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International Legislation and Regulations for Wind Turbine Noise

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Summary
Wind farms are becoming a critical and significant alternative energy resource throughout the world, where wind turbine noise is at times considered an afterthought during the planning process. If a commercial wind energy project is not properly developed, the annoyance level of noise produced by operational turbines can become a nuisance to nearby communities. With this topic in mind, it is the intent of this study to provide a comparison of wind turbine noise regulations in the countries of Belgium, The Netherlands, Germany, France, United Kingdom, Denmark, Sweden, Norway, Australia, United States of America, and Canada. Research shows numerous European countries have strict regulations for wind turbine compliance noise threshold limits. Other countries describe the use of turbine setback distances or impose a penalty for tonal or impulse noise characteristics where regulatory noise limits, and the parameters to describe these specific metrics, differ per country. In converse to Europe, the United States and Canada do not include national legislation whereby deferring to local province, state, and county. In instances where there is no wind turbine noise legislation, the applicable threshold limits are enforced by standardized noise ordinances of the governing jurisdiction or simply rely on national environmental noise guidelines, such as seen in the Environmental Protection Agency (EPA) publications within the United States. Overall, research indicates that noise regulations implemented for limiting wind turbine noise is shown to widely vary between these countries. The findings of this study are proposed to further educate the noise consulting community and assist to improve the quality of advice within industry and governing authorities.

1. Introduction
Around the world, wind turbine noise regulations in most cases vary from country to country. This includes noise parameters, such as annoyance impact metrics, tonal or impulsive noise characteristics, and turbine setback distances from adjacent property boundaries, dwellings, and varying land uses. This study provides a summary

evaluation of a variety of these regulations by identifying and comparing specific noise metrics incorporated within governing legislation and regulations of various countries and local jurisdictions for comparison of the disparities that currently exist today. In total, 39 governing jurisdictions were evaluated and are succinctly summarized in Section 2 of this study.

2. Legislation and Regulations Governing Wind Turbine Noise

To give the reader a sense of the disparity of wind turbine noise code regulations, an overview is presented in Table 1 below summarizing the noise regulations and threshold limits as published by a variety of different countries and jurisdictions. A brief explanation of each referenced noise threshold guideline established by country or local governing jurisdiction is given in the following paragraphs.

Table 1: Overview of Noise Metrics and Threshold Limits

Governing Jurisdiction	Noise Metric	Rural Area	Residential Area	Residential Area Near Industrial Area	Other Areas
Belgium - Flanders	LAeq @ 95% nominal power [dB(A)]	Day: 48 Evening/night: 43	Day: 44 Evening/night: 39	Day: 48 Evening/night: 43	Day: 44-60 Evening/night: 39-55
Belgium - Wallonia	LAeq @ all wind speeds [dB(A)]	45	45	45	45
Canada	No National Legislation for Wind Turbine Noise				
Canada - Alberta	LAeq [dB(A)]	Night: 40	Night: 40	Night: 40	Night: 40
Canada - Prince Edward Island	No Province Legislation for Wind Turbine Noise				
Denmark	Lr @ 6 m/s [dB(A)] Lr @ 8 m/s [dB(A)]	42 @ 6 m/s 44 @ 8 m/s	37 @ 6 m/s 39 @ 8 m/s	37 @ 6 m/s 39 @ 8 m/s	37/42 @ 6 m/s 39/44 @ 8 m/s
France	LAeq @ all wind speeds [dB(A)]	increase of 5 dB(A) with reference to background noise level increase of 3 dB(A) with reference to background noise level			
Germany	Lr @ all wind speeds [dB(A)]	Day: 60 Night: 45	Day: 50-55 Night: 35-40	Day: 60 Night: 45	Day: 45-70 Night: 35-70
The Netherlands	Lden [dB] Lnight [dB]	Lden: 47 Lnight: 41			
New Zealand	LA90(10min) [dB(A)]	35 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5
Norway	Lden [dB]	Lden: 45	Lden: 45	Lden: 45	Lden: 45
South Australia	LA90,10 [dB(A)]	35 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5	40 or background LA90(10 min) + 5
Sweden	LAeq @ 8 m/s [dB(A)]	35	40	40	40
United Kingdom	LA90(10min) [dB(A)]	Day: background + 5 dB(A), with a lower limit of 35 to 40 dB(A) Night: background + 5 dB(A) with a lower limit of 43 dB(A)			

Governing Jurisdiction	Noise Metric	Rural Area	Residential Area	Residential Area Near Industrial Area	Other Areas
United States of America	No National Legislation for Wind Turbine Noise EPA: Ldn [dB(A)]	Ldn: 55	Ldn: 55	---	---
Colorado	No State Legislation for Wind Turbine Noise				
Colorado - Arapahoe County	LAeq [dB(A)]	---	Day: <55 Night: <50	---	Day: <65-<80 Night: <60-<75
Georgia	LAeq [dB(A)]	55	55	55	55
Illinois	Octave Band Analysis (see Table 6)				
Indiana	No State Legislation for Wind Turbine Noise				
Indiana - Tipton County	Octave Band Analysis (see Table 7)				
Michigan	LAeq [dB(A)]	55 or background + 5 dB(A)	55 or background + 5 dB(A)	55 or background + 5 dB(A)	55 or background + 5 dB(A)
Michigan - Huron County	LA90 [dB(A)]	55 or background + 5 dB(A)	50 or background + 5 dB(A)	55 or background + 5 dB(A)	55 or background + 5 dB(A)
Minnesota	LAeq [dB(A)]	50	50	50	---
Minnesota - Lincoln County	LAeq [dB(A)]	50	50	50	---
Nevada	No State Legislation for Wind Turbine Noise				
Nevada - Lyon County	LAeq [dB(A)]	55	55	55	55
New Mexico	No State Legislation for Wind Turbine Noise				
New Mexico - San Miguel County	LAeq [dB(A)]	< background	< background	< background	< background
New York	No State Legislation for Wind Turbine Noise				
New York - Town of Jefferson	LA10 [dB(A)]	---	50 or background + 5 dB(A)	---	---
North Carolina	LAeq [dB(A)]	55	55	55	---
Oregon	LA50	Day: 55 Night: 50			
Pennsylvania	No State Legislation for Wind Turbine Noise				
Pennsylvania - Potter County	LAeq [dB(A)]	background + 5 dB(A)	background + 5 dB(A)	background + 5 dB(A)	background + 5 dB(A)
Wisconsin	LAeq [dB(A)]	Day: 50 Night: 45			

Governing Jurisdiction	Noise Metric	Rural Area	Residential Area	Residential Area Near Industrial Area	Other Areas
Wisconsin - Shawano County	LAeq [dB(A)] / Octave Band Analysis (see Table 9)	background + 5 dB(A)	background + 5 dB(A)	background + 5 dB(A)	background + 5 dB(A)
Wyoming	No State Legislation for Wind Turbine Noise				
Wyoming - Larmaie County	LAeq [dB(A)]	50	50	50	50

2.1. Belgium

Belgium consists of three regions: The Flemish Region, the Walloon Region and the Brussels-Capital Region. For this study we looked into the legislation in the Flemish and Walloon Region. The Brussels-Capital Region is an urban area, which is not really suited for wind farms.

2.1.1. Flanders

The Flemish Region, named Flanders, has specific legislation for wind turbine noise [1]. The current legislation was implemented on January 1st, 2012.

The sound power level used for the calculations is to be determined at 95 % of the nominal power from the wind turbine. An accuracy margin of standard 1 dB(A) is assumed. If the accuracy margin exceeds 1 dB(A), the difference has to be added to the sound power level.

The target values for wind turbine noise are summarized in Table 2 below. If the background noise level is higher than the values as stated in the table, then the noise limit is equal to the background noise level. In this situation a setback distance of a minimum of 3 times the rotor diameter is taken into account.

Table 2. The Flemish Region Wind Turbine Noise Threshold Limits

Area	Target Value in dB(A) in Open Air		
	Day	Evening	Night
residential areas, areas for recreation residence	44	39	39
rural areas, residential areas at less than 500 m from industrial areas, recreational areas	48	43	43
industrial areas	60	55	55
other areas	44-55	39-50	39-50

2.1.2. Wallonia

On 21 February 2013, a recently approved noise limit of 45 dB(A) has been established for all wind speeds at the façade of dwellings [2][2]. A setback distance of minimum 3 times the total height for large wind turbines and 350 meters for medium large wind turbines was also established.

It is possible to deviate from these requirements if the background noise already exceeds 45 dB(A) and sufficient noise insulation is guaranteed or an agreement is made between the developer/owner of the wind farm and the inhabitants of specific dwellings, while a minimum distance of minimum 3 times the height of the turbines and 400 meters is respected.

2.2. Canada

Canada does not contain established national legislation for wind turbines whereby deferring to provincial regulations. These regulations are further discussed below.

2.2.1. Alberta

Within the province of Alberta noise generated from wind turbines is regulated by the Alberta Utilities Commission (AUC) [3]. The AUC regulates wind turbine noise impacts during the nighttime period from 10:00 p.m. to 7:00 a.m. This regulation provides the minimum basic sound level for calculating the permissible sound level, which is 40 dBA L_{eq}. Adjustments are then made for proximity to transportation and population density. The basic noise threshold limits for the nighttime period are summarized in Table 3.

Table 3. Alberta Province Basic Sound Level Limits for Nighttime

Proximity to Transportation	**(1) 1 to 8 dwellings; 22:00 to 7:00 (nighttime) (dB(A) Leq)**	**(2) 9 to 160 dwellings; 22:00 to 7:00 (nighttime) (dB(A) Leq)**	**(3) 160 dwellings; 22:00 to 7:00 (nighttime) (dB(A) Leq)**
Category 1	40	43	46
Category 2	45	48	51
Category 3	50	53	56

These regulations assume that the nighttime ambient sound level is 5 dB less than the applicable basic sound level. Category 1 represents dwellings located 500m or more from heavily travelled roadways or rail lines and not subject to frequent aircraft over flights; Category 2 represents dwellings located 30m or more, but less than 500m from heavily travelled roadways or rail lines and not subject to frequent aircraft over flights; Category 3 represents dwellings located 30m or less from heavily travelled roadways or rail lines or are subject to frequent aircraft over flights.

2.2.2. Prince Edward Island

The province of Prince Edward Island does not have specific state legislation in regards to wind turbine noise; however, it does regulate setback distances [4]. Setbacks for neighboring residences must be 3 times the total height of the turbine and 1 times the height from the developer's home.

2.3. Denmark

Denmark has specific legislation on noise from wind turbines. In 2011 the existing statutory order on noise from wind turbines was revised to include limit values for low frequency noise [5]. The new legislation entered into force on January 1st, 2012.

The noise parameters used are:

- the noise exposure level L_r for the total noise;
- the noise level L_{pALF} for the A-weighted low frequency noise in dwellings in the frequency range from 10 to 160 Hz.

The L_r-level includes a supplement of 5 dB(A) if the noise contains clearly audible tones.

The limit values for the noise exposure level L_r are:

- At dwellings in residential areas, holiday homes, etc.
    - 37 dB(A) at a wind speed of 6 m/s.
    - 39 dB(A) at a wind speed of 8 m/s.
- At dwellings in rural areas
    - 42 dB(A) at a wind speed of 6 m/s.
    - 44 dB(A) at a wind speed of 8 m/s.

The limit value for low frequency noise L_{pALF} is 20 dB at a wind speed of 6 and 8 m/s indoors in dwellings in both residential areas and rural areas.

In addition to the above mentioned noise limits, a setback distance of 4 times the total height of the wind turbine to dwellings has to be respected [6].

2.4. France

France has a specific noise code for wind turbines [7]. The established noise parameter used is L_{Aeq}. The noise limits at noise sensitive buildings and locations are:

- Day (7 a.m. tot 10 p.m.): increase of 5 dB(A) with reference to the background level
- Night (10 p.m. to 7 a.m.): increase of 3 dB(A) with reference to the background level

Noise levels lower than 35 dB(A) are always accepted.

At a radius of 1.2 times the total turbine height, an equivalent noise level is allowed of 70 dB(A) during the day and 60 dB(A) during the night. Additionally, a fixed setback distance of 500 m to residential buildings and areas has to be respected.

2.5. Germany

Currently Germany has no specific legislation regarding noise from wind turbines. The noise from wind turbines is regulated by the legislation for industrial noise, named 'TA-Lärm 1998' (Technical Guidance for Protection against Noise) [8]. The parameter rating level L_r (long time average noise level) is used. The target values depend on the area where noise sensitive buildings are located and are stated in Table 4 below.

Table 4. Germany Wind Turbine Noise Threshold Limits

Area	Target Value in dB(A) in Open Air	
	Day (6 to 10 p.m)	Night (10 p.m. to 6 a.m.)
spa areas, for hospitals and nursing homes	45	35
purely residential areas	50	35
general residential areas and small residential estate areas	55	40
village areas and mixed-use zones, central city areas	60	45
in commercial zones	65	50
in industrial areas	70	70

For tonal noise a supplement K_T of 3 or 6 dB is applied depending on the distinctiveness. For impulse noise a supplement K_I of 3 or 6 dB is applied depending on the exposure.

A number of state governments in Germany have issued wind energy decrees as a guideline for planning and licensing of wind farms. Often these decrees recommend set back distances for regional planning. Depending on the state, the recommended set back distances [9] vary from:

- Solitary dwellings or small settlings: 300 to 1000 meters;
- Residential areas: 500 to 1000 meters

For the state of Nordrhein-Westfalen a distance of 1500 m is mentioned as the typical distance at which usually no adverse environmental effects are present [10]. This distance is based on the required distance from a wind farm consisting of seven 2 megawatt (MW)-class wind turbines to a purely residential area [target value 35 dB(A)]. Smaller distances are possible, but the noise levels of the wind farm must first be examined and compared against the noise limits in the TA-Lärm 1998.

2.6. The Netherlands

The Netherlands has a specific noise code for wind turbines [11][12]. The current legislation has been implemented on January 1st, 2011. The noise parameters used are the L_{den} and the L_{night}. At noise sensitive objects and locations the noise level from a wind farm should not exceed:

- 47 dB L_{den}
- 41 dB L_{night}

The authorities can chose to, but are not obliged to, take cumulative effects with neighboring wind farms into account. The authorities can decide to set different noise limits taking special local circumstances into account. In The Netherlands no penalties are used for impulsive or tonal noise. Also, no fixed set back distance is used.

2.7. New Zealand

New Zealand has a specific standard for wind farm noise, titled NZS 6808:2010 Acoustics – Wind farm [13]. New Zealand uses the noise parameter $L_{A90(10\ min)}$ for wind farm noise and for background noise.

NZS 6808:2010 recommends a noise limit at dwellings of the background noise level plus 5 dB(A) or a level of 40 dB(A) $L_{A90(10\ min)}$,whichever is the greater. In special circumstances for particularly quiet locations a lower, more stringent limit is recommended during the evening and night time of background noise level plus 5 dB(A) or a level of 35 dB(A) $L_{A90(10\ min)}$, whichever is the greater.

2.8. Norway

Norway has a guideline for the treatment of noise in spatial planning [14]. This guideline includes a specific noise limit for wind turbines. The noise parameter used is L_{den}. The noise limit at dwellings and other noise sensitive buildings is 45 dB L_{den}.

For wind turbines, no penalties are applied for possible tonal or impulsive noise. There are also no required setback distances established in these guidelines.

2.9. South Australia

The Environmental Protection Agency of South Australia has issued a guideline to assess wind farm noise [15]. South Australia uses the noise parameter $L_{Aeq,10}$ for wind farm noise and $L_{A90,10}$ for background noise. The equivalent noise level ($L_{Aeq,10}$), adjusted for possible tonality, should not exceed:

- 35 dB(A) $L_{Aeq,10}$ at relevant receivers in localities which are primarily intended for rural living, or
- 40 dB(A) $L_{Aeq,10}$ at relevant receivers in localities in other zones, or
- the background noise ($L_{A90,10}$) by more than 5 dB(A), whichever is the greater, at all relevant receivers for wind speeds from cut-in to rated power of the WTG and each integer wind speed in between.

A penalty of 5 dB(A) is applied for tonal noise. No fixed set back distance is used. Staged developments or cumulative developments have to meet the criteria using the original background noise levels.

2.10. Sweden

The recommended noise limit for wind turbines in Sweden is an equivalent noise level (L_{Aeq}) at 8 m/s of 40 dB(A) L_{Aeq} for residential areas and 35 dB(A) L_{Aeq} for areas with low background noise like rural areas [16].

If the sound contains clearly audible tones a penalty of 5 dB(A) is applied.

2.11. United Kingdom (UK)

In the UK the report 'The Assessment and Rating of Noise from Wind Farms', ETSU-R-97 is used to assess wind farm noise [17]. The noise parameter used is $L_{A90,10\ min}$. It is stated within the report that the $L_{A90,10\ min}$ is typically 1.5 to 2.5 dB(A) less than $L_{Aeq,10\ min}$.

The recommended noise limits at the nearest noise sensitive properties are:

- Day (7 a.m. – 11 p.m.): background noise level plus 5 dB(A) with a lower limit of 35 to 40 dB(A) $L_{A90,10\ min}$;
- Night (11 p.m. – 7 a.m.): background level plus 5 dB(A) with a lower limit of 43 dB(A) $L_{A90,10\ min}$.

The day-time noise limits are derived from background noise data taken during quiet periods of the day. These are defined as all evenings from 6:00 p.m. to 11:00 p.m. Saturday afternoons from 1:00 p.m. to 6:00 p.m. and all day Sundays from 7:00 a.m. to 6:00 p.m.

The published report established that the lower limit for the night time period to be higher than the lower limit for the day time period. The UK report explains this because that during the night time period the protection of the external amenity is considered less important and the emphasis is put on preventing sleep disturbance.

If the noise consists of audible tones a penalty of up to 5 dB is added to the measured noise levels.

The daytime and nighttime lower limits can be increased to 45 dB(A) $L_{A90,10\ min}$ and the permissible margin above background can increased, if the occupier of the property has some financial involvement in the wind farm.

2.12. United States of America (USA)

The United States of America does not contain established national legislation for wind turbines whereby deferring to local state or county regulations. These regulations are further discussed in relevant sections below.

In instances where there is no wind farm legislation, noise limits are enforced by standardized noise ordinances of the governing jurisdiction or simply rely on national environmental noise guidelines, such as the Environmental Protection Agency (EPA). The EPA has published guidelines for environmental noise levels with a directive to protect public health and welfare with an adequate margin of safety; however, these guidelines were not established to regulate noise from wind turbines and are generally referenced for community noise [18].

The EPA established its criteria using the day-night average sound exposure (L_{dn}) metric. According to the EPA guidelines, a 45 L_{dn} dB(A) indoors and 55 L_{dn} dB(A) outdoors for residential areas in a rural setting is identified as the maximum allowable noise level. Furthermore, the EPA guidelines do not include information or requirements for setback distances and tonality issues that arise during wind turbine operation.

2.12.1. Colorado

The State of Colorado does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties located within the State when applicable.

2.12.1.1. Arapahoe County

Arapahoe County restrictions for noise levels associated with wind turbines depend on the classification of the neighboring land use [19]. Daytime and nighttime dB(A) L_{eq} noise limits for neighboring land uses are stated in Table 5 below.

Table 5. Arapahoe County Noise Threshold Limits

Land Use	Daytime Noise Limit in dB(A) (7:00 a.m. to 7:00 p.m.)	Nighttime Noise Limit in dB(A) (7:00 p.m. to 7:00 a.m.)
Residential	<55	<50
Commercial	<65	<60
Light Industrial	<70	<65
Industrial	<80	<75

Additionally, a fixed setback distance of 100% of the wind turbine system height from all property lines has to be respected. No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.2. Georgia

The State of Georgia Wind Working Group Model Wind Ordinance for wind energy facilities presents a single noise limit for wind energy facilities in dB(A) L_{eq} [20]. Audible sound from a Wind Energy Facility shall not exceed 55 dB(A) L_{eq} at any time, as measured at the property line of a non-participating landowner. No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

Setbacks are measured from the center of the wind turbine base to the property line or nearest point on the foundation of an occupied building. Minimum setback requirements vary based on the height of the wind turbine and adjacencies such as neighboring participating and non-participating landowner buildings or non-participating landowner property lines.

No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.3. Illinois

The State of Illinois does not have specific state legislation in regards to wind turbine noise and defers to applicable Illinois Pollution Control Board (IPCB) state noise regulations [21]. These regulations provide octave band sound pressure level limits (dB, L_{eq}) at neighboring property lines. Noise limits are specified in terms of receiving and source land use classifications. The land use classifications are: Class A (Residential), Class B (Commercial/retail), and Class C (Agricultural/Industrial). A rural property, even in an agricultural setting, is considered a Class A residence. The State considers wind

farms to be a Class C land use. The table below summarizes the applicable octave band noise criteria for noise emitting from Class C Land (Industrial) to a Class A Land (Residential) receiving source.

Table 6. Illinois Noise Regulation – Sound Pressure Levels Emitting from Class C (Industrial) to Class A (Residential) (dB)

Scenario	Octave Band Center Frequency (Hertz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Daytime Limit (L_{eq}) (7:00 a.m. to 10:00 p.m.)	75	74	69	64	58	52	47	43	40
Nighttime Limit (Leq) (10:00 p.m. to 7:00 a.m.)	69	67	62	54	47	41	36	32	32

The State of Illinois's regulations do not include information or requirements for setback distance and tonality for wind farms.

2.12.4. Indiana

The State of Indiana does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

2.12.4.1. Tipton County

Tipton County Zoning Ordinance regulates noise associated Wind Energy Conversion Systems (WECS) within 200 feet of a residence with octave band maximum noise level threshold limits [22]. These limits are summarized in Table 7 below.

Table 7. Tipton County Octave Band Noise Threshold Limits

Octave Bands (Hz)	Maximum Permitted Sound Level (dB)
63	75
125	70
250	65
500	59
1000	53
2000	48
4000	44
8000	41

2.12.5. Michigan

The State of Michigan Siting Guidelines for Wind Energy Systems enforces a single noise limit for wind farms in dB(A) L_{eq} at the closest neighboring property line [23]. These guidelines state that On-Site Use wind energy systems shall not exceed 55 dB(A) L_{eq} at the property line closest to the wind energy system. Exceptions for neighboring property are allowed with the written consent of those property owners. This sound pressure level may be exceeded during short-term events such as utility outages and/or severe wind storms. If the ambient sound pressure level exceeds 55 dB(A) L_{eq}, then the standard shall be the ambient dB(A) plus 5 dB(A).

No penalties are applied for possible tonal or impulsive noise associated with wind turbines and State regulations do not include a specific setback distance.

2.12.5.1. Huron County

Huron County has more stringent noise regulations than those set forth by the State of Michigan Siting Guidelines for Wind Energy Systems. The County regulations limit noise levels associated with the operation of Wind Energy Facilities to 50 dB(A) L_{90}, or the ambient sound pressure level plus 5 dB(A), whichever is greater, measured at the building exterior of any residence [24].

In the event that the audible noise from the operation of the Wind Energy Facility contains a steady pure tone, a 5 dB(A) penalty is enforced. The County regulations do not include a specific setback distance.

2.12.6. Minnesota

Minnesota Pollution Control Agency (MPCA), Chapter 7030-Noise, states that noise generated from the operation of a large wind energy system may not exceed 50 dB(A) L_{eq} at 5 feet above grade at the geometric center of a back or front yard of any adjacent farm residence [25].

No penalties are applied for possible tonal or impulsive noise associated with wind turbines and the state regulations do not include a specific setback distance.

2.12.6.1. Lincoln County

Lincoln County refers to the MPCA noise regulations where noise generated from the operation of a large wind energy system may not exceed 50 dB(A) L_{eq} at 5 feet above grade at the geometric center of a back or front yard of any adjacent farm residence.

The County does set forth the following setback requirements for wind turbines [26]. The setback distance range from 300 feet for wind turbines under 100kw to 750 feet for wind turbines over 100kw.

County regulations do not provide specific penalties for possible tonal or impulsive noise associated with wind turbines. However, it does state that the MPCA noise regulation noted above may not be sufficient for the “preservation of public health and welfare” in

relation to impulsive noises and that additional local limits relative to impulsive and pure tone noises may be appropriate.

2.12.7. Nevada

The State of Nevada does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

2.12.8. Lyon County

Lyon County provides a single noise limit for wind farms in dB(A) [27]. The County Ordinance enforces a noise limit of 55 dB(A) L_{eq} at any adjacent property line.

Setbacks for wind farms are to be 2 times the system height from any property line.

No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.9. New Mexico

The State of New Mexico does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

2.12.9.1. San Miguel County

San Miguel County requires that wind turbine noise levels are not to exceed any hourly L_{eq} (as determined by independent consultant retained by the county, and previous amended hereinabove) at any of the closest noise sensitive receptors, including residences, schools, hospitals, and places of worship [28].

Setback distances for wind turbines must meet the following criteria as set forth by the County:

- Project buildings and accessory structures shall be at least 100 feet distant from property boundary.
- Each project tower shall be 2 times the system height from all property boundaries.
- Each project tower shall be at least one-half (1/2) miles distant from any occupied residence, commercial building, hospital, school, or place of worship.

The county may impose a more stringent noise setback that exceeds the distance setbacks provided above. These more stringent setback distances may be necessary to protect the public health and safety and promote the general welfare of the citizens of San Miguel County.

No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.10. New York

The State of New York does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

2.12.10.1. Township of Jefferson

The Town of Jefferson enforces a single L_{A10} noise limit for wind farms [29]. The statistical sound pressure level generated by a wind turbine can't exceed a 50 L_{A10} dBA at the nearest residence. If the ambient noise level exceeds the applicable standard given above, the applicable standard shall be the ambient dB(A) plus 5 dB(A).

In the event that the audible noise from the operation of the Wind Energy Facility contains a steady pure tone, a 5 dB(A) penalty is enforced.

Setback distances for wind turbines must meet the following criteria:

- Distance of 1,000 feet from each wind turbine to any public road, residence, lodging facility, camp, public building, church or other institution.
- Wind turbines must be set back from the nearest occupied residence located on a non-participating landowner's property by a distance of not less than 5 times the hub height, as measured from the center of the wind turbine base to the nearest point on the foundation of the occupied building.

2.12.11. North Carolina

The State of North Carolina Model Wind Ordinance addresses noise for small and medium wind energy facilities by setbacks or by existing noise ordinances [30]. The State Ordinance presents a single noise limit for wind farms in dB(A) L_{eq}. The County Ordinance provides a noise limit of 55 dB(A) L_{eq} at any occupied building of a non-participating landowner. Restrictions may be waived under certain conditions.

Setback distances are calculated by multiplying the required setback number by the wind turbine height and measured from the center of the wind turbine base to the property line, building or road. Minimum setback requirements vary based on the height of the wind turbine and adjacencies such as neighboring participating and non-participating landowner buildings or non-participating landowner property lines.

No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.12. Oregon

The State of Oregon 340-035-0035 Noise Control Regulations for Industry and Commerce enforces noise from wind energy facilities based on an assumed L_{A50} of 26 dB(A) background noise level or the actual ambient background level [31]. The person owning the wind energy facility may conduct measurements to determine the actual ambient L_{A10} and L_{A50} background level. The ambient statistical L_{A10} and L_{A50} background level may increase by more than 10 dB(A) but not above the limits specified in the table below at either 25 feet (7.6 meters) from the nearest noise sensitive building

or at the point on the neighboring noise sensitive property line nearest the wind turbine facility, depending on which is closer. These statistical limits are summarized in Table 8 below.

Table 8.New Industrial and Commercial Noise Source Standards Allowable Statistical Noise Levels in Any One Hour

7 a.m. - 10 p.m.	**10 p.m. - 7 a.m.**
L_{50} - 55 dBA	L_{50} - 50 dBA
L_{10} - 60 dBA	L_{10} - 55 dBA
L_1 - 75 dBA	L_1 - 60 dBA

No penalties are applied for possible tonal or impulsive noise associated with wind turbines and the state regulations do not include a specific setback distance.

2.12.13. Pennsylvania

The State of Pennsylvania does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

2.12.13.1. Potter County

Potter County Ordinance regulates wind farm noise by taking into account background noise levels at the property line of any non-participating property owner [32]. Noise associated with wind farms cannot exceed 5 dB(A) above the background noise levels at these property lines.

Setback distances for wind turbines must meet the following County criteria:

- The greater of 5 times the system height or 1,750 feet from the nearest occupied building on any non-participating property
- 1,000 feet from the nearest non-participating property boundary line

No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

2.12.14. Wisconsin

The State of Wisconsin Legislation, Chapter PSC 128 Wind Energy Systems states that noise attributed to wind energy systems cannot exceed 50 dB(A) L_{eq} during daytime hours during daytime hours from 6:00 a.m. to 10:00 p.m. and 45 dB(A) L_{eq} during nighttime hours from 10:00 p.m. to 6:00 a.m. at the outside wall of non-participating residences or occupied community buildings [33]. In the event that the noise from the wind energy systems contains a steady pure tone, the owner must take corrective action to permanently eliminate the noise.

Setback distances must be the lesser of 1,250 feet or 3.1 times the maximum blade tip height from occupied community buildings and non-participating residences and 1.1 times the maximum blade tip height from participating residences and non-participating property lines.

2.12.14.1. Shawano County

Shawano County Ordinance regulates wind turbine noise by taking into account background noise levels at the property line of any non-participating property owner [34]. Noise associated with wind farms cannot exceed 5 dB(A) above the background noise levels for more than 5 minutes out of any one-hour time period at these property lines.

The County Ordinance also states that no low frequency noise or infrasound noise from wind turbine operations shall be created which causes the noise level both within the project boundary and a one-mile radius beyond the project boundary to exceed the limits provided in Table 9 below.

Table 9. Shawano County One-Third Octave Band Noise Threshold Limits

1/3 Octave Band Center Frequency (Hz)	Sound Pressure Level (dB)
2 to 1	70 (each band)
16	68
20	68
25	67
31.5	65
40	62
50	60
63	57
80	55
100	52
125	50
250	47
500	45
1000	42
2000	40
4000	37
8000	35

Wind turbines that emit impulsive sound below 20 Hz that adversely affects the habitability or use of any existing dwelling unit, hospital, school, library, nursing home, or other sensitive noise receptor are considered unsafe and must be shut down immediately.

In the event that the audible noise from the operation of the Wind Energy Facility contains a steady pure tone, repetitive, and/or impulsive sound, a 5 dB(A) penalty is enforced.

Setback distances for wind turbines must meet the following criteria as set forth by the County:

- 400% of system height from all sensitive receptors, but in no case less than 1,000 feet
- 200% of system height from all ownership property lines, but in no case less than 500 feet

2.12.15. Wyoming

The State of Wyoming does not have specific state legislation in regards to wind turbine noise and defers to the jurisdiction of the Counties or Cities located within the State when applicable.

However, the State does have regulations for setbacks [35]. The State requires that the base of any tower be at a distance of at least 110% of the maximum height of the tower from any property line contiguous or adjacent to the facility. Any tower must be at least 5.5 times the maximum height of the tower and not less than 1,000 feet from any platted subdivision. The base of the tower is also required to be the same distance from any residential dwelling or occupied structure. Towers also cannot be located within one-half mile from the limits of any city or town.

2.12.15.1. Laramie County

Laramie County provides a single noise limit for large wind energy system or wind farms in dB(A) [36]. The County Ordinance enforces a noise limit of 50 dB(A) at any point along common property lines between a non-participating property and a participating property. Noise levels may exceed the 50 dB(A) limit along common property if written permission is granted by the affected adjacent non-participating property owners.

Setbacks defer to regulations set forth by the State. No penalties are applied for possible tonal or impulsive noise associated with wind turbines.

3. Wind Turbine Noise Parameters and Limits Comparative Evaluation

Noise limits are established and regulated by applying specific noise metrics to ensure the quality of life within local communities. The noise metrics used to regulate noise from wind turbines have been shown to contain a large variation between countries and jurisdictions where disparities are identified in the noise measurement duration, wind speed, statistical data collection, and community ambient penalties applied.

Research shows that the L_{Aeq} metric is the most common metric used for regulating wind farm noise. A total of 16 of the 39 governing jurisdictions sampled in this analysis use the L_{Aeq} metric. Five countries use a metric that is derived from the L_{Aeq} metric, like L_r, L_{dn}, L_{den} and L_{night}, but include a penalty for times of day with increased sensitivity like part of the day (L_r in Germany), the evening (L_{den}) and the night (L_{den}, L_{dn}). Further, L_{den} and L_{night} as defined in the EU Directive Environmental Noise (2002/49/EC) are year average noise levels. The metric L_{Aeq} is defined as the “equivalent sound level” and is based on a time-integrated measurement period which does vary between countries and jurisdictions. These integrated time periods range from a 1 hour measurement to a 24 hour measurement (evaluation period). The noise threshold established for the L_{Aeq} metric shows to be an approximate 20 decibel variation depending on the governing jurisdiction. These variations are further described in Figure 1 below.

Figure 1: Comparison Between Countries with dB L_{Aeq} Noise Limits for Residential Areas[1]

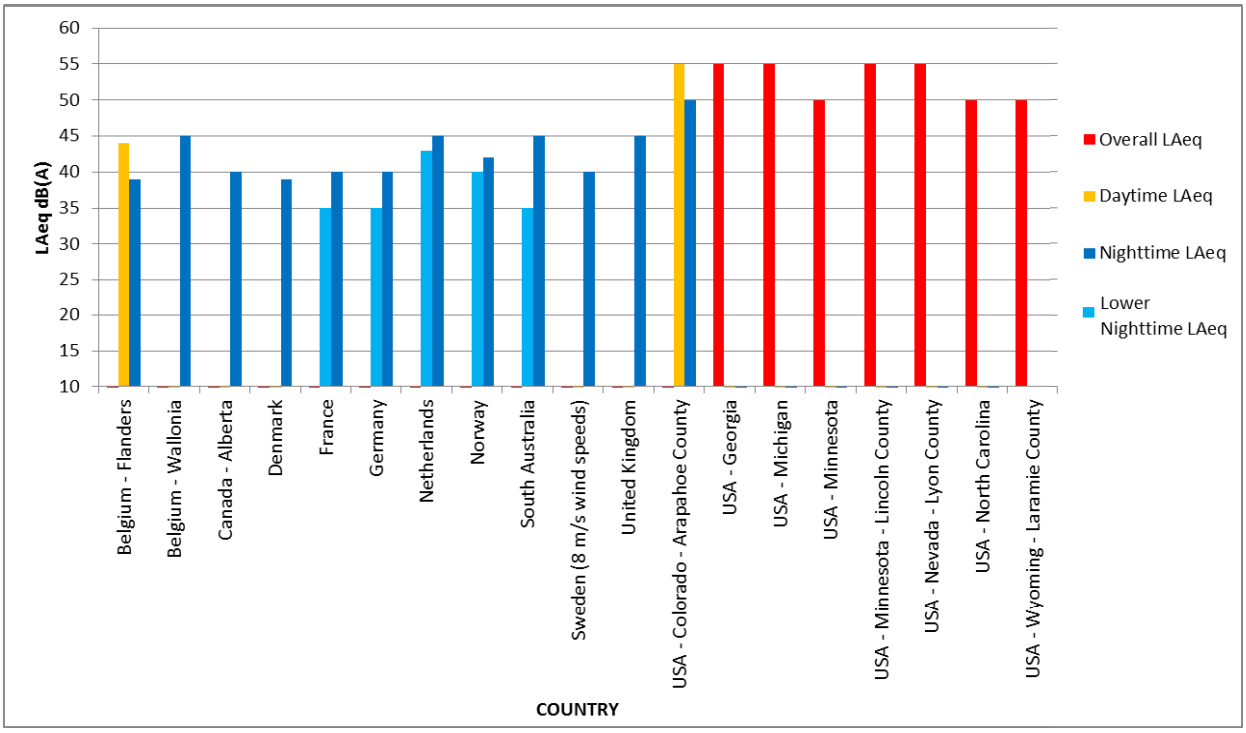


Figure 1 shows that jurisdictions within the United States have higher noise threshold limits for wind turbine regulations, than Europe and South Australia. France, Germany and South Australia contain the lowest threshold limits when applying the L_{Aeq} metric.

Most countries in Europe, but also South Australia, New Zealand and a number of states and counties in the USA, have a noise limit which depends on the type of area or the existing background noise levels. Exceptions are The Netherlands, Norway, the Belgian Region Wallonia, the Canadian province of Alberta and a number of states and counties in the USA, which all have fixed limit values.

Countries like France, Sweden, South Australia and New Zealand have more stringent noise limits for rural areas with relatively low background noise levels than for residential areas. In contrary, the Belgian Region Flanders, Denmark and Germany in general allow higher noise levels at dwellings in a rural area than at residential areas.

Statistical noise metrics (L_{90}, L_{50}, and L_{10}) were found in 5 of the 39 of the wind turbine governing jurisdictions. Additionally noted were frequency octave band noise threshold limits which were found to be incorporated into 3 of the jurisdictions as well. However, similar to the L_{Aeq} metric, these metrics showed variation in threshold values and time

[1] The upper nighttime L_{Aeq} for France and South Australia in Figure 1 is based on an assumed background noise level of 40 dB(A). For The Netherlands and Norway L_{Aeq} levels were calculated from L_{den} values.

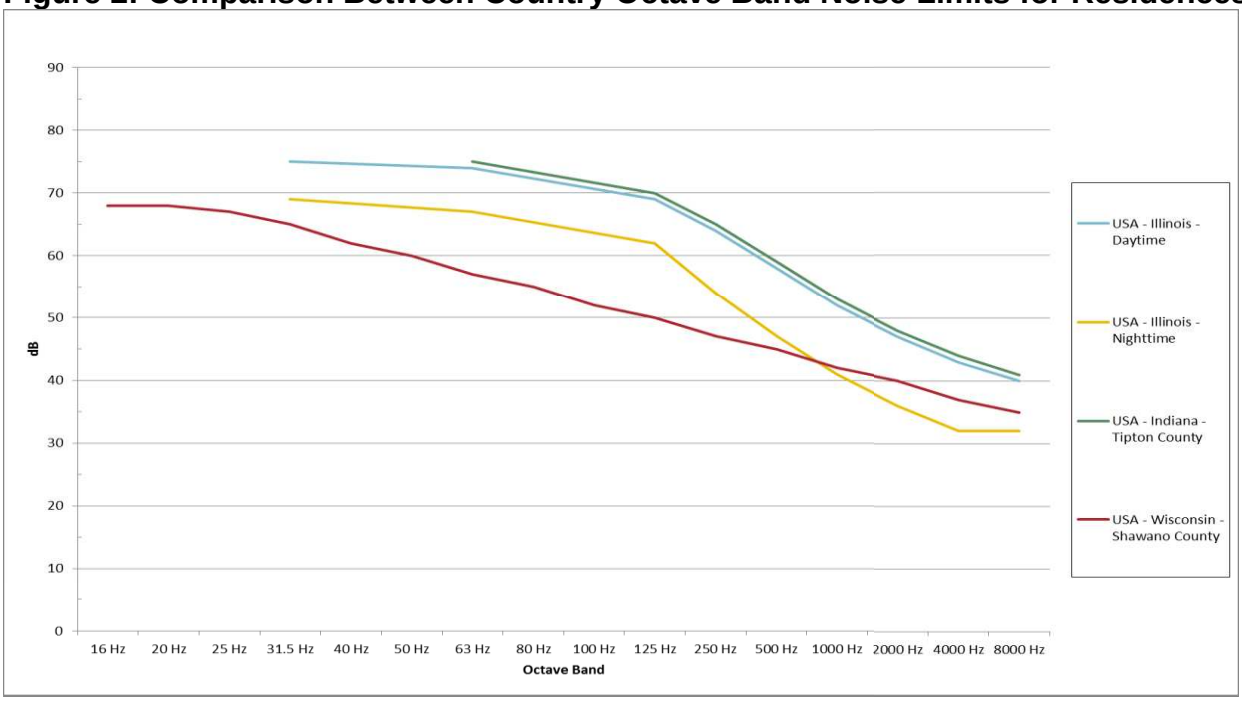
durations. An analysis of the octave band threshold limit was conducted and these variations are illustrated in Figure 2.

Possible tonal issues associated with wind turbines were addressed in a number of the governing jurisdictions. This included several in Europe (Denmark, Germany, Sweden, and the United Kingdom), South Australia and two in the USA (Township of Jefferson and Shawano County). The tonal analysis was identical within all but one of these jurisdictions, which incorporated a 5 dB penalty added to the established threshold limits. Germany is the exception. It does include a penalty for possible tonal noise, but the penalty is 3 or 6 dB depending on the distinctiveness. Out of these jurisdictions, Shawano County was the only one that included a low frequency one-third octave band analysis. Denmark regulations also include a low frequency analysis from 10 Hz to 160 Hz, but this was a single overall number for this frequency range.

Furthermore, 9 of the 39 jurisdictions did not contain any published noise regulations. These jurisdictions were typically Countries or States that would defer noise regulations to the local providence or county. This was most common in North America and found in both the United States and Canada.

A high percentage of jurisdictions evaluated contain set back requirements for wind turbines. However, these setback requirements were mainly enforced for safety issues or visual impact and, in most cases, were not related to noise.

Figure 2: Comparison Between Country Octave Band Noise Limits for Residences



4. Conclusion

This overview study is an initial attempt to conduct a comparative analysis incorporating 39 governing jurisdictions spanning Europe, Australia, New Zealand and North America. Research shows that the most common noise metric used with wind turbine regulation is the L_{Aeq} metric. Statistical and 24 hour metric regulations, as well as frequency octave band noise threshold limits, are also discovered to be prevalent within governing regulations but with less occurrence. Moreover, an interesting variation is discovered when comparing the applicable threshold limits to time integrated durations. Variations in time periods range from 1 hour to 24 hours, which in some jurisdictions include daytime and nighttime periods. Additionally, the noise thresholds established for the L_{Aeq} metric showed a comparative difference of a 20 decibel variation depending on the jurisdiction.

When distilling the information surrounding a turbine's possible tonal noise issue, the findings show the most similarity. However, this was only found in 6 of the 39 jurisdictions. The way these jurisdictions addressed the tonal noise issue was identical, which incorporated a 5 dB penalty added to the established threshold limits.

It can be said that today many jurisdictions responsible for governing wind turbine noise possess a wide range of noise regulations that span between country and county authorities. There is no common influence or application of metrics that can be identified between the sampled jurisdictions. And, there is a wide range on how stringent a jurisdiction is when regulating noise from wind turbines. Depending on the noise metric used, this range in noise impact threshold limits could be a difference of 20 decibels or greater; a difference significant enough to consider whether or not a wind farm may be permitted for development and whether or not it may generate community complaints.

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