sound levels for the time before, during, and after the shutdown period can be calculated. The sound level from the shutdown period is then energetically subtracted from the operational period before and after the shutdown resulting in a before and after sound level that is attributable to the wind power project.

4.0 Comparison of Results from the Shielding and Shutdown Methods

For some measurement periods and monitoring sites, RSG has used both the shielding and shutdown methods simultaneously to assess background sound levels and calculate the sound levels attributable to the wind power projects. This allows us to compare the results for both methods to get a sense of how consistent results are. Shown in Table 1 are the average differences in wind power sound levels (dBA) between the shutdown method and shielding method for three different sites.

Table 1: Comparison of Results from the Shutdown and Shielding Methods

Site	Statistic	Difference in Wind Power Sound Levels (dBA): Shutdown Method Minus Shielding Method	Number of hours (n)
X	Average	0	150
	Stdev	3.3	
Y	Average	3.1	142
	Stdev	3.2	
Z	Average	2	289
	Stdev	3.5	
All	Average	1.7	581
	Stdev	3.5	

As shown, the average difference between the shutdown method and shielding method is 1.7 dB with a standard deviation of 3.5 dB across all sites. The site with the smallest difference between the two methods is Site X, with an average difference of 0 dB and a standard deviation of 3.3 dB. The site with the greatest difference between Methods 2 and 3 is Site Y with an average difference of 3.1 dB and a standard deviation of 3.2 dB.

We then compared the differences as a function of the shutdown method sound level. Figure 3 shows that, at the higher sound levels, the variance between the shutdown method and shielding method decreases. The shielding method is thus most accurate when the turbine sound is higher. This may be because the effect of localized sound sources is minimized. When sound levels are low, the short-term contaminating events, such a wind gusts, car passbys, and biogenic sounds have a greater impact.

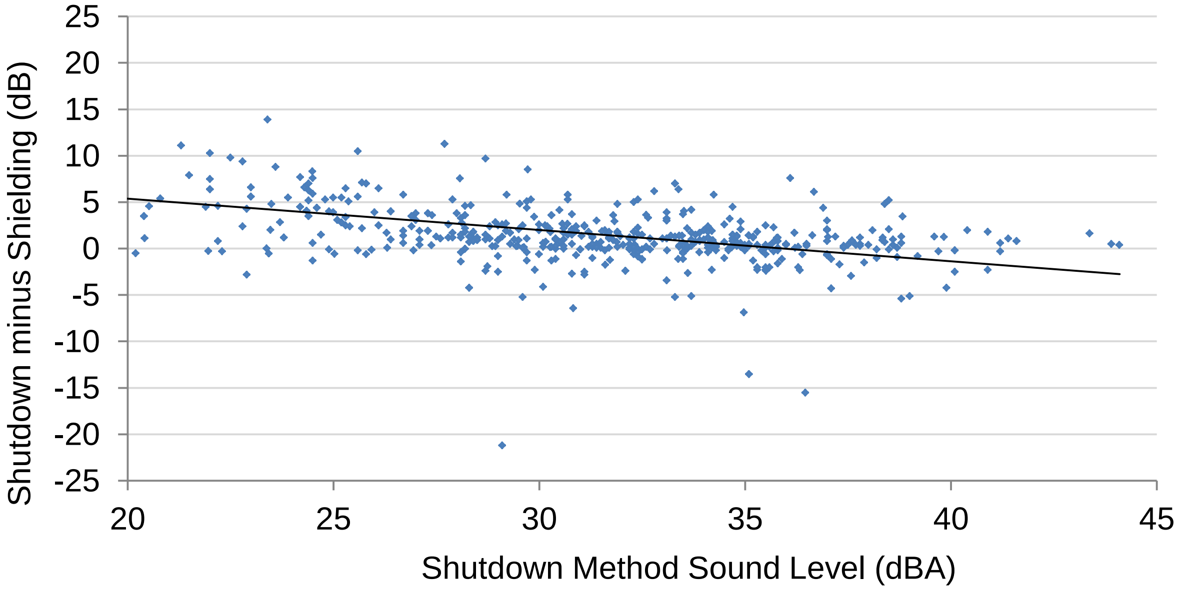


Figure 3: Shutdown Minus Shielding Method Differences vs Shutdown Method Sound Levels

As discussed above, Site X appears to have the best shielding method precision, based on using the shutdown method for comparison. One reason for this may be that the shielding mechanism at Site X does better at blocking sound than at the other sites. To evaluate this, we plotted the difference in sound level at the shielded monitors between when the turbines were on and shutdown. Ideally, the background sound levels will not change at the shielded monitors when the turbines are turned off.

The results, presented in Table 2, show that, on average, the sound levels drop by 2.2 dB when the turbines are turned off. The standard deviation is 4.0 dB. This indicates that, on average, there is some turbine sound at the shielded monitor. However, since the range of one standard deviation from the average also drops below zero, it is also the case that, at times, the shielded monitor is picking up sounds that do not exist at the open monitor which would lead to an overestimate of wind turbine sound levels. Site X has the lowest change at 1.2 dB with a standard deviation of 4.0. This would indicate that, among the sites analyse here, the shielding mechanism at Site X does a good job at blocking turbine sound.

The effect of these differences has a smaller impact on the resulting wind turbine sound levels than the value of the difference. For example, suppose the measured sound level at the open monitor with the turbines on is 39.0 dBA and the background sound level at the shielded monitor is 32.0 dBA. The shielded method wind turbine sound level would be calculated as 38.0 dBA. If the true background level is 1.2 dB lower, or 30.8 dB, this would change the wind turbine sound level from the shielded method to 38.3 dB, a 0.3 dB difference.

Table 2: Difference in Sound Levels at Shielded Monitors between Turbine-on and Turbine-off

Site	Statistic	Turbine-on minus Turbine-off	Number of hours (n)
X	Average	1.2	150
	Stdev	4	
Y	Average	2.1	142
	Stdev	3.3	
Z	Average	2.9	289
	Stdev	4.1	
All	Average	2.2	581
	Stdev	4	

Based on the above analysis, we have found that the shielding method can provide reasonable estimates of wind turbine sound levels at some locations, on average. However, because of the variability in sound from other sources, individual time periods used for compliance determinations must be reviewed carefully to determine whether the measured background sound is representative of true background sound.

Given the differences and standard deviations in wind turbine sound levels between the shutdown and shielded methods, careful selection and evaluation of a shielding mechanism is critical to the accuracy of the final results. And while the shielding method provides a reasonable estimation of wind turbine sound levels, it does not appear to be as good as the shutdown method. Understanding the differences between the two methods for a given site, may allow for regular use of the shielding method with periodic validation via the shutdown method.

References

1) Hessler, David. “Accounting for Background Noise when Measuring Operational Sound Levels from Wind Turbine Projects.” *Fourth International Meeting on Wind Turbine Noise.* Rome, Italy: 12-14 April 2011.