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Which limits for wind turbine noise? A comparison with other types of sources using a common metric.

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Summary

Wind turbine noise (WTN) is more annoying than a conventional noise sources with equivalent intensity. This aspect and the continuous installation of wind farms, closer and closer to houses, led to an increase in complaints from receivers. The disputes that follow often become legal actions, because the existing limit values have not been thought for WTN. The aim of our work was to suggest specific limits for WTN that consider the real annoyance perceived by population in relation with the type of the source. To do this, from Miedema's curves we extracted the number of highly annoyed (HA) that corresponds to the Italian limits for road traffic noise. The sound level for WTN corresponding to that %HA has been determined from recent dose-response relationships.

The results have been compared with the limits issued in various national regulations, in order to evaluate their accordance with this approach. The method can be a useful tool to update limits when when further studies will be performed to improve the reliability of dose-

response relationship for WTN in relation to different contexts. The limit here proposed, however, can be used immediately to guide national legislation and to provide a scientific criterion to address the disputes between citizens and the wind farms operators.

1. Introduction

The installations of wind farms are continuously increasing, as well as the complaints from receivers. These are caused by a variety of factors, including that in some countries wind turbines are also planned in amazing and quiet areas (i.e. Mediterranean countries), where dwellings are restored for touristic reasons and are chosen for their amenity and quietness as principal attractiveness. Wind turbine noise (WTN) may be quite low, but noise emitted is different from other sources in terms of generation, propagation and perception by neighbors. It is easily understandable why WTN is more annoying than the conventional noise sources of equivalent intensity [1].

The disputes that follow the complaints often become legal actions, because the existing limit values have not been thought for WTN and there are still no well defined limits at international level, but they are fixed following different approaches.

The evaluation of noise to the receiver is performed using outdoor measurements, obviously dependent on the measurements of background noise, that it variables with wind speed. The solution adopted by some standards (i.e. Netherlands, Ontario) is to use limits variable with wind speed at a standard height. The assessment of background noise remains a problem: in Ontario a possible definition of it was given as a function of wind speed [2], which, however, is strongly dependent on the measurement site, on the eventual complex terrain and on the boundary conditions, that can be very different and variable [3]. It is therefore impossible to correlate a measure of the wind speed at microphone height with a simultaneous one at hub height [4].

In Italy the assessment is even more critical, because the regulations requires to calculate the difference between environmental noise and background noise in the same weather conditions. To get a measure of residual, therefore, it’s necessary to turn off the wind farm or to find some other method [5].

In common between all normative approaches there is often a lack of a scientific reason for the choice of the limit value. The aim of our work was to suggest specific limits for WTN that consider the real annoyance perceived by population in relation with the specific

source, considering the annoyance dose-response relationships for different sources and deriving a limit value according with ones already issued for those other sources.

2. International legislative and regulatory framework

The international legislative and regulatory framework is not very uniform, although some general remarks are now widespread [6]. Among these:

- WTN has the unique characteristic that the noise level from each wind turbine generator (WTG) increases as the wind speed at the site increases.
- The background noise also generally increases under these conditions and can mask the WTN.

As the impact of all the other noise sources, WTN is closely linked to the amount it exceeds the background noise, but the same noise in a quiet rural area will generally have a greater adverse impact than in a busy urban area, because of the masking effect of high ambient noise environments.

The assessment of WTN can be done comparing the noise impact of the source with a base noise level, but this is not sufficient: a wind farm could comply with this base level at lower wind speeds and exceed it at higher wind speeds. Most international jurisdictions, but not all, set a base noise level for low wind speeds and also ensure that WTN does not exceed the background noise by more than 5 dB(A) when the wind speed increases.

Some of the most important regulations are summarized below:

2.1 U.K.

The ETSU-R-97 noise limit [7] is a combination of a fixed limit (in the range of 35 dB to 40 dB L_{A90}) and a derived relative limit (prevailing background curve + 5 dB). For the protection of the sleep during night, an external free field level of 43 dB L_{A90} is appropriate when background noise levels are low. When background noise levels are sufficiently high, then the noise limits are set to the prevailing background +5 dB.

A single lower fixed limit of 35–40 dB(A) can be imposed when the background noise levels do not vary significantly, based upon background noise levels taken during the amenity periods and the night analyzed together.

2.2 France

A wind turbine specific standard (NF S31-114–Acoustics– Measurement of Environmental Noise Before and After Wind Turbine Installation) is in production. At the present time, however, the applicable guidance is the Decret 2006-1099 of 2006 which specifies that the combined effect of any new noise with the existing noise should not exceed the existing noise level by more than 5 dB during the day and 3 dB at night.
Noise levels are required to be measured in octave bands.

2.3 Germany

Noise limits are defined in a generic document from 1998, the TA Lärm [9], and reported in Table 1.

Area	Day	Night
Industrial area	70/65 dB(A)	70/50 dB(A)
Mixed residential area and industry Or Residential areas mixed with industry	60 dB(A)	45 dB(A)
Purely residential areas with no commercial developments	55/50 dB(A)	40/35 dB(A)
Areas with hospitals, health resorts, etc.	45 dB(A)	35 dB(A)

Table 1: Summary of limits for WTN in Germany.

2.4 Netherlands

Regulations on noise from wind turbines were introduced in the Netherlands 2001 [10].
The limits follow a wind speed dependent curve. For the night the limit starts at 40 dB(A) at 1 m/s and increases with the wind speed to 50 dB(A) at 12 m/s. For daytime the limit starts at 50 dB(A) and for evenings at 45 dB(A).

2.5 New Zealand

WTN should not exceed the background sound level by more than 5 dB, or a level of 40 dB L_{A90} (10 min), whichever is the greater. For some locations that are particularly quiet this limit of 40 dB would be considered to be unreasonable. For this purpose, the 2010 Standard introduces a lower limit of 35 dB L_{A90} (10 min) for high amenity areas.

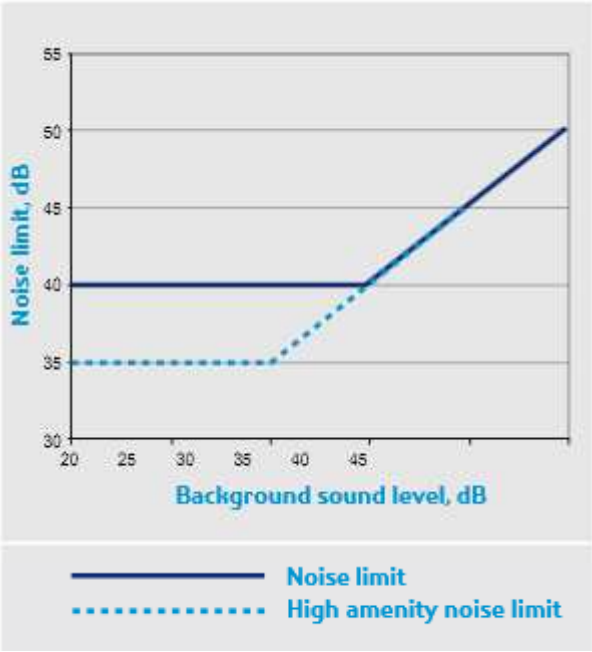

Figure 1: Representation of WTN limits in New Zealand [11].

2.6 South Australia and NSW

The predicted equivalent noise level $L_{Aeq,10}$, adjusted for tonality in accordance with the guidelines, must be evaluated at all relevant receivers for each integer wind speed from cut-in to rated power of the wind turbines. It should not exceed 35 dB(A) or the background noise ($L_{A90,10}$) by more than 5 dB(A), whichever is the greater [12].

2.7 Denmark

WTN may not exceed the following limit values:

1) At the most noise-exposed point in outdoor living area, no more than 15 meters from dwellings in open countryside:
   - (a) 44 dB(A) at a wind speed of 8 m/s.
   - (b) 42 dB(A) at a wind speed of 6 m/s.
2) At the most noise-exposed point in areas with noise-sensitive land use:
   - (a) 39 dB(A) at a wind speed of 8 m/s.
   - (b) 37 dB(A) at a wind speed of 6 m/s.

Where “noise-sensitive land use” are the areas designated for residential, institutional, holiday home, camping, allotment purposes or recreational activities [13].

2.8 Canada

Ontario, Alberta and British Columbia are the only Canadian provinces with guidance specific to wind turbines.

In Ontario the current Guide [14] sets the noise limits at a receiver in rural areas (class 3) ranging from 40 dB(A) to 51 dB(A), depending on wind speeds in the range of 6 to 10 m/s at 10 m of height. For class 1 and 2 the limits range from 45 dB(A) to 51 dB(A), as shown in Table 2 and Figure 2.

Wind Speed (m/s) at 10 m height	4	5	6	7	8	9	10
Wind Turbine Sound Level Limits Class 3 Area, dBA	40.0	40.0	40.0	43.0	45.0	49.0	51.0
Wind Turbine Sound Level Limits Class 1 & 2 Areas, dBA	45.0	45.0	45.0	45.0	45.0	49.0	51.0

Table 2: Summary of limits for WTN in Ontario [14].

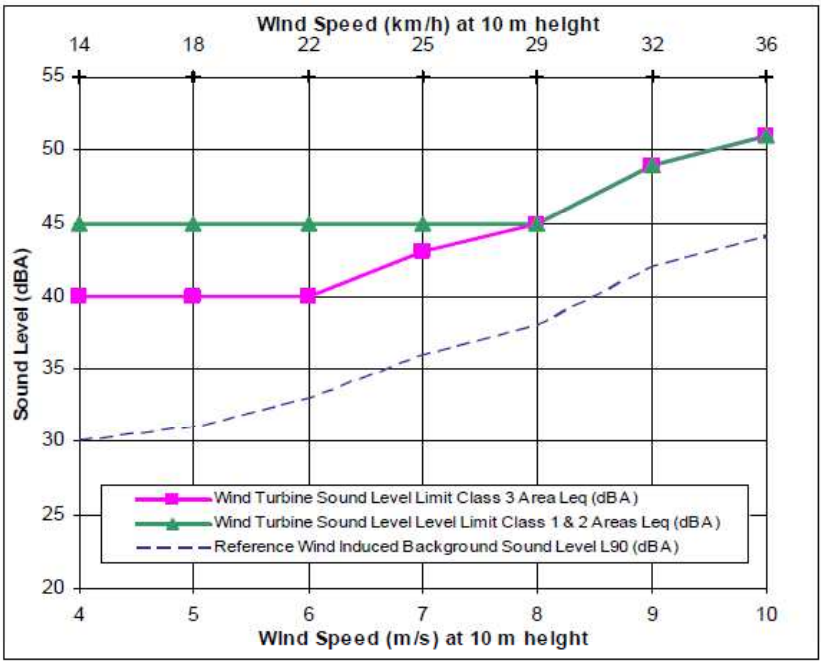

Figure 2: Summary of limits for WTN in Ontario and reference wind induced background noise [14].

Due to the particular acoustic emission as a function of wind speed, the critical condition for compliance with the noise limits in most cases occurs at the 6 m/s wind speed. Therefore, the noise limit at the receiver is generally considered to be the same for all wind speeds and wind turbine operating conditions at 40 dB(A) [15].

In a quiet rural area, application of Alberta's Energy Utilities Board Directive 038 [16] would yield a criterion with a night time L_{eq} of 40 dB(A) for rural area. This is because the average rural ambient noise level in Alberta is about 35 dB(A) during night and the limit is fixed 5 dB(A) above it. The only wind speeds for which the Directive prescribes predictions are between 6 and 9 m/s. The limit increase depending on the number of dwellings in the area and on the category of the area, as shown in Table 3.

	Dwelling unit density per quarter section of land		
Proximity to transportation	1 - 8 dwellings; 22:00 - 07:00 (nighttime) (dBA Leq)	9 - 160 dwellings; 22:00 - 07:00 (nighttime) (dBA Leq)	>160 dwellings; 22:00 - 07:00 (nighttime) (dBA Leq)
Category 1	40	43	46
Category 2	45	48	51
Category 3	50	53	56

Table 3: Summary of limits for WTN in Alberta [16].

In British Columbia the “Land use operational policy, wind power projects on Crown land" [17] fixes the maximum WTN level at 40 dB(A), determined at constant wind speeds between 8 and 10 m/s.

3. Estimate of a tolerance threshold for WTN

Depending on the type of the source, a noise can be more or less disturbing than others while having the same energy. A parameter used to measure this reaction is the percentage of highly annoyed (% HA) to the specific source. Therefore, our assessment is based on the perceived noise and its degree of acceptability compared to other type of sources, rather than sound energy detected. Annoyance is estimated through specific socio-acoustical surveys that comply with well defined international standards.

To the best knowledge of the author, the following studies are those that have provided various degrees of relationship between WTN and annoyance:

(i) a European study carried out in Denmark, the Netherlands and Germany (Wolsink et al, 1993; Wolsink and Sprengers, 1993) [18];

(ii) a complementary Danish study (Pedersen and Nielsen, 1994) [19];

(iii) the first Swedish study (Pedersen and Persson Waye, 2004) [1];

(iv) a more recent Swedish study (Pedersen and Persson Waye, 2007) [20];

(v) a Dutch study (Pedersen and van den Berg, 2009) [21];

(vi) an analysis of previous studies (Janssen and Vos, 2011) which provides a curve that takes into account the consequent results so far [22].

The (iii) and (v) studies use the L_{Aeq} simulated on a hypothetical period of time outside receivers. The noise levels are simulated using the sound emission of all turbines in conditions favorable to the propagation and with 8 m/s of wind measured at 10 m height. For the purpose of our work and given the limited number of papers published on the subject, we consider only the outdoor sound levels.

Michaud [23] underlined the role of %HA as one of most important health end points for an environmental assessment and used it to justify the limit fixed in Ontario. Michaud [24] used the Schultz relation (1978), reviewed in [23], for %HA that is generic for all noise source. Following that approach, we used the more recent and detailed psychoacoustic studies as a starting point for our calculation of the tolerance threshold for WTN.

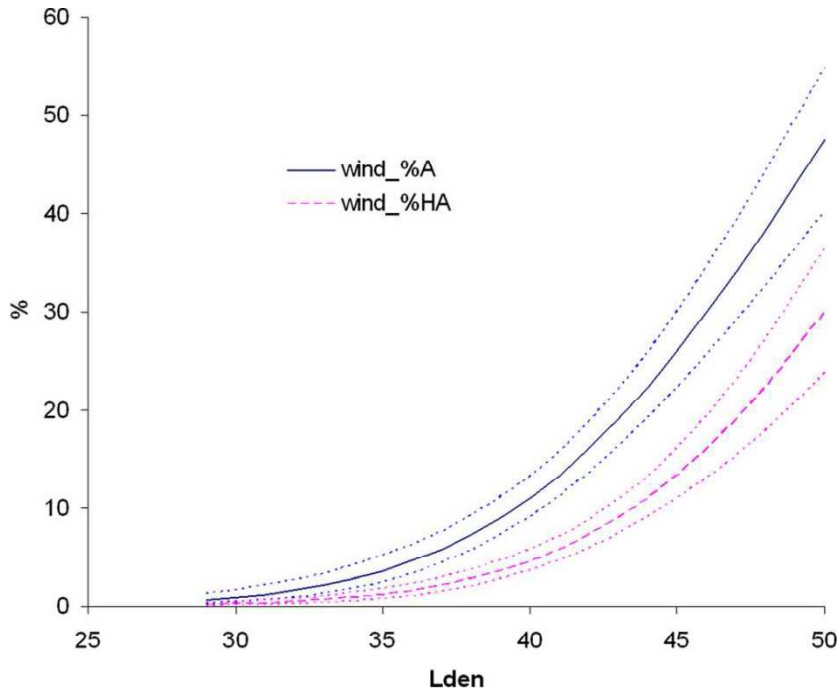

Figure 3: Janssen [22] dose–response relationship for annoyed (%A) and for highly annoyed (%HA) in outdoor environment.

The following steps are necessary to correctly use the data in Figure 3:

1. Conversion from L_{Aeq} to L_{den} of the Italian law limits for road traffic noise.
2. Determination of %HA corresponding to the law limits for road traffic noise through their dose-response relationship for highly annoyed.
3. Calculation of the tolerance threshold for outdoor wind turbine noise levels corresponding to the %HA identified.

3.1 Conversion from LAeq to Lden of the Italian law limits for road traffic noise

The maximum noise level admitted in Italy according to the Law No. 447 of 26th October 1995 "Framework Law on noise pollution" [25] for outdoor road traffic noise is 70 dB(A) during the daytime (day and evening) and 60 dB(A) during nighttime. These values correspond to road type D (urban fast road, dual carriage ways) in the acoustic area V, the last for which residential settlements are authorized. These limits are also almost the same or similar as those in most European countries, including the Czech Republic, France, Germany, Netherlands, Spain, Sweden [26].

The transformation of L_{Aeq} in L_{den} can be done trough the formula reported by R. Makarewic and M. Galuszka [27], adapted according to the definition of L_{den} in Italy that considers only 2 hours for evening period and 14 for the day period:

$$L_{DEN} = 10log_{10}\left\{\frac{14}{24}\times 10^{0,1L_{day}} + \frac{2\cdot\sqrt{10}}{24}\times 10^{0,1L_{evening}} + \frac{8\cdot 10}{24}\times 10^{0,1L_{night}}\right\}$$

Assuming a road where the noise is exactly equal to the limit, the value corresponding to the limits in Italy for roads obtained is 70.7 dB (A) of L_{den}.

3.2 Determination of %HA corresponding to the law limits for road traffic noise through their dose-response relationship for highly annoyed.

In order to calculate the %HA corresponding to the law limits for road traffic noise we can use the formula given in the EEA Technical report of 2010, "Good practice guide on noise exposure and potential health effects" [28], referring to Miedema's studies [29], that is:

$$\%\,HA = 9.868 * 10^{-4}\,(L_{den} - 42)^3 - 1.436 * 10^{-2}\,(L_{den} - 42)^2 + 0.5118\,(L_{den} - 42)$$

With 70.7 dB (A) of L_{den}, the %HA corresponding to the law limits for road traffic noise is the 26.2%.

3.3 Calculation of the tolerance threshold for outdoor wind turbine noise levels corresponding to the %HA identified

This calculation is based on the assumption that the% HA obtained is considered tolerable according to generic Italian noise limits. This percentage should be the same for each type of source for a uniformity in the treatment of people exposed to noise, given that the specificity of the source is already considered in the diversity of the dose-response relationship.

A tolerance threshold of 49.1 dB(A) of L_{den} can be obtained inverting the Janssen's equation of the dose-response relationship for %HA in outdoor environment ($\%HA_{outdoors}$):

$$\%HA_{outdoors} = -97.94 + 9.627\ L_{den} - 0.3175\ L_{den}^2 + 0.003522\ L_{den}^3$$

The corresponding L_{Aeq} limit for WTN is then calculated with the equation in chapter 3.1 ad it's equal to 42.9 dB(A).

The starting point of the derivation of this limit were the studies of Jensen, that refer to those of Pedersen and Van den Berg [1][20][21], in which the WTN has been calculated for a wind speed of 8 m/s at 10 meter of height from the ground, in flat terrain and without background noise.

WTN will surely change with wind speed or with the stability class, as well as the contribution of the background noise. In addition, uncertainty remains in considering what actually happens at ground height (2 m), since the conversion of wind speed based on the logarithmic profile of the wind shear is not reliable for such low heights.

4. Conclusions

A limit value for WTN has been determined starting from the Italian one for road traffic noise during daytime and nighttime, equal or similar to those of many European countries. The %HA corresponding to the limit for road traffic noise, converted in L_{den}, have been extracted from its dose-response relationship for highly annoyed. Then, the tolerance threshold for outdoor WTN levels have been taken from the WTN dose-response relationship [jansen] at the %HA identified for road traffic noise.

This limit value is derived from the curve of Jansen, which is calculated using also the data from Pedersen and van den Berg. Thus, this curve is determined by calculating the noise at receiver and through propagation models in generic conditions of wind (8 m/s wind speed at 10 m height). Such operational conditions not necessarily determine those noise levels in any environmental condition, because they also depend on other factors, including the atmospheric stability and the topography of the site.

The limit value obtained, calculated with negligible background noise, is 42.9 dB(A) and is comparable with the standards analyzed in the article, particularly the British and the Danish ones. The regulations also establish limit values increasing with residual noise, and therefore with the speed of the wind. The derivation of these values with general validity,

however, is complex, because residual noise levels depends exclusively on the environmental and weather conditions of the measurement site.

The measuring mode then becomes determinant to the results, which are dependent on the wind, on the direction of sound propagation, on the presence of any other source, on the distance from obstacles, etc. Also the presence of vegetation, which varies seasonally, could influences the outcome of a measurement campaign which may result in exceeding the limit or not if carried out in winter rather than summer. So, in any legislation, the period in which to perform the measurement campaign of the residual noise and the duration of it has to be chosen very carefully.

The method can be a useful tool to update limits when further studies will be performed to improve the reliability of dose-response relationship for WTN in relation to different contexts. The limit here proposed, however, can be used immediately to guide national legislation and to provide a scientific criterion to address the disputes between citizens and the wind farms operators.

It remains an open problem how translate the limit in a distance between the receiver and the source. It may be necessary to define case by case the operational conditions for which the limit is respected, taking into consideration the conditions of places.

The process of preventive impact assessment can lead to conditions on the use of the wind farm, which could affect the placement of the plant or the mode of operation of the wind turbines (if supplied with the particular model).

References

[1] E. Pedersen, K. Persson Waye, “Perception and annoyance due to wind turbine noise: A dose–response relationship,” J. Acoust. Soc. Am. 116, 3460–3470, 2004.

[2] A. D. Lightstone, Guangsheng (Sam) Du And Ian Matthew, “Simultaneous measurements of ambient sound levels and wind speeds”, Canadian Acoustics Vo. 38 No. 4, 2010.

[3] K. Bolin, “The infuence of natural ambient sounds on wind turbine noise “, 3° International meeting on wind turbine noise, Aalborg, june 2009.

[4] L. Fredianelli, G. Licitra et al., “The suitable parameters to assess noise impact of a wind farm in a complex terrain: a case-study in Tuscan hills”, Euronoise Prague, 2012.

[5] G. Licitra, L. Fredianelli, et al., “A new procedure for the assessment of wind turbine noise”, Outgoing, 2013.

[6] C. Weed “Examples of noise standards and wind turbine noise regulations”, Centerville Township Commercial Wind Ordinance Committee August 7, 2006
[7] ETSU for the Department of Trade and Industry, “The Assessment and Rating of Noise from Wind Farms”, Report ETSU-R-97, 2005.
[8] Decret n° 2006-1099 relatif a la lutte contre les bruits de voisinage et modifiant le code de la sante publique - dispositions reglementaires, 31 aout 2006.
[9] Technische Anleitung zum Schutz gegen Lärm Sechste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz (TA Lärm) vom 26. August 1998.
[10] Besluit van houdende regels voor voorzieningen en installaties; Besluit voorzieningen en installaties milieubeheer; Staatsblad van het, Koninkrijk der Nederlanden 487, 18 oktober 2001.
[11] 6808:2010 “Acoustics –Wind farm noise”, 2010.
[12] South Australia Environment Protection Authority, “Wind farms environmental noise guidelines”, 2009.
[13] Statutory Order no. 1284 on Noise from Wind Turbines, 15 December 2011.
[14] Noise Guidelines for Wind Farms – Interpretation for Applying MOE NPC Publications to Wind Power Generating Facilities - October 2008.
[15] Environmental Protection Act R.S.O. 1990 “Development of Noise Setbacks for Wind Farms:Requirements for Compliance with MOE Noise Limits”September 2009.
[16] Energy Resources Conservation Board Directive 038: Noise Control February 16, 2007.
[17] Columbia Ministry of Agriculture and Lands (2007). “Land use operational policy, wind power projects on Crown land,” effective Oct 2005, amended Dec 2007.
[18] M.Wolsink, M. Sprengers, “Wind turbine noise: A new environmental threat?,” Proceedings of the Sixth International Congress on the Biological Effects of Noise, ICBEN, Nice, France, Vol. 2, pp. 235–238, 1993.
[19] T. H. Pedersen, K. S. Nielsen, “Genvirkning af støj fra vindmøller - Annoyance by noise from wind turbines”, Report No. 150, DELTA Acoustic and Vibration, Lydtekniske Institut, Copenhagen, 1994.
[20] E. Pedersen, K. Persson Waye, “Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments,” Occup. Environ. Med. 64, 480–486, 2007.

[21] E. Pedersen, F. Van den Berg , R. Bakker, J. Bouma, “Response to noise from modern wind farms in the Netherlands”, J Acou Soc Am, 126, 634-643, 2009.
[22] S. A. Janssen, H. Vos, A. R. Eisses, E. Pedersen, “A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources”, J. Acoust. Soc. Am. 130, December 2011.
[23] D. S. Michaud, S. H. P. Bly, S. E. Keith “Using a change in percent highly annoyed with noise as a potential health effect measure for projects under the Canadian Environmental Assessment Act”, Canadian Acoustics Vo. 36 No. 2, 2008.
[24] S. E. Keith, D. S. Michaud, S.H.P. Bly, “A justification for using A 45 dBA sound level criterion for wind turbine projects”, Canadian Acoustics Vo. 36 No. 3, 2008.
[25] Italian Law No. 447 of 26th October 1995, "Framework Law on noise pollution”, 1995.
[26] Milieu, Final Report on Task 1 “Review of the Implementation of Directive 2002/49/EC on Environmental Noise”, May 2010.
[27] R. Makarewic, M. Galuszka, “Empirical revision of noise mapping”, Applied Acoustics, Vol. 72 (8), Elsevier – Jul 1, 2011.
[28] EEA, “Good practice guide on noise exposure and potential health effects”, EEA Technical report No. 11/2010, 2010.
[29] H.M.E. Miedema, H. Vos, “Exposure-response relationships for transportation noise, Journal of the Acoustical Society of America 104, pp. 3432-3445, 1998.