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Guidelines for developing regulations for acoustic impact, based on the stage of operation of wind farms in Chile

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Wind farms manifest different sonic characteristics than other sources, highlighting the presence of tonal components, low frequency noise and amplitude modulation effect (AM). For these reasons, the international community has developed specific regulations and technical documents to assess the acoustic impact of these cases. Nevertheless, the present Chilean noise regulation, Decreto Supremo N°38/2011 of the Environment Ministry, is not adjusted properly to the situation described above. Considering the exponential increase experienced by this energy source in recent years in Chile, the development of regulations for such features in the operational stage is suggested so that the noise impact can be properly addressed and quantified. Guidelines for the development of an eventual specific Chilean regulation will be proposed by analyzing and comparing international standards. From this work, we will determine the maximum noise levels, methodologies and other suggestions for the proposed target issues.

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1. Introduction

The government of Chile, with the aim of promoting the use of Non-Conventional Renewable Energy (NCRE), promulgated Law 20,698 [1], which requires big power generating companies to ensure that 20% of its energy comes from such types of energy, implementing gradually until 2025.

There are several NCRE options to consider, such as solar, small hydro, bioenergy and wind, among others. The wind resource in recent years has experienced a remarkable increase in installed capacity in Chile by implementing wind farms [2].

It is known that the acoustic impact of wind farms is different from other sources of noise, mainly because it contains low frequency sound signals, tonal components and amplitude modulation noise (AM). This last because its operation depends on the wind speed, which may vary depending on the time of year and/or by the topographic profile of the associated environment [3] [4] [5].

For such reasons, the international community has undertaken to evaluate these acoustic impacts through regulations specifically designed to address their particularities correctly. However, Chile lacks specialized standards and assesses their current acoustic impact with the Decreto Supremo No. 38/2011 of the Ministry of Environment (DS N°38/11 of MMA) [6], which differs significantly from the methodologies and criteria for international standards, specifically in the operational stage of these wind farms [7].

Given the above, this paper will present guidelines to consider for the eventual development of specific Chilean regulations associated with the evaluation of acoustic impact, in the operational stage, of wind farms through the comparative study of the main foreign standards.

2. Presentation of international standards

The regulations and technical documents to study can be classified into two main groups: a first set defining fixed maximum noise levels at the receptor depending on the wind speed associated with the operation of the wind turbine; and a second set of standards that define maximum noise levels at the receiver that varies according to background noise (considering multiple wind speeds) plus a certain level of dB added, which is generally 5 dB(A).

Despite the differences that may exist between them, all consider a key factor: the wind, and it is vital to keep in mind that the noise generated by wind farms is proportional to this important element.

There are several noise regulations of wind farms worldwide. However, the documents reviewed in this paper are most complete in its group. Among different standards to be considered, we have:

- Canada, Ontario: *Noise Guidelines for Wind Farms* [8].
- Denmark: *Statutory Order on Noise from Wind Turbines* [9].
- Massachusetts, United States: *MassCEC Acoustic Study for Wind Turbine Projects Methodology* [10].
- United Kingdom: *ETSU-R-97 The Assessment and Rating of Noise from Wind Farms* [11] and its application guide *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* [12].
- South Australia: *Wind Farms Environmental Noise Guidelines* [13].

The following analysis criteria were defined, which corresponds to the key aspects to consider and allow the orderly study of these standards:

- Maximum noise levels in the receptor (rural/urban areas).
- Location, height and duration of the noise measurements.

● Location, height and duration of the wind measurements.
● Prediction method.
● Others

2.1.- Ontario, Canada: ***Noise Guidelines for Wind Farms*** [8]

The overall purpose of this document is to establish the maximum noise levels of wind farms, in addition to providing clarity in communication between stakeholders and the competent authorities to expedite the review and approval process.

The sound level limits for wind farms in the receiver's location, in equivalent continuous level L_{eq}, "A" weighted, are:

Table 1. Summary of maximum limits [8]

Wind speed [m/s] at 10 [m] height	4	5	6	7	8	9	10
Sound level limits, class 3 area, dB(A)	40	40	40	43	45	49	51
Sound level limits, class 1 & 2 area, dB(A)	45	45	45	45	45	49	51

Where zone 1 represents urban areas, zone 2 semi-urban areas and zone 3, rural areas. Noise limits are defined for specific wind speed values, without decimals. These are presented in Figure 1. The dashed line is only referential, representing background noise (L_{90} in dB(A)) taken with average wind speeds in a quiet place in order to establish it as the basis for the limits shown in Table 1 by adding 7 dB to the background noise (assuming L_{eq}-L_{90}= 2 dB):

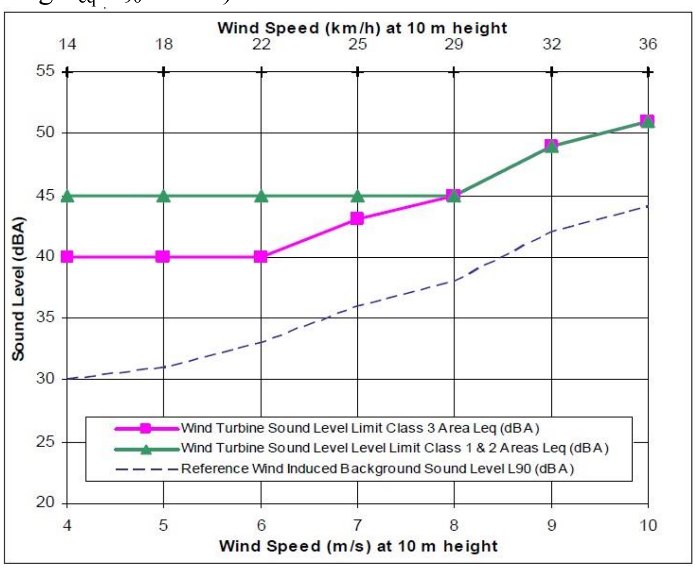

Figure 1. Summary of maximum limits in $L_{eq(A)}$ [8]

Noise measurements should be performed on the property of the nearest receiver to the wind farm, at a height between 1.5 and 4.5 meters, depending on how many floors the house has. The document does not indicate the duration of noise measurements, nor the class of sound level meter associated.

Wind measurements should be made at 10 meters; however, neither the place of these nor its duration is specified.

This legislation considers the drafting of a noise map adopting the use of method ISO 9613-2 [14].

If the manufacturer's specifications of the turbines indicate the presence of tonal noise, a study should be performed in octave bands. If confirmed, a penalty of 5 dB will be applied to the projected levels. This document takes into account also the acoustic impact given by the electrical substation.

2.2.- Denmark: *Statutory Order on Noise from Wind Turbines* [9]

The standard *Statutory on Noise from Wind Turbines*, presented in late 2011 after the revision of the first document *Statutory Order no. 304 of 14 May 1991 on Noise from Wind Turbines 1991* [15] and a second document *Statutory Order no. 1518 of 14 December 2006 on Noise from Wind Turbines* [16], addresses the installation, modification and operation of wind turbines. Notifications, permits and associated audits are conducted at a local level, being in charge, the municipal authorities.

The maximum values of noise levels in the receiver are:

1. For rural areas, no more than 15 meters from dwellings:
   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. For urban or residential areas:
   a) 39 dB(A) at a wind speed of 8 [m/s].
   b) 37 dB(A) at a wind speed of 6 [m/s].

The wind turbine low frequency noise should not exceed 20 dB(A) within the dwellings, at wind speeds of 6 and 8 [m/s], according to the quantifying method of this standard. On the other hand, if the frequency analysis indicates the presence of tonal noise, it will receive a penalty of 5 dB.

Noise measurements should be made with "A" weighting, using the noise parameter "$L_{p(A),tot}$" (derived from a method shown in the document), at a height of 1.5 meters, no more than 15 meters from dwellings, with corrected wind speeds (6 and 8 [m/s]) at a height of 10 meters. In this regulation, the sound level meter class and the duration of the noise measurement are not specified, excepting the indication of intervals of 10 or 60 seconds.

In relation to wind speed measurements, they must be taken at the wind farm, at the height of a representative wind turbine and at 10 meters above ground level.

This standard does not indicate the development of a noise map, but adopts the use of a own sound propagation method indicated in the document, whose uncertainty is ± 2 dB.

2.3.- Massachusetts, USA: *MassCEC Acoustic Study for Wind Turbine Projects Methodology* [10]

The standard *MassCEC Acoustic Study for Wind Turbines Projects Methodology* provides a methodology for studies of noise impact of wind turbines.

As indicated by the *Massachusetts Department of Environmental Protection's noise regulation* (MassDEP), the violation of noise regulations occurs when:

- The background noise is exceeded by 10 dB(A), or
- The existence of tonal noise is verified by analysis in octave bands, when any band exceeds the adjacent bands by 3 dB or more.

The maximum noise level will be determined by the noise metric L_{eq} and L_{90}, both with "A" weighting and integration periods of 10 minutes. The use of a Type 1 sound level meter will be considered according to ANSI standard [17].

The levels will be verified at the boundary of the property (inhabited or uninhabited) closest to the wind farm, at a height between 1 and 2 meters above the ground, at 7.5 meters (at least) from reflective surfaces, during a period of 14 consecutive days, not indicating a particular period of the year, but avoiding rainy seasons.

The wind speeds must be obtained at a representative point of the wind farm, at hub height. Failing that, they can be obtained at a height of 10 meters and then extrapolated to the hub height. Such measurements should consider integration periods of 10 minutes, for 14 consecutive days, and coinciding with noise measurements.

Finally, this standard considers the development of a noise map adopting the use of the sound propagation method ISO 9613-2 [14].

2.4.- United Kingdom: *ETSU-R-97 The Assessment and Rating of Noise from Wind Farms* [11]

The standard *ETSU-R-97 The Assessment and Rating of Noise from Wind Farms* points out the framework within which the noise measurements should be based for wind farms and indicates maximum noise levels in order to provide reasonable protection to the surrounding community.

The acoustic impact of a wind farm will be limited to 5 dB(A) above background noise for both day and night periods. It may be considered the exception of a simplified method: in environments with low noise levels, the daytime level may be limited to an absolute level within the range 35-40 dB(A), depending on the number of the properties near the wind farm, the effects of noise caused depending on kW/h generated and the duration and level of noise in the receptors. In the case of nighttime levels, it is recommended that the fixed maximum level is 43 dB(A). For both periods, fixed values may be increased to 45 dB(A), as long as the receptors have an economic incentive by the wind farm.

The Figure 2 presents typical background noise levels and daytime limits:

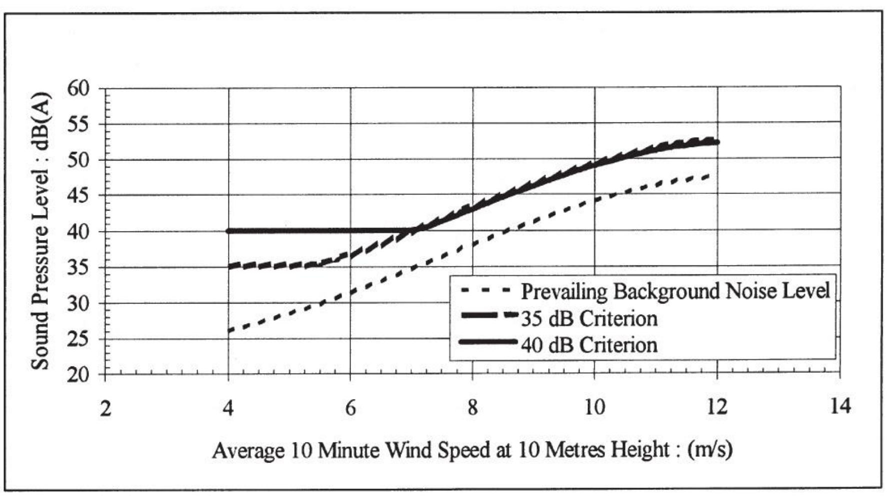

Figure 2. Day-time maximum noise levels [11]

The British standard considers the use of the noise parameter L_{90}, "A" weighting, with intervals of 10 minutes for measurements of background and wind farm noise. It will be considered Class 1/Type 1 sound level meter, as stated the document *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* [12].

Noise measurements will be made at the nearest properties to the wind farm, at a height between 1.2 and 1.5 meters above ground level, 3.5 meters (at least) from reflective surfaces. The duration of these should not be less than 14 days, in continuous day and night periods.

Wind measurements should be made at a representative point of the wind farm by a SODAR or LIDAR system, at a height of 10 meters. In the case of measuring wind speeds at hub height, 10 meters data will be extrapolated by the formula (1), considering ground roughness z_0 = 0.05. These measurements should temporarily match with the noise measurements.

$$v_{10} = v_{hh} \cdot \left(\frac{\mathrm{Ln}\left(\frac{10}{z_0}\right)}{\mathrm{Ln}\left(\frac{hh}{z_0}\right)} \right) \tag{1}$$

Where:
v_{10}= Calculated Wind speed [m/s] at 10 m height.
v_{hh}= Measured wind speed [m/s] at hub height.
hh= Hub height [m].
z_0= Reference roughness.

Finally, the British regulation does not mention the elaboration of a noise map, but indicates the predicted levels by the ISO 9613-2 method [14].

In the case that a wind farm already exists at the time of an acoustic evaluation for a new project, the first noise should not be considered as part of the background noise.

In order to properly identify and assess the tonal noise, it shall proceed according to the *Joint Nordic Method* standard [18].

2.5.- South Australia: *Wind Farms Environmental Noise Guidelines* [13].

The standard *Wind Farms Environmental Noise Guidelines* has been created because wind turbines have a unique noise, generating characteristics and the environments surrounding wind farms usually have low ambient noise. The objective of these guidelines is to protect the surrounding community from the inherent acoustic impact.

The equivalent continuous noise level ($L_{eq(A),10}$) of the operational noise of the wind farm, considering the appropriate tonal corrections, shall not exceed:

- 35 dB(A) for receptors in rural areas, or
- 40 dB(A) for receptors in urban areas, or
- The background noise ($L_{90(A),10min}$) by more than 5 dB(A)

Of these three options, the highest value will be chosen from the recorded levels in the receptor, considering all of the wind speeds which operate a wind turbine.

Noise measurements will be made with the noise metric L_{90}, "A" weighting, with integration periods of 10 minutes and sound level meters at least Class 2 according to IEC-60942 standard [19]. In addition, this procedure will consider the microphones at a height between 1.2 and 1.5 meters, outside of dwellings, and at least 5 meters from reflective surfaces. Measurements should not be affected by rainy days. It is permitted to report noise measurement over 5 [m/s] if they have been taken with special windshields. At least 2000 intervals should be considered, measured both for background noise as well as the noise of the wind farm operation.

Wind measurements should be obtained at hub height, with intervals of 10 minutes in a representative site of the wind farm, considering 2000 intervals and temporary coinciding with noise measurements in the receivers.

This regulation also considers the elaboration of a noise map, with its prediction being made by ISO 9613-2 [14] or CONCAWE [20].

2.6.- Comparative analysis

After studying selected standards in this paper, the regulations with fixed noise limits show that for rural areas the maximum values are similar, although in urban areas Denmark adopts lower limits than rural areas. Both consider frequency analysis in octave bands, noise measurements at a height of 1.5 meters (Ontario also considers at 4.5 meters) and wind measurements at least at a height of 10 meters. Ontario takes into account the acoustic impact given by the electrical substation.

In relation with the standards that consider background noise as base, two deemed a margin of 5 dB and one a margin of 10 dB. It is noteworthy that all regulations pertaining to this group adopted the use of the noise metric $L_{90(A),10min}$ for measurements of background noise, with justification for not considering occasional, impulsive or short-term noise (such as aircraft, pets, automobiles) in registers and establish more representative values. Noise measurements around a height of 1.5 meters, with continuous monitoring for two weeks, are also taken. Except for a few times mentioned in the guidelines of Massachusetts, all studied cases consider penalties due to tonal noise.

In sum, excepting only certain details (such as the contemplation of low frequency noise in Denmark), all regulations (according to the category they belong) adopt criteria and methodologies of the same type.

The next chapter presents guidelines taking into account the comparative analysis of the documents (for a brief comparative table, see Appendix).

3. Proposed guidelines

Considering the revision made to the standards presented above, the following guidelines and considerations for an eventual specific Chilean regulation are proposed. The detailed analysis and respective justification for each point are described in chapter 4:

1. Sound level limits (the highest value between):
    a. Fixed noise level given for each wind speed in integer values (within a defined range), and
    b. Background noise + 5 dB

2. Noise and wind monitoring:
    a. Use of noise parameter $L_{90(A)}$ with integration periods of 10 minutes.
    b. Noise measurements outside of the dwellings closest to the wind farm.
    c. Continuous monitoring from 10 to 14 days in the absence of rain, within a wind speed range of 3-12 [m/s].
    d. Wind measurements at 10 meters height, in sync with noise measurements.

3. Sound prediction:
    a. Use of prediction method CONCAWE [20] or Nord2000 [21].

4. Analysis and discussion

After studying and analyzing the documents presented, the question is what significant aspects should be considered for the development of an eventual Chilean regulation. These guidelines, as well as observing the standard *ETSU-R-97*, should "*offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities*" [11]. Among the most important issues to discuss and analyze, are proposed:

Maximum noise levels

Globally, there are three general ways to set noise limits:

- A minimum distance between a turbine and the nearest dwelling.
- Fixed limits.
- Variable limits.

According to the document *ETSU-R-97*, the experience in Europe indicates that it is unlikely to manifest problems with noise when the wind turbine-receiver distance is greater than 400 meters [11]. However, due to the topographic variability and the emission of low frequency noise [5] [22], it is not always a valid parameter by itself, though it is useful to mitigate the visual impact.

The proposed fixed noise limits according to wind speeds (as in the case of Ontario and Denmark), proves to be a simple and effective method by not requiring a survey of several days of background noise. To reach set maximum fixed values, they must be based on studies in Chilean territory, considering the sound characteristics of each environment and national reality in terms of natural landscapes and climatic seasonality, with an appropriate temporary representation.

On the other hand, the maximum levels given by the background noise plus a certain margin properly fit to a scenario that escapes the fixed maximum levels obtained from generic situations, i.e., a place with high background noise levels due to the proximity of a river, sea or excess foliage. In parallel, continuous noise monitoring in both the north and south of Chile show two completely opposite scenarios: the first case with measurements free of rainfall in the majority of the year and a second case with frequent and torrential rainfall.

Other standards [23] suggest using both methods mentioned: the use of fixed noise limits and background noise plus a margin. With the exception of one case, this margin is 5 dB(A).

Considering the foregoing, it is suggested that for an eventual Chilean specific regulation, maximum noise limits be adopted according to the last two methods. It is proposed that each wind farm respect the highest value between a fixed maximum level at the receiver (according to wind speed in integer values) and the background noise plus a margin. These fixed values must be established as a result of an acoustic and wind study by a competent authority, even considering that there may be critical conditions caused by dense foliage, proximity to a river, sea or the wide range of wind speeds throughout the Chilean territory[1]. If the noise levels studied are low, it is suggested that the maximum fixed limit vary between 35 and 40 dB(A) due to:

- Other international standards adopted these values.
- The World Health Organization (WHO) recommends a maximum value of 40 dB (outside housing) in order to avoid disruptions in sleep [25].
- Within these values, the percentage of annoying people is acceptable (≈26%) [26].

In the case of the background noise plus a margin, due to frequent international use of this value, the proposed delta is 5 dB(A). Thus, the facility is given to the wind farm to meet the criteria in one way or the other, taking care of the integrity of nearby receivers.

One issue to consider is that if the noise of the wind farm still exceeds 5 dB(A) of background noise in the receiver, it is proposed that as a last option, and with due assessment of the competent authorities, to establish compensation to those affected for each dB exceeded, as long as they agree. Among the topics to be defined, include:

[1] A clear example of this is that in the ideal areas for wind farms in the second region of Chile, the annual wind speeds ranging between 7 and 10 m/s; while in the Patagonian regions such values vary between 10 and 15 m/s [24].

- Maximum value in exceeded dB to compensate.
- Type of compensation (monetary, energy, material, etc.) and
- Mediator in negotiating an eventual compensation.

Noise and wind monitoring

The purpose of noise monitoring is to obtain levels of background noise in the receptor, considering a wide range of wind speeds (3-12m/s).

Due to the variability that can present the parameter $L_{eq(A)}$, being a victim of occasional noises (barking dogs, aircrafts, vehicle horns) and also by the experience in other countries, it is suggested that the noise metric used is $L_{90(A),10min}$, both for background noise and noise measurements of wind farms. This ensures reliable values, free from the influence of occasional noise unless they are present 90% of the study time. Notwithstanding the foregoing, it should analyze the usefulness of the metric $L_{90(A)}$ or another noise metric, when the phenomenon of amplitude modulation is present, so that it can be properly addressed later.

It is proposed that the measurements are taken outside the dwellings of the receptors closest to the wind farm (representing the worst case), at a minimum height of 1.5 meters, to (at least) five meters from reflective surfaces such as walls, facades and gates.

The regulations of the UK and Massachusetts propose to carry out continuous monitoring of background noise for at least two weeks. While Australia, for the same purposes, requests a minimum of 2000 samples of 10 minutes. Considering how unstable wind speeds can be in a given area, it is proposed that for reliable levels of background noise, measurements should be extended for a period of 10 to 14 days, carried out continuously with noise metric $L_{90(A),10min}$, especially in the windiest months of the year and, as far as possible, in the absence of rain. This will allow the obtainment of noise levels of the wind farm with low and high wind speeds.

It is proposed, with noise measurements, to record wind speeds in a representative place on the wind farm, with both coinciding temporarily. Because practically all regulations considered measure at a height of 10 meters (or extrapolated to that elevation), it is therefore suggested to adopt this consideration. These wind measurements should be limited to 12 [m/s], at 10 meters height, due to:

- According to wind records in Chile, there are few times at 10 meters of height that the speed is exceeded [24].
- At higher speeds, measurements of background and wind farm noise could be masked and thus provide unreliable data.
- Due to the above, it is unlikely that wind turbine manufacturers provide sound power levels at that speed.

Eventually, if the wind speed history shows little scatter data, it is suggested to discuss carefully reducing monitoring days.

To quantify the noise level of wind farm operations, it is proposed to follow the same protocol established for monitoring background noise, including wind records and the duration of the monitoring, respecting the same measurement points. Although there are developed methods to detect and filter the exclusive contribution of the park [27] [28], it is possible to obtain the wind farm contribution by applying an energy subtraction between the noise of the operation of the wind farm and the background noise previously registered for each wind speed.

In presence of tonal noise, whose characteristic is mentioned in almost all of the documents studied in this work, it is proposed to add a penalty of 5 dB(A) to the overall sound pressure level obtained. It is suggested that the analysis is done by studying frequency bands, either in 1/1 octave or 1/3 octave. The choice of the band is left to the judgment and study of a competent authority. Figure 3 shows the comparison made by Pedersen of the same wind turbine noise by different spectral analysis methods [29].

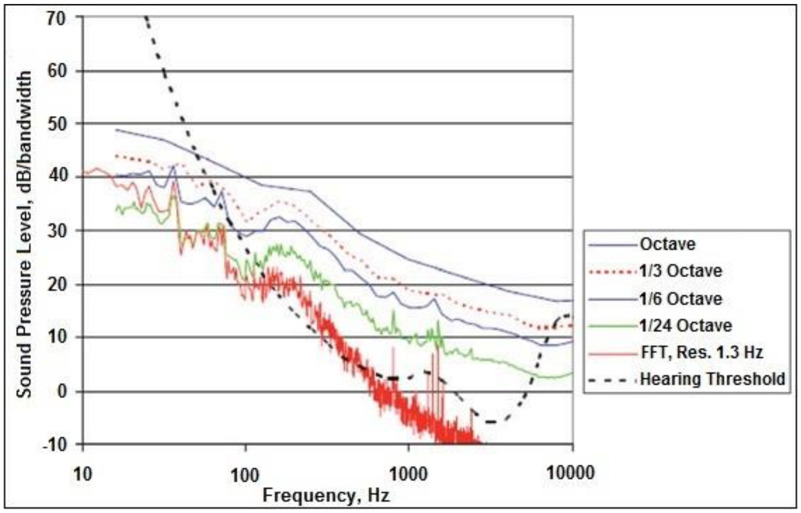

Figure 3. Different spectral analysis with the same signal of a wind turbine [29]

Sound prediction

The prediction and modeling of the sound environment are extremely important in the operational stage of the wind farm prior to construction, as it facilitates and streamlines the geographical position of the turbines, allowing the acoustic impact on the receptors to be mitigated to acceptable levels beforehand. However, none of the studied standards specifies the specific characteristics of sound modeling (sound directivity, type of noise source, etc).

There are three well known sound propagation standards: ISO 9613-2 [14], CONCAWE [20] and Nord2000 [21], which take into account the main sound attenuation variables such as geometric divergence, ground, obstacles and meteorological variables.

Concerning sound propagation models employed in the studied regulations from Ontario, Massachusetts and the UK, it is suggested the implementation of the model ISO 9613-2. For its part, the Danish regulation adopts its own model of propagation with an associated uncertainty of 2 dB. Finally, the Australian guidelines allow the use of standard ISO 9613-2 or CONCAWE hosting a climate category No 6. Once the method of propagation is adopted, and in order to obtain the sound power level (L_W), all studied regulations manifest the use of the specifications given by the manufacturer or its quantification according to the standard IEC 61400-11 [30].

A study made to 6 wind farms in Australia [31], where the predictions of wind farms with known methods and field measurements were compared, stated that ISO 9613-2 presented levels with greater uncertainties, especially on flat terrain or a constant slope, as a result of the associated topography surrounding wind turbines. For its part, CONCAWE adopted more reliable values up to distances of 2000 meters from the source, while the Nord2000 method had extremely accurate predictions. These results agree with those obtained by Søndergaard [32].

Although some of the documents studied adopt their use, as well as the DS N° 38/2011 of MMA [6], the standard ISO 9613-2 has uncertainty values known only for winds up to 5 [m/s] (measured at a height of 3 to 11 meters above ground level) with a maximum height average between the source and receiver of 30 meters, a condition that does not conform to the normal performance of wind farms. This situation was reflected in a remark made by a competent Chilean authority to a wind project in its study stage, stating that "ISO 9613-2 applies for a wind condition no greater than 5 [m/s], a condition that does not adjust to the operation of wind turbines. Therefore, we suggest using another prediction method... in order to provide safety margins to the sound modeling... "[33]. In response, they proceeded to make predictions with Nord2000, which became known to the competent authority, showing it is in compliance [34].

It is proposed, therefore, to consider using the standard CONCAWE or Nord2000 for purposes of modeling and prediction, in the operational stage of wind farms, due to:

- In the studies reviewed [31] [32], these methods proved to be the most conservative.
- In the parameters that adopt CONCAWE and Nord2000, the source heights and wind speeds related to the operation of wind turbines are considered.
- The Chilean competent authority said that, for purposes of prediction of wind farms, it is not sufficient to use the ISO 9613-2 method, showing compliance with regulations using Nord2000.

5. Conclusions

Five international documents of noise impact of wind farms were studied and summarized, highlighting their main aspects, methodologies and maximum acceptable limits, allowing the proposal of guidelines for an eventual specific regulation for the Chilean territory. In all analyzed documents, the influence of wind was considered as the main factor in determining the maximum permitted noise at the receptor.

Regarding the proposed guidelines for the Chilean territory, in order to determine the maximum permitted levels in the receptor, it is suggested to respect the highest value between either a fixed limit, according to wind speed in integer values, established as a result of a full study by Chilean competent authorities in the country or a maximum limit by meeting a given background noise level plus a margin of 5 dB(A). If the above is not achieved, it is suggested as a last resort to establish compensation to the receptors for each dB exceeded.

For purposes of noise monitoring (either background or wind farm), it is proposed the use of the parameter $L_{90(A),10min}$, which ensures freedom from the influence of occasional noises. It is recommended that such monitoring is carried out in the dwellings closest to the wind farm, at a height of 1.5 meters above the ground and away from reflective surfaces. It is suggested, in order to collect reliable data, a period of continuous measurements of 10 to 14 days for both background and wind farm operational noise, avoiding rainy days. In parallel, it is proposed to record the wind speed at a height of 10 meters on the wind farm or in a representative area. If there is proof of tonal noise by frequency bands analysis, a penalty of 5 dB will be proposed.

Prior to the construction of a wind farm, in the planning stage, it is proposed that the prediction and modeling of the sound environment be developed during the operation of the project, using CONCAWE or Nord2000, giving special emphasis on the topographical features of the environment under study.

As well as was demonstrated with the variability of maximum limits in different worldwide regulations, the choice of these values, along with methods and considerations, will determine the integrity and amenity or discomfort and rejection of the communities near wind farms.

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Appendix

A summary of the regulations and its main considerations are presented in Table 2.

Table 2. Main considerations of the studied regulations

	Ontario, Canada	Denmark	MA, USA	UK	South Australia
Maximum level, rural area [dB(A)]	40@4 m/s; 45@8 m/s; 51@10 m/s	42@6 m/s; 44@8 m/s; 20@6-8 m/s (LF)	Background + 10 dB(A)	Day: background + 5 dB(A), or a lower limit of 35 to 40 dB(A)	35 or background + 5 dB(A)
Maximum level, residential area [dB(A)]	45@4 m/s; 45@8 m/s; 51@10 m/s	37@6 m/s; 39@8 m/s; 20@6-8 m/s (LF)		Night: background + 5 dB(A), or a lower limit of 43 dB(A)	40 or background + 5 dB(A)
Noise metric	Leq(A)	Lp(A),tot and Lp(A)LF,tot	L90(A) and Leq(A)	L90(A)	L90(A)
Frequency analysis	Octave band	Octave band or one-third band	Octave band	According *Joint Nordic Method*.	Octave band
Consideration of low frequency impact	No, but it considers the impact associated with electrical substations	Yes	Not specified	Not specified	Not specified
Sound level meter Class or Type	Not specified	Not specified	ANSI Type 1	Class 1/Type 1 (Precision standars)	Class 2 according IEC
Noise measurement location	Receptor's dwelling	Receptor's dwelling	Receptor's dwelling	Receptor's dwelling	Receptor's dwelling
Noise measurement height	1.5/4.5 meters	1.5 meters	1 to 2 meters	1.2 to 1.5 meters	1.2 to 1.5 meters
Noise measurement extension	Not specified	10 or 60 seconds intervals	14 days, with 10 minutes intervals	14 days, with 10 minutes intervals	2000 intervals of 10 minutes
Wind measurement location	Not specified	Wind farm	Wind farm or representative place	Wind farm	Wind farm
Wind measurement height	10 meters	Hub height and 10 meters	Hub height or 10 meters	Extrapolate to 10 meters	Hub height
Wind measurement extension	Not specified	Not specified	14 days, with 10 minutes intervals	14 days, with 10 minutes intervals	2000 intervals of 10 minutes
Graph noise according to wind	Not specified	Not specified	Yes	Yes	Yes
Penalties	Tonality: 5 dB	Tonality: 5 dB	Not specified	Tonality: given by graph	Tonality: 5 dB
Economic agreement between the affected	No, but distinguishes receptors related with project	Not specified	Not specified	Yes, allowing fixed maximum increase to 45 dB(A)	Yes
Noise map	Yes	Prediction mentioned, but no map	Yes	Prediction mentioned, but no map	Yes
Propagation method	ISO 9613-2	Their own method	ISO 9613-2	ISO 9613-2	ISO 9613-2 or CONCAWE

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