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# WIND TURBINE NOISE: HOW THE ENVIRONMENTAL AUTHORITIES GOT IT WRONG

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## ABSTRACT

In the analogue days of acoustics (pre-digital and pre-personal computers) acousticians in solving noise problems relied upon correlation of what they heard with their observations of the deflection on a sound level meter, and a considerable degree of thought process. Environmental authorities tend to remain in their ivory towers and have little interface with the end users to which it is purported their policy or guidelines are protecting. With advice from the wind industry, early noise guidelines proposed for wind turbines were based on the dB(A) value and noise targets from non-wind turbine noise sources. Often when working backwards to the original references one finds reliance upon sleep disturbance criteria from early WHO publications, where the sleep disturbance criteria are related to road traffic noise. Consequently, when new wind turbine facilities come into operation and the community identifies sleep disturbance and noise impacts as a result of the wind turbines, the general bureaucratic response is that they satisfy the guidelines and no further consideration is undertaken. Over the last 25 years there has been a proliferation of wind turbines around the world and also a dramatic increase in complaints concerning wind turbines. Acoustic investigations over the last 10 years working from the residents end of the problem have identified a lack of scientific data in the noise criteria issued by environmental authorities, who as a result of future class actions may be held to account for their failure to provide qualification to their criteria, or failure to adopt a precautionary principle.

## 1. INTRODUCTION

Acoustic criteria specified by environmental authorities in Australia in relation to wind turbines [1-4] rely upon the concept of protection of sleep disturbance promoted by the WHO [5,6]. An examination of these references finds that there is no material pertaining to wind turbine noise, but the sleep disturbance criteria is based primarily on road traffic noise studies.

The methodology for assessing wind turbine noise in Australia is based upon ETSU-R-97 “The assessment and rating of noise from wind farms” [7] that in turn relies upon the aforementioned WHO assessment of sleep disturbance criteria based on a dB(A) Leq level.

Examination of the ETSU-R-97 document does not find any dose-response information with respect to wind turbine noise and annoyance, but instead finds an emphasis of the need for acoustic criteria so as to permit the development of energy from wind turbines.

On the basis of the source material cited above the setting of noise criteria by environmental authorities in Australia is one of “borrowing” noise targets from noise sources that do not exhibit the same acoustic characteristics of wind turbines and then utilize the “borrowed” criteria without any qualification as to the relevance of the criteria or identification that the material should be considered precautionary.

For example, the Executive Summary of ETSU-R-97 states:

*This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to 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. The suggested noise limits and the reasonableness have been evaluated with regard to regulating the development of wind energy in the public interest. They have been presented in a manner that makes a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.*

*The noise limits have been derived with reference to:*

- *existing standards and guidance relating to noise emissions.*
- *the need of society for renewable energy sources to reduce emission of pollutants in pursuant of government energy policy.*
- *The ability of manufacturers and developments to meet these noise limits.*

The qualification or basis of “reasonable degree of protection to wind farm neighbours” is not identified in ETSU-R-97 even though the material in the report identified and included wind farm operations that did give rise to disturbance complaints. Residents subject to wind farm that complies with the recommendations in ETSU-R-97 claim the “reasonable degree of protection” is inadequate.

Because the operation of a wind farm requires the presence of wind, then the challenge presented in formulating ETSU-R-97 was to introduce a sliding noise criterion that would reflect the change in noise level as a result of wind, and the ability to evaluate wind turbine noise. This is because general environmental noise standards excluded measurement data where the wind at the microphone is greater than 5 m/s.

The ETSU-R-97 methodology of utilizing a

regression analysis procedure using 10 minute L90 (or L95) levels has been adopted by environmental agencies in Australia for wind farm developments.

The first set of wind farm criteria used in Australia adopted the New Zealand Standard NZS 6808:1998 [1] where the Standard identifies the basis of the criteria was to protect against sleep disturbance – using the WHO recommendations associated with road traffic noise [5].

The first set of guidelines produced in Australia for wind turbine noise was issued by the South Australian Environment Protection Authority [3] that references ETSU-R-97 and the Community Noise (1999) document from the WHO [6].

The SA EPA Guideline [3] provides in its introduction the following.

*This document aims to help developers, planning and enforcement authorities, other government agencies and the broader community assess environmental noise impacts from wind farms.*

*The core objective of these guidelines is to balance the advantage of developing wind energy projects in this State with protecting the amenity of the surrounding community from adverse noise impacts.*

*Wind farms need specific guidelines because wind turbines have unique noise generating characteristics and the environments surrounding wind farm sites usually have low ambient noise.*

The problem that occurs when investigating complaints in relation to wind turbine noise is that neither ETSU-R-97 or the above South Australian EPA guideline identifies what noise levels will protect the amenity of the surrounding community from adverse noise impacts, simply because there is no identification of what levels from wind turbines produce adverse noise impacts.

Citing the above two documents identifies a clear issue that the environmental authorities in their haste to create wind farm noise guidelines to permit the generation of electrical power have failed to address their fundamental obligations as environmental authorities to protect the community.

## 2. WHAT DID THEY GET WRONG?

Basically, the EPA failed to provide wind farm acoustic criteria that would protect the community from adverse impacts.

In hindsight, testing has identified that wind turbine noise is not the same as traffic noise or industrial noise, and has a different dose-response, i.e. there is a lower threshold of noise annoyance for wind turbines [8].

At this point in time there are no wind farm noise criteria that guarantee there will be no adverse impacts because such studies have not been undertaken.

The principal impact often cited by residents is sleep disturbance. After time other impacts in relation to annoyance and effects on individuals that did not exist prior to the wind farm become apparent. Is wind turbine noise something that over time akin to an allergy or people become sensitized to the “noise” rather than habituated.

The WHO in 2009 [9] identify that ongoing sleep disturbance can result in health effects.

The failure of environmental authorities to fulfil their statutory and moral obligations to protect communities in proximity to wind farms is evident in terms of community reaction, citing regular sleep disturbance, annoyance, or health impacts, to the extent in some in some cases residents abandon their homes.

If communities around wind farms (in Australia) protest to the extent of presenting their complaints in the public domain then it must follow that the core objectives cited by the SA EPA in their wind farm guideline are not being met.

When pressed with the mounting evidence of such disturbance, and even when matters come before the courts it is often the case that the court identifies they have to abide by the law, and in the case of environmental noise law it is that set by the environmental authorities.

If that is the case then under the law the EPA are responsible in terms of noise disturbance and adverse impacts created by wind farms (that comply with EPA criteria) and there is something wrong with that criteria.

An examination of ETSU-R-97 and the South Australian EPA windfarm guideline reveals that there is no material in either of the documents to identify other than sleep disturbance what is an adverse impact as a result of the operation of a wind farm. More importantly neither document identifies what levels of noise from wind turbines would not create an adverse impact or not create sleep disturbance.

In hindsight, one can look at the criteria that have been provided by environmental authorities for wind turbine noise and ascertain whether the appropriate due diligence was undertaken in setting noise criteria for wind farms without the appropriate dose responses response material, or identification of the unique acoustic signature of wind turbines versus traditional environmental noise sources upon which criteria have been “borrowed”.

For example, the introduction of jet aircraft for use in commercial situations produced an entirely different noise characteristic to that of propeller aircraft. As a result of the widespread community concern in relation to the introduction of jet aircraft valuable acoustic research was undertaken to ascertain the annoyance characteristics of this new and significant noise source, leading to consideration of subjective assessments of aircraft noise and modification of acoustic criteria.

If the appropriate due diligence had been undertaken when considering noise guidelines for wind farms then a reasonable literature research would uncover the pioneering work associated with the NASA program for developing wind turbines (that occurred in the 1980s) [10, 11].

As a student of acoustics, it is worthwhile reviewing the work undertaken by the US Department of Energy under the leadership of Dr Kelley and in particular the pioneering work with respect to the Mod-1 turbine [12].

NASA developed a number of horizontal axis 2 bladed downwind turbines commencing with first generation machines (Mod-0 and Mod-0A), involving a 100 kW and a 200 kW unit, respectively. The Mod-0 turbines were not considered to create significant noise [13].

The Mod-1 project was initiated in 1974 based on the Mod-0 results and involved the construction of a 200 ft diameter wind turbine with a rated power of 2000 kW. At the time, the turbine represented the largest in the world. The Mod-0 and Mod-1 turbines were developed with the turbine blades being downwind of the tower structure, which was a lattice type construction.

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The Mod-1 turbine resulted in noise complaints to a small fraction of families living within a 3 km radius of the turbine. A detailed investigation was undertaken by the Solar Energy Research Institute (“SERI”) for the US Department of Energy [12].

Kelley et al. [12] identified the acoustic pulsations emitted from the Mod-1 turbine, the level of sound above human perception thresholds and the excitation of building/room modes in dwellings.

The Executive Summary of the SERI report [12] identified the perception of the complaints for the single Mod-1 turbine. The description of the complaints/impacts for the Mo-01 turbine are similar to that obtained for current wind farm (multiple wind turbine) installations. The key findings in the SERI report were that the annoyance was real and not imagined, and the source of the annoyance was aerodynamic, that involved the passage of the turbine blades through the lee wakes of the large, 0.5 m cylindrical tower legs. In some instances, the acoustic impulses transmitted through the air were being focused on the complainant’s homes, as a consequence of ground reflection and refraction by the atmosphere.

As a result of the Mod-1 acoustic issues, the design of the NASA turbine program moved to the use of upwind turbines, starting with Mod-2, where the turbine blades were positioned in front of a circular tower.

From the Mod-1 turbine investigations, Kelley examined several acoustic metrics for assessing the interior low frequency annoyance [14], considering the overall degree of annoyance, any sensations of vibration or pressure or the sensing of any pulsations. Kelley proposed the use of the LSL or low frequency sound level weighting [15] or the C-weighting.

Kelley’s proposal was not adopted by authorities, although Jakobsen [16] proposed an internal low frequency parameter  $L_{pA, LF}$  as the A-weighted level, in the frequency range of 10-160 Hz. The Jakobsen limit is used in Denmark.

The Kelley material was available at the time of the preparation of ETSU-R-97 and the SA EPA Guideline but does not appear to have considered in the development of those two documents.

Whilst ETSU-R-97 has not been revised the SA EPA Guidelines have been revised but have not addressed concerns of communities in South Australia as the same criteria still prevail and there is still no reference material in relation to criteria to address sleep disturbance.

### 3. ADDITIONAL WIND TURBINE MATERIAL THAT IS AVAILABLE

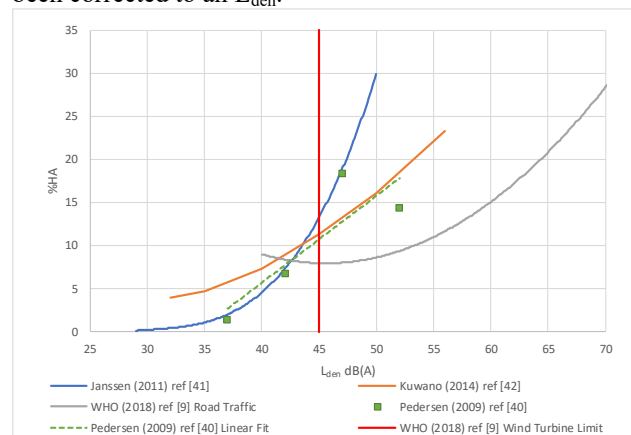
In 2009, Pedersen, Van den Berg, Bakker and Bourma [17], reported on the response to noise from modern wind farms in the Netherlands, and provided a comparison of dose-response curves of wind turbine noise with other sources of community noise. The dose response curves developed by Pedersen et al. had a small number of data points, but showed that “the proportion of respondents annoyed with wind turbine noise below 50 dB(A)  $L_{den}$  is larger than the proportion annoyed with noise from all other sources except shunting yards”.

A relevant issue to the curves that were derived was that the material relied upon predicted wind turbine noise. The Pedersen et al. paper does not identify any correlation of predicted levels versus measured levels, or the actual operation of the wind farms relative to the assumed operation used for the predicted levels.

Janssen, Vos, Eisses and Pedersen [18] reviewed the data from the three studies in reference [17], to derive a dose response curve for wind turbines that is included in the WHO 2018 Guidelines [19] in relation to wind turbines. The WHO Guidelines provide in the section dealing with wind turbine noise a dose response curve from Kuwano [20] that does not agree with the Janssen dose response curves.

Figure 1 (from the authors work in [8]) presents the three dose response curves for wind turbine noise referred to above as  $L_{den}$  values, and the  $L_{den}$  45 limit for wind turbines and the WHO  $L_{den}$  limit. Included in Figure 1 (for comparison purposes) is the WHO road traffic dose response curve (extracted from the 2018 WHO Guideline [9]), noting that the WHO recommend a 53  $L_{den}$  limit for adverse health effects and related to 10% of the population being highly annoyed.

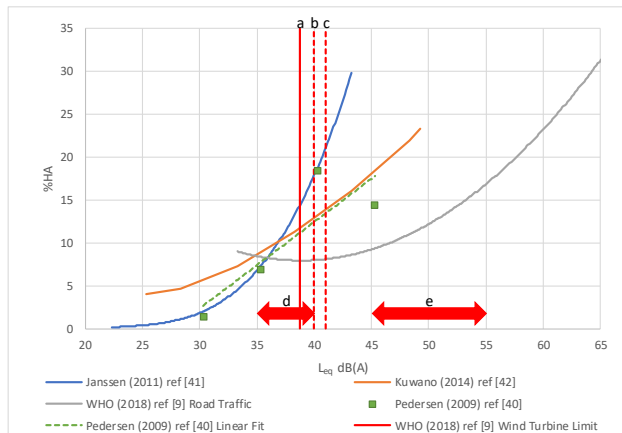
The Kuwano curve in Figure 1 relies upon measurements near the wind farm and an extrapolation to the surveyed areas. The Kuwano curve in the WHO Noise Guidelines (2018) was presented as an  $L_{dn}$ . On the assumption that the Kuwano wind farm noise is constant throughout the day, the Kuwano curve in Figure 1 has been corrected to an  $L_{den}$ .



**Figure 1.** Proportion of respondents highly annoyed from wind turbines, Pedersen (2009), Janssen (2011), Kuwano (2014), re  $L_{den}$  and compared with road traffic (WHO 2018) – from ref 8.

Adopting the general approach of setting a noise limit and the basis of 10% of the population being highly annoyed, from Figure 1, the WHO limit should be  $L_{den}$  43.5 dB(A).

On the assumption of a steady noise level throughout a 24 h period to convert an  $L_{den}$  to an  $L_{eq}$  one subtracts 6.7 dB(A) off the  $L_{den}$  value. Figure 2 presents the results in Figure 1 to  $L_{eq}$  levels, to permit a comparison with  $L_{eq}$  limits used in other countries around the world.



**Figure 2.** Proportion of respondents highly annoyed from wind turbines, Pedersen (2009), Janssen (2011), Kuwano (2014), re  $L_{den}$  and compared with road traffic (WHO 2018) in terms of  $L_{eq}$  levels. N.B. **a.** is the WHO wind turbine noise limit, **b.** is the WHO road traffic limit, **c.** is the Norway night time limit, **d.** is the minimum limits in Australia and **e.** is the range of limits in the USA (from ref 8).

In Figures 1 and 2, it can be seen that, if the acoustic impact of wind turbines is greater than the road traffic noise, then the basis of wind turbine noise targets that were determined in ETSU-R-97 to protect sleep (using the WHO recommendation) could be inadequate. In the absence of the validation of the wind turbine contributions, that were impacting upon the surveyed population, the actual contributions could be higher or lower than the predicted levels.

A similar result to the above surveys is obtained in relation to the Canadian Health study into two wind farms [20,21]. The analysis of the noise results with respect to impacts in the Canadian Health Study were based upon predicted levels [22], with no verification of the wind turbine noise levels experienced by the people involved in the study. Davy et al. [23] compared the percentage of highly annoyed people from the Canadian Study to the Dutch and Sweden survey data [17], to reveal a greater disturbance. Arising from the Canadian Health Study, Michaud et al. [21] reviewed published data on annoyance with wind turbines, using the community tolerance level (CTL), previously used for transportation noise [24,25].

The Cape Bridgewater study undertaken (by the authors) in Australia [26] was required to independently assess the impacts from residents' complaints—akin to a Soundscape investigation. The Cape Bridgewater Study had the unique situation of full and unfettered access to

the wind farm, the provision of individual wind turbine data for the entire testing and the unique situation of multiple shutdowns of the entire wind farm (for high voltage cabling work at the main substation), that permitted the identification of the ambient noise levels in the presence of wind and no turbines operating.

The Cape Bridgewater study could not find any correlation between the operation of the wind farm and the A-weighted level (or 22 other noise metrics that were assessed). However, a correlation of the dB(A) level versus the wind speed was obtained.

In Australia, for general environmental noise, the fundamental basis of assessment is to protect 90% of the people for 90% of the time. Both the Department of Planning in New South Wales [27] and the New South Wales EPA [28] have specified the use of noise logger data (excluding any data obtained where the wind speed of the microphone is greater than 5 m/s), to determine the individual daily  $L_{90}$  levels and then for a five or seven day period, to take the median of the individual days. This median is identified as the rating background level [27, 28].

An intrusive noise target is then set at 5 dB(A) above the rating background level.

The concept set out in ETSU-R-97 (and referred to in Australasian wind farm guidelines) uses a polynomial regression line of wind speed versus the background level, to which there is then an application of a base criteria and/or background +5 dB, whichever is the greater.

For the ETSU-R-97 situation, whether one considers a linear or polynomial fit of the regression line, the curve represents approximately 50% of the population. If one then applies the regression background level plus 5 dB(A), is one only looking to protect 50% of the people 90% of the time? For the region where the base level of 35 dB(A) or 40 dB(A) is applied, the consequence of such criteria is protecting a much smaller percentage of the population for 90% of the time.

The NSW EPA identify that an intrusive noise target of rating background +5 dB(A) aims to result in the intrusive noise criterion being met for at least 90% of the time periods over which annoyance reactions can occur [70].

The use of the ETSU-R-97 regression line method for wind turbines in NSW fails to achieve the stated aim of the NSW Department of Planning and Infrastructure, where the general NSW objective is to set where possible noise goals are, to ensure that at least 90% of the population are protected from being highly annoyed for at least 90% of the time [27].

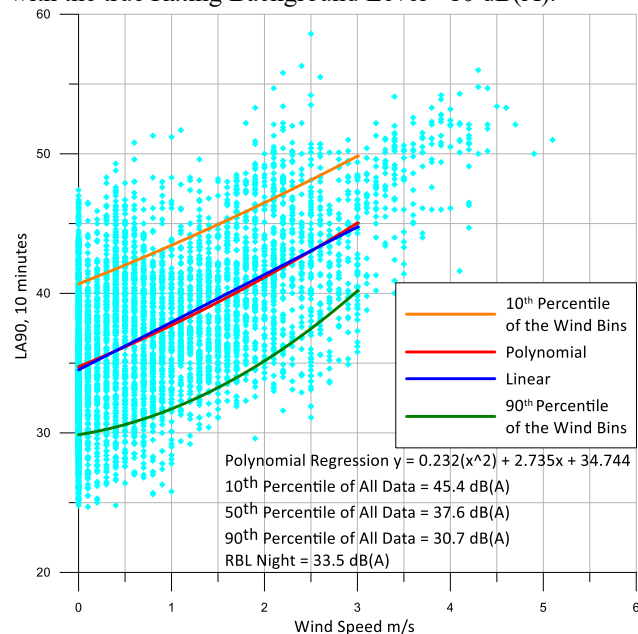
In Environmental Acoustics in Australia the general concept is to utilize a background level for 90% of the time and consider the intruding level of the 10% of annoyed concept that aligns with the background + 5 dB(A) principle.

The ETSU-R-97 regression analysis uses a line through the  $L_{90}$  data that is a polynomial fit that approximates the  $L_{90}$  level for 50% of the time.

In reference 8 the author examined the regression line approach by taking the wind data (and corresponding time aligned noise levels) were separated into wind speed

bins. A statistical analysis of each wind bin was undertaken to determine the 90th percentile of the  $L_{A90, 10 \text{ min}}$  level. Using the lowest 90th percentile in each wind bin permits the derivation of the true ambient background level across the wind speed (the green trace).

Figure 3 (from ref 8) reveals a significant difference between the “regression background level” versus the L90 percentile line. Using the ETSU-R-97 concept, the regression line background +5 dB limit is more in line with the true Rating Background Level +10 dB(A).



**Figure 3.** Waubra Wind Farm Nighttime Regression Curve-Post Construction, wind and noise at 1.5 m AGL, 12 June–11 September 2012 (from ref 8).

Reference 8 identifies other issues that (in hindsight) have not been appropriately addressed by the Environmental Authorities and go to identifying wind farm operations (such as wake turbulence, modulation of the amplitude and variation in power output of a wind farm) that space does not permit to be included in this presentation.

#### 4. CORRECTING THE ENVIRONMENTAL AUTHORITIES ERRORS/“BORROWING”

In the June 2017 meeting of the Acoustical Society of America’s Wind Turbine Working Group, Dr Paul Schomer (former Director of Standards of the ASA and Co-Chair of the Wind Turbine Working Group) identified that the material presented to the working group since its inception had identified that on a statistical basis the distribution of complaints around wind farms was above the norm to the point that we as acousticians could not ignore that statistical anomaly, if we are to abide by our Code of Ethics/Conduct to protect the health and well-being of the community.

The issue of health impacts as a result of noise from wind farms and the appropriate noise limits to protect against health impacts is unknown. The Massachusetts Wind Turbine Health Study [22] identifies the need for

wind turbine sleep studies to determine health impacts, whilst page 62 in the WHO Night Guidelines [23] identifies that ongoing sleep disturbance can result in health impacts.

The WHO 2018 Guidelines (for the European Region [9]) noted the low quantity and heterogeneous nature of the evidence on sleep disturbance. There are no nighttime criteria specified for wind turbine noise to protect against sleep effects in the WHO 2018 Guidelines.

The starting point in providing noise criteria for wind farms is to determine the wind farm noise levels that give rise to/not give rise to adverse impacts.

Nuisance is a tangible concept of disturbance and annoyance that does not relate to compliance with an unsubstantiated noise guideline. The issue of sleep disturbance is a tangible component of nuisance.

Starting with sleep disturbance the following questions need a response from the Environmental Authorities responsible for developing and publishing appropriate noise limits to protect the community.

1. Please provide studies upon which the wind turbine/farm criteria for have been developed?
2. Please identify the noise source(s) that have been used in the studies related to question 1?
3. Please provide the dose-response data related to wind turbine/farms on which the criteria are based on, and the corresponding level that represents 10% of the population that is highly affected?
4. The most common complaint from residents relates to sleep disturbance. Please provide the studies of wind farm noise that identifies the noise (in any relevant acoustic index) that gives rise to sleep disturbance?
5. Please provide studies of wind farm noise that identify the noise level (in any relevant acoustic index) that will not give rise to sleep disturbance.
6. Please provide studies of wind farm noise that identifies the noise level that would protect the acoustic amenity of residents in proximity to wind farms.

In view of the potential health impacts that can arise from ongoing sleep disturbance paragraph 470 of a decision (in Australia) by the Administrative Appeals Tribunal in the matter of Waubra Foundation and Commissioner of Australian Charities and Not-for-profits Commission (file 2015/4289 decision date 4 December 2017) [29] states:

*There are as yet no comprehensive studies which have combined objective health measurements with actual sound measurements in order to determine for a given population the relationships between the sound emissions of wind turbines, annoyance, and adverse health outcomes. Indeed, there is as yet no study which has given rise to a soundly based understanding of the degree to which particular types or levels of wind turbine emissions give rise to annoyance, or what levels or types of emissions are associated with what level of annoyance*

in the population. Because it relied on calculated rather than actual sound measurements and was limited to the A and C-weighted systems, the Health Canada study did not do this.

The above extract from the decision is relevant in that there was no material presented to the AAT as to what constitutes an acceptable level or not create an adverse impact – which goes to the very heart of the lack of specificity in the objectives of the various versions of the SA EPA Guidelines.

As a result of this decision our research work ventured into the fascinating world of psychoacoustics to investigate the nature of wind turbine noise – after we had ascertained how to accurately reproduce the signals in our laboratory.

One fundamental outcome of those investigations has been to clarify the nature of the time signal of wind farms and the generation of pulsations occurring at an infrasound rate which lead to the hearing mechanism sensing the pulsations even though the signals were inaudible [30-35].

Those investigations have led to the use of modulation indices arising from different operating scenarios of wind farms that have now been related to sleep disturbance[36,37].

## 5. CONCLUSIONS

The operation of wind farms in Australia that are compliant with noise criteria “borrowed” from other noise sources have been found to give rise to significant disturbance and adverse noise impacts.

As such, the noise criteria for wind farms used in Australia does not achieve the nominated goal of protecting residents from sleep disturbance and adverse impacts.

Working from the complaint side of the equation it has been ascertained that wind turbine noise gives rise to a greater level of annoyance when the same A-weighted noise levels are assessed against road traffic noise.

The WHO 2018 Guideline [19] included wind turbine noise Lden limits with a qualification that on the small amount of studies of such limits being precautionary. The WHO 2018 Guideline was unable to provide any recommendations in relation to sleep disturbance.

The appropriate noise levels to avoid sleep disturbance from wind turbines has not been yet established. However promising work from psychoacoustics investigations coupled with sleep studies may provide the necessary data to correct the lack of scientific rigor that should have occurred in the preparation of noise guidelines to protect the acoustic amenity of communities in proximity to wind farms.

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