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IN CONFIDENCE

BALD HILLS WIND POWERSTATION

ACOUSTICAL ASSESSMENT

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INTRODUCTION

Graeme E Harding & Associates has been retained by the Tarwin Valley Coastal Guardians to advise on a proposed wind power station at Bald Hills.

The developer, Wind Power Pty Ltd, proposes to construct a power station comprised of fifty-two REpower MM82, 2MW wind turbine generators.

The nearest residential premises which will have turbines on the property, will be about 760m from the nearest turbine.

The nearest resident that does not have any financial arrangement with the developer is located about 710m from the nearest turbine.

Bald Hills is located near Tarwin Lower, about 45km SSE of Wonthaggi.

Wind turbine generators convert power from the wind into electricity.

Turbines vary significantly in size. In Australia the range turbines used in wind energy projects is from 0.3kW to 1.8MW (www.auswea.com.au).

Many older installations in Europe were with quite small units. Work carried out by the ETSU in Britain in 1996 was based on wind turbines no larger than 450kW. European studies into noise carried out by Wolsink in 1993 were carried out in three countries and sixteen sites. Most of the 134 turbines were small. Only 20 of them had a power of 500kW and the rest were 300kW or less.

A more recent noise study in Sweden in 2000 showed that of the 16 wind turbines studied 14 had a rated power of 600kW.

The trend for wind energy projects appears to be for larger turbines with associated economies of scale. Units of up to 3MW are now available commercially.

The units proposed for Bald Hills are 2MW units.

The amount of power that can be extracted from the wind is dependent on the diameter of the unit.

Current wind turbines are of two types. These are either constant rotational speed or variable rotational speed types. Wind turbines can only supply power when there is sufficient wind. Above a certain wind speed, the "cut in" speed, electrical power can be delivered to the grid. As the wind speed increases the amount of power delivered increases until the rated power of the unit is achieved.
At speeds below the "cut in" speed, the blades are kept rotating.

The noise from wind turbines is either aerodynamic or mechanical (from Report ETSU-R-97).

Mechanical sources include gearbox tooth mesh frequencies, generator noise, cooling fan noise, etc. Again it is claimed that newer models have reduced noise from these sources. In practice, some of these noises become audible at residential premises near to turbines when turbines are idling.

Aerodynamic noises include:

1. Self noise due to the interaction of the turbulent boundary layer with the blade trailing edge.
2. Noise due to inflow turbulence (turbulence in the wind interacting with the blades)
3. Discrete frequency noise due to trailing edge thickness
4. Discrete frequency noise due to laminar boundary layer instabilities (unstable flow close to the surface of the blade)
5. Noise generated by the rotor tips.

It is claimed mechanisms 3 and 4 can be reduced to insignificant levels by careful design.

Residents who live near wind turbines speak of swishing, whooshing, chomping and thumping noises.

Near to the turbine the (A)-weighted noise level modulates by 2-3dB(A) for typical turbine conditions. This modulation is greater if measurements are made in 1/3 octaves (this can provide a closer representation of how the ear hears). Close to the turbine the swishing sound in the 800-1000Hz region.

It is claimed (ETSU-R-97) that this swishing sound decreases with distance and that for exposed locations, where background noise is due to wind in trees, etc. the background level of noise will mask the noise at a certain distance.

Modern wind turbines have the blades in a vertical plane and rotate on a horizontal axis. The blades are upwind of the tower and are constantly controlled to face into the wind. Some large research units built in America (2 - 4.2MW) prior to 1991 had rotors downward of the towers. Complaints from these turbines occurred up to 2km, and these were about perceived vibration. Studies ("Physical Characteristics and Perception of Low Frequency Noise from wind Turbines" K.P. Shepherd and H.H. Hubbard, N.C.E.J., Jan-Feb 1991) showed that these turbines produced significant amounts of low frequency energy capable of causing window vibration, wall vibration and also low frequency noise within dwellings. The indications are however that upwind rotors do not have this environmental problem to the same degree.

The study also showed that very low frequency noise in the range of 8 to 16Hz reduced in level by only 3dB per doubling of distance. This is unlike the normal frequencies of hearing where reductions of 6 dB per doubling of distance is more common

CRITERIA FOR WIND TURBINE NOISE

Local Standards

In Victoria, the Environment Protection Authority (EPA) of Victoria is the statutory body established under the Act of a Victorian Parliament in response to community concerns about pollution.

"Planning and Policy Guidelines for the Development of Wind Energy Facilities in Victoria" has been issued by the Sustainable Energy Authority Victoria. This states the evaluation of a wind energy facility should comply with the noise levels recommended for dwellings in New Zealand Standard NZS 6808:1998 Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators. It is understood that these guidelines were issued without a public review process. From discussions with EPA officers, the EPA has not adopted the above guidelines as the standard for use in Victoria, but it is one of the guidelines that could be used. The Victorian EPA is also aware of the South Australian requirements. Within the Melbourne metropolitan area State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade) No. N-1 (SEPP N-1) applies but does not apply in non-metropolitan area.

EPA has issued Interim Guidelines for Control of Noise from Industry in country Victoria N3/89 (Publication N3). Much of the requirements in the Interim Guidelines are similar to SEPP N-1. The EPA currently has the view that as wind turbines operate only at higher wind speeds and that the provisions of SEPP N-1 (and also Publication N3) incorporate criteria based upon background noise levels for low wind speed conditions, the provisions would be difficult to apply.

Interim guidelines for control of noise from industry in country Victoria - Publication N3/89

The Environment Protection Authority has issued these guidelines as SEPP. N-1 only applies to industry in the Melbourne metropolitan area.

Under the guideline, the procedures stated in SEPP N-1 are to be used.

The procedures stated in SEPP No. N-1 have been extensively discussed at VCAT hearings etc., however a short summary follows:

- there are separate noise limits for the Day (0700 to1800 hour), Evening (1800 to 2200 hours) and Night (2200 to 0700 hours).
- the limits for each period are based on both the (land use) zoning level, or the background level. The background level being the arithmetic average of the $L_{A90,1h}$ levels over each relevant period.
- the limits are defined for noise sensitive areas.
- SEPP N-1 has minimum limits of:

Day	45dB(A)
Evening	40dB(A)
Night	35dB(A)

- the measurement is generally made out of doors, and shall be made where the maximum effective noise level occurs. It is acceptable to measure noise near to walls etc. but if measurements are made closer than 1 and 2m an adjustment for reflection off the wall of -2dB is required.
- the measurement of the industry noise is to be made as an L_{Aeq} which is adjusted for noise character. The measured L_{Aeq} is required to be representative of the noise from the industry. It is accepted and appropriate practice to delete any extraneous events from the noise analysis.
- the measured noise level is adjusted for character. For minor premises character adjustments include:
  - tonal adjustments of 0, +2 or +5dB
  - impulsive adjustment of 0, +2 or +5dB
- where the effective noise level at the residential premises may be significantly affected by atmospheric effects, then amongst other things, 3 measurements shall be made over a 30 day period at the noise sensitive area, and the results averaged.
- the beneficial uses as defined under the Act, “shall be the normal domestic and recreational activities including, *in particular, sleep in the night period*” (My emphasis).

- it is understood that a wind turbine installation would be a minor premises under the SEPP N-1.

The Interim guidelines generally follow all of the above requirements except that:

- for very low background, minimum limits become:

Day	45dB(A)
Evening	37dB(A)
Night	32dB(A)

- where possible, designers should aim to meet octave band levels of L_{bg} plus 5 ~10dB.

South Australia

The Government of South Australia issued “Environmental Noise Guidelines - Windfarms” in February 2003.

In summary, for planning assessment purposes the predicted equivalent noise level ($L_{Aeq,10}$) (L_{eq}, A-weighted measured over a 10 minute period), adjusted for tonality should not exceed:

- 35dB(A), or
- the background level ($L_{A90,\ 10}$) by more than 5dB(A).

whichever is greater.

The background level should be as determined by the data collection and regression analysis procedure recommended. The average wind speed at 10m height is measured at the same time as the $L_{A90,\ 10}$ noise level at any residential premises. The two data sets are then correlated and a regression curve of best fit of noise level and wind speed is developed.

For compliance checking, measurements are made using similar procedures and the measured level of the turbine (now and $L_{A90,10}$ instead of an $L_{Aeq,10}$) is not to exceed the above.

The guideline states that if there is community concern that a limited period of measurement (minimum 2 weeks) is not representative of the rest of the year, then compliance checking is to be reported at different times of the year.

This guideline requires compliance testing to only be made when the wind direction spread is 45º either side of a line between source and receiver, and when the receiver is down wind.

The guideline does not require the background noise level, which are the basis of the criteria, to be divided into time zones (Day, Evening, Night or whatever) and does not require the background data to be individually assessed, having regard to wind direction.

Data below the cut in speed are not to be included or data above the speed to rated power. The guideline assumes that the wind speed measurement at 10m height, correlates with the cut in speed.

The guideline recognises that adjustments for characteristics such as tonality are to be applied to the measured level, but assumes “blade swish” is not to be adjusted for.

It is understood that the guidelines were developed by workshops with around 40 participants.

International

Britain

In Britain, the Department of Trade and Industry, the ETSU and other working group members issued ETSU-R-97 "The Assessment and Rating of Noise from Windfarms" in September 1996.

The criterion given in the document is for all affected residential premises. The measured level for the wind turbine and background based on the $L_{A90,10}$ regression curve for all wind speeds is not to exceed:

For Day:

- 35dB(A) or 40dB(A) external, or
- the regression curve of the background levels, LA90, 10 (or 5 minute period)

whichever is the higher.

For Night:

- 43dB(A)(sic) external, or
- the regression curve of the background levels only, $L_{A90,\ 10}$

whichever is the higher.

The actual daytime level depends on subjective assessment based on the proportion of homes in the area and how low the background gets.

The nighttime criteria is apparently based upon a WHO suggestion of 35dB(A)Leq for sleep disturbance criteria. An adjustment of +10dB(A) is applied for the effect of the window, and –2dB for the effect of the level/time variation of a turbine. That is, the L_{A90} of turbine is 1.5-2.5dB below the L_{Aeq}.

In assessing the background best fit regression curve, the document provides a very careful and considered approach to determining what method should be used.

In particular:

- background noise curves are required for *both* the day-time quiet periods and the night-time not just for the 24 hour period (p.86, para 6).
- it is considered appropriate that measurements that include rainfall are removed from the analysis (p.86, para 5).
- careful consideration is to be given to the correlation coefficient of the data (the amount of "spread" in the data). For the worked example the regression curve was based on the wind from the turbine to the resident, and was specifically shown for the evening night periods. Using all wind directions to obtain the regression curve is apparently not appropriate.
- there is a risk that the measured noise description, $L_{A90,10}$ can become contaminated by the effect of wind noise on the microphone when using wind shields commercially available. Additional care to avoid this problem is required.
- following the installation of the wind turbines, monitoring of noise emission may be required. "If monitoring is required in response to complaints then a log of times at which the turbine noise is most intrusive, taken by the complainant, will enable to developer to establish the conditions which require further investigation" (p.87, para 4). The "measurement should be taken in representative conditions and not, for example, whether

wind is in a direction rarely encountered". The document does not explain what "representative conditions" are.

- the noise limit is for the windfarm only. (p.60, para 2). Thus for a particular period (say evening-night) to obtain the level of the windfarm only, the noise level of the background is to be subtracted from the level of the windfarm and background:

$$L_{ph} = 10\log_{10} (10^{Lpc/10} - 10\log^{Lpb/10})$$

L_{ph} = windfarm noise, dB(A)
L_{pc} = combined windfarm and background noise measured, dB(A)
L_{pb} = background noise only, dB(A)

Finally, it should be recognised that:

- the document was developed around small wind turbines by today's standard (300-400kW).
- no sociological surveys were carried out to determine the appropriateness of the levels adopted.
- "on balance, it is considered that a margin of 5dB(A) reasonable degree of protection to both internal and external environment without unduly restricting the development of wind energy which itself has other environmental benefits" (p.60, para 4).

New Zealand Standard NZS6808:1998

NZS6808 appears to be based on most of the principles of ETSU-R-97.

The predicted sound level at any residential premises is derived from the sound power level of a WTG(s)(wind turbine generator(s)), based on a simple model of divergence loss, with the only correction being for air absorption. No corrections are applied for ground absorption, meteorological enhancement, etc.

"As a *guide* (my emphasis) to the limits of acceptability, the sound level from the WTG (or windfarm) should not exceed, at any residential site, and at any of the nominated windspeeds the background sound level (L_{95}) by more than 5dB(A), or a level of 40dB(A) L_{95}, whichever is the greater". (4.4.2).

Further the standard states "Nothing in this standard prevents the Territorial Local Authority from specifying an alternative compliance level ....". (4.4.4).

The L_{A95} wind levels are measured at residential premises, with concurrent wind speed and direction taken within the windfarm. (4.5.3)

The standard states that it may be necessary to separately correlate background sound levels with wind speed for different wind directions and/or time of day. (4.5.5.).

The wind speed should be monitored on the windfarm site, and measured preferably at the WTG hub heights. (4.5.6. note) (rather than at the more usual 10m height)

For compliance testing, the procedure is repeated, but in this case with the wind turbine(s) operating. The windspeed is to be monitored at the same height as previously and preferably at the WTG hub height.

For any special audible characteristics, which make the sound from a WTG is likely to arouse community response, then a 5dB maximum penalty shall be applied (5.3.1.). Compliance is determined by comparison of the best fit regression curve of measured noise levels (windfarm and background) with the acceptability curve.

The Standard itself does not require any adjustments for the summing effect of background and turbine noise. Appendix A, a worked example, however states "since the 'operational' measurements will be combined windfarm and background levels, it *may* (my emphasis) be necessary to adjust these measurements to determine the windfarm only levels". (A1.3).

As this is 'may', and not 'must', it could be concluded that this is an option and should only be applied if agreed to and if appropriate by all parties. It is technically acceptable to compare the limit to the combined windfarm and background level without applying any adjustments.

European Requirements

The following is taken from "Noise Annoyance from Wind Turbines - A Review". Swedish Environment Protection Authority - Report 5308, Aug 2003.

The recommended highest sound pressure level for noise from wind turbines in Sweden is 40dBA outside dwellings (Naturvårdsverket webbplats). In noise sensitive areas as in the mountain wilderness or in the archipelago, a lower value is preferable. In practice the sound pressure levels at dwellings nearby a planned wind turbine site are calculated according to Naturvårdsverket 2001 during the process of applying for a permission to build. Measurements on site are only performed in case of complaints and then as measurements of imission at the dwelling of the complainant at wind speeds of 8m/s at 10m height.

Denmark has a special legislation governing noise from wind turbines (Bekendtgorelse om stoj fra vindmoller BEK nr 304 af 14/05/1991). The limit outside dwellings is 45dBA and for sensitive areas 40dBA Leq. Sensitive areas are areas planned for institutions, non-permanent dwellings or allotment-gardens, or for recreation. In case of complaints emissions measurements are performed according to the legislation, i.e. on a plate on the ground at a distance of 1-2 times the hub height of the turbine. Noise imission at the dwelling of the complainant is then calculated.

The legal base for noise pollution in Germany is the Federal clean air act from 1974 (Bundes-Immissionschultz-Gesetzes. BimSchG, Germany, 1974). The limits for sound pressure levels are defined in TA Lärm (Technische Anleitung Lärm, Germany, 1998).

German noise regulations

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

Calculation of sound propagation is done according to DIN ISO 9613-2. All calculations have to be done with a reference wind speed of 10m/s at 10m heights.
The French legislation used in the case of wind turbines is the neighbour noise regulation law (Loi no. 92-1444 du 31 Décembre 1992: Loi trelative à la lutte contre le bruit). This legislation is based on the principle of noise emergence above the background level and there is no absolute noise limit. The permitted emergence is 3dBA at night and 5dBA at day. The background noise level has to be measured at a wind speed below 5m/s. The legislation is not adjusted to wind turbine cases, and in practice the noise measurements are made at 8m/s when the wind turbine noise is expected to exceed the background noise levels the most.

New regulations on noise including noise from wind turbines were introduced in the Netherlands 2001 (Besluit van 18 october 2001, houdende regels voor voorzieningen en installaties; Besluit voorzieningen en installaties milieubeheer; Staatsblad van het Koninkrijk der Nederlanden 487). The limits follow a wind speed dependant curve. For the night the limit starts at 40dBA at 1m/s and increases with the wind speed to 50dBA at 12m/s. For daytime the limit starts at 50dBA and for the evenings 45dBA.

RESPONSE OF INDIVIDUALS AND COMMUNITIES TO NOISE

General

An extremely important part of the setting of acceptable noise levels is defining the problem that is causing the complaints about noise. This involves talking to people affected to define what character and time of day that they are most affected.

For example, with gunshot noise from a firing range the maximum A-weighted level of the noise from the range and the number of events heard during a period are both important.

Music and noise from discos and the like have a totally different sound character to gunshots. The A-weighted level has been found to be totally inappropriate to assess the intrusion inside a dwelling from low frequency thumping bass. In this instance, the spectrum of the background noise is compared to the spectrum of the intruding noise.

Having accurately established the character of the noise, a noise index can be developed to set limits.

Historically, expert individuals or groups who had an understanding of the noise issue would develop guidelines, criteria or a standard.

As the science of acoustics has developed, sociological surveys have become an important aspect in developing noise criteria. These surveys, combined with accurate measurements of the noise, enable a reliable assessment of the percentage of people likely to be annoyed to be developed. These figures enabled governments through environmental agencies to set noise limits.

Exceptionally good survey work has been done in Australia on this basis in the past for aircraft noise (A. J. Hede and R. B. Bullen "Aircraft noise in Australia: A survey of community reaction" NAL Report No.88, 1982) and artillery range noise (R. B. Bullen and A. J. Hede "Community response to impulsive noise" NAL Report 1984).

It is usually accepted that a reasonable level of noise intrusion is that level when 10% of respondents say they are "highly annoyed". This is for a survey where the intention is "hidden" (many other questions about the neighbourhood are asked at the same time as noise issues).

Noise limits do not protect all people affected by noise. However without well researched surveys, the is not possible to set fair limits

The point being noise limits should not be set in an arbitrary way. Any noise limit should be subject to review by other experts and the community, prior to coming into force.

SEPP N-1 for industrial noise and SEPP N-2 for entertainment noise were issued for extended review periods, as has Vicroads Draft Traffic Noise Policy.

Wind Turbines

"Only a few field studies on noise annoyance amongst people living close to wind turbines have been carried out" (Swedish EPA Report 5308 August 2003.

ETSU-R-97

In the setting of levels in ETSU-R-97 no sociological surveys were carried out. A questionnaire was sent out to local authorities having windfarms in their area and a summary included in that document (p.39).

Swedish Environment Protection Agency - Report 5308 - August 2003 – Noise Annoyance From Wind Turbines - A Review

The following is summarised from this report.

A major study, party financed by the European Community, was performed in Denmark, the Netherlands and Germany in the beginning of the 1990s (Wolsink et al 1993).

Results from the Danish part of the study were analysed further and presented in a separate report (Holm Pedersen and Skovgard Nielsen 1994).

A Swedish dose-response study was performed in 2000 (Pedersen and Persson Waye 2002).

The three studies all explore the correlation between noise exposure from wind turbines (dose) and the noise annoyance among the residents (response), as well as other variables of importance for annoyance. Unfortunately none of these studies has yet been published in refereed journals.

In the study presented by Wolsink et al (1993), sixteen sites in the three countries comprising residents living within noise levels at 35dBA were selected. The major portion or 70% lived within noise levels 30-40dBA. The sites comprised a total of 134 turbines: 86 in the Netherlands, 30 in Germany and 18 in Denmark. Most of the turbines were small. Only 20 of them had a power of 500kW, all the rest were 300kW or less.

The results presented were based on a total of 574 interviews: the questionnaire included questions on noise (annoyance, perceived loudness and interference), attitude to wind power, residential quality and stress were used for the interviews. Sound pressure levels were measured on sites, but how these measurements were made is not clear. Sound pressure level strata were calculated with 5dBA intervals.

Only a weak correlation between sound pressure level and noise annoyance caused by wind turbines could be found. The proportion annoyed by noise from wind turbines was 6.4% (n=37). The perceived loudness was also low, as well as the interference of noise with various daily activities. Residents complaining about wind turbines noise perceived more sound characteristics and reported more interference of daily activities. The noise produced by the blades lead to most complaints. Most of the annoyance was experienced between 16.00p.m.(sic) and midnight.

The Danish part of the study was, as mentioned, was presented in a separate report. The 18 wind turbines on the selected sites were rather small; i.e. they had a power of 45kW to 155kW. The hub height ranged from 18 to 33 meters, with a median of 23 meters. Interviews with 200 residents were performed.

Sound pressure levels were measured on a ground board at a distance of 1-2 times the hub-height behind the turbine at the same time as the wind was measured at 10 meters height in front of the turbine. Sound pressure levels for each dwelling were then calculated in two ways; not including the influence of barriers and including the influence of barriers. Both reflect downwind conditions at 5 and 8 m/s. The sound was also analysed for tones.

The proportion rather annoyed by noise from wind turbines was 7% (n=14) and the proportion very annoyed was 4% (n=4).

The Swedish study was performed in Laholm during May-June 2000. The areas chosen comprised in total 16 wind turbines of which 14 had a power of 600kW. The study base comprised one randomly selected subject between the ages of 18 and 75 in each household living within a calculated wind turbine sound pressure level of 25 to 40dBA (n=518).

The annoyance was measured using a questionnaire. The purpose of the study was masked and among questions on living conditions in the countryside, questions directly related to wind turbines were included. Annoyance from several outdoor sources was asked for regarding the degree of annoyance both outdoor and indoor. Annoyance was measured with a 5-graded verbal scale ranging from “do not notice” to “very annoyed”. The same scale was used for measuring annoyance from wind turbines specifically (noise, shadows, reflections, changed view and psycho-acoustical characters). The respondents’ attitude of the impact of wind turbines on the landscape scenery and the attitude to wind power in general were also measured with a 5-graded verbal scale, ranging from “very positive” to “very negative”. Questions regarding living conditions, health, sensitivity to noise and employment were also included. A total of 356 respondents answered the questionnaire, which gave a total response-rate of 69%.

For each respondent calculated A-weighted sound pressure level as well as distance and direction to the nearest wind turbine was obtained. Sound pressure levels (dBA) were calculated at 2.5-decibel intervals for each household. The calculations were done in accordance with Naturvårdsverket 2001 and reflect downwind conditions. Data about the distance between the dwelling of the respondent and the nearest wind turbine, as well as the direction, was obtained from maps.

The correlation between noise annoyance from wind turbines and sound pressure level was statistically significant ($r_s = 0.399$; n=341; p<0.001). The annoyance increased with increasing sound pressure level at sound pressure levels exceeding 35dBA. No respondent stated themselves very annoyed at sound pressure levels below 32.5dBA. At sound pressure levels in the range of 37.5 to 40.0dBA, 20% were very annoyed and above 40dBA 36%. The confidence intervals were though wide.

The respondents were asked to rate the perception and annoyance of noise from the rotor blades and the noise from the machinery. Noise annoyance from rotor blades and machine were positively correlated to sound pressure level. At all sound pressure levels, a higher proportion of respondents notices sound from rotor blades than from the machinery. The same proportion that noticed sound from wind turbines in general noticed sound from the rotor blades. Among those who could notice sound from wind turbines, swishing (33.3%, n=64), followed by whistling (26.5%, n=40) and pulsating/throbbing (20.4%, n=31), were the most common sources of annoyance regarding sound properties.

In the Swedish study, the proportion very annoyed from wind turbine noise was rather high at sound pressure levels exceeding 37.5dBA, and a firm correlation between sound pressure level and annoyance was found.

All studies find a relation between noise annoyance and visual factors such as visual intrusion and shadows. These factors probably explain part of the noise annoyance. All three studies were performed among residents exposed to rather low sound pressure levels from wind turbines. Still annoyance occurred to some extent. In the noise, the aerodynamic part was found to be the most annoying, stressing the relevance of the sound characteristic, which is also in accordance with previous experimental studies (Persson Waye and Öhrström 2002).

Also included in the report was the following:

In summary it can be concluded that the modulating characteristics of the sound makes it more likely to be noticed and less masked by background noise. Recent reports have indicated yet another complication. Common hub height of the operating wind turbines today in Sweden is 40-50 meters. The new larger turbines are often placed on towers of 80-90 meters. The wind speed at this height compared to the wind speed at the ground might (up to now) been underestimated. In a report published by Rijksuniversiteit Groningen it was found that the wind speed at 80 meter was 4.9 times higher than at 10 meter at night instead of 1.45 times as calculated (Kloosterman et al 2002). The study was rather small, but indicates that the masking of the background noise is lower than calculated. Further studies need to be performed.

Topographical conditions at site have importance for the degrees to which the noises from wind turbines are masked by the wind. Dwellings that are positioned within deep valleys or are sheltered from the wind in other ways may be exposed to low levels of background noise, even though the wind is strong at the position of the wind turbine (Hayes 1996). The noise from the turbine may on these conditions be perceived at lower sound pressure levels than expected. Current recommendations state that measures and sound propagation calculations should be based on a wind speed of 8 m/s at 10 meter above the ground, down wind conditions, creating a “worst case” scenario. This recommendation does not consider the case described above.

Case Study

Frits G.P. van den Berg delivered a paper at Euronoise, Naples 2003 titled "Wind turbines at night: acoustical practice and sound research".

The investigation was carried out because the wind turbines located in Germany conformed to the German requirements based on near measurements that were then used to predict imission levels.

However, the paper stated that sound levels from a turbine park at night were much higher than predicted and the character of the noise much worse than expected.

The author himself notes "until some years ago, I myself could not imagine how people could hear wind turbines 2km away when the (calculated) imission level was, for a given wind speed, already equal to the ambient background sound level (L_{95})"(p.3, para 5). He states on the noise character "The primary factor for this is the well known swishing sound caused by the pressure fluctuation when a wing passes the turbine mast. For a single turbine these 1-2dB broad band sound pressure fluctuation would not classify as impulsive. When several turbines operate nearly synchronously the pulses however may occur in phase: two equal pulses give a doubling in pulse height (+3dB), three a tripling (+5dB). Several low magnitude pulse trains thus cause sound with an unexpected, relatively strong impulsive character whenever they synchronise. *The sound then resembles distant pile driving or, as a resident said: "an endless train".*(My emphasis) Synchronisation here refers to the sound that the wind turbines contribute at the imission point. In the wind park we never heard the impulsiveness".

The paper at Euronoise, Naples 2003 does not provide a significant amount of noise data.

However, an article for the Journal of Sound and Vibration (accepted 22 September 2003) by the same author but yet to be published provides objective data on the situation.

The report shows that imission noise levels from wind parks differs greatly between the daytime and nighttime. "On a summer's day in moderate, or even strong wind, the turbines may only be heard within a few hundred meters, and one might wonder why residents should complain about noise by the wind park. However, on quiet nights the wind park can be heard at distances up to several kilometers when the turbines rotate at high speed. On these nights, certainly at distances between 500m and 1000m from the wind park, one can hear a low pitched thumping noise with a repetition rate of once a second (coinciding with the frequency of blades passing a turbine mast) not unlike pile driving, superimposed on constant broadband 'noisy' sound".(p.6, para 5)

The Rhede Wind Park, is located in Germany, with seventeen 1.8MW turbines of 98m hub height and 3 blade propellers of 35m wing length. The turbines have a variable speed increasing with wind speed. Starting at 10rpm at a wind speed of 2.5 m/s at hub height, up to 22rpm at wind speeds of 12 m/s and over.(p.1, para 1)

The closest resident, across the border in Holland, is about 500m west of the nearest wind turbine.

Enercon 66 turbines were used at Rhede. The rated sound power level of these units was $101dBA_W$ (wind speed 8m/s at 10m height) (p.6, para 5). These units are about 3.5 to 4dB quieter than those proposed for Bald Hills.

At Location A, the residential location 400m from the turbines, the turbine was dominant (by the author's definition) for 72% at night, and hardly audible during daytime (4%).(p.8, para 2)

At Location B, at 1500m from the nearest turbine, the turbine was dominant for 38% at night.

The study showed that at night the expected noise level for Location A, 400m from the turbines, the measured levels for a specified low wind speed of 3 and 4 m/s (at 10m reference height) was about 15dB more than expected.(p.14, para 3)

At Location B, at 1500m from the turbines at low wind speeds of 2 to 4 m/s (at 10m reference height) the actual sound level is up to 18dB higher than expected.

The reason that the predicted level from the turbine park was greater than the measured levels, is that sometimes at night the wind profile is quite different to that during the day.

Usually a fixed relationship is assumed between the wind speed υ_h at height h and the wind speed υ_{ref} at a reference height h_{ref} (usually 10m), which is the widely used logarithmic wind profile with surface roughness z as the only parameter. This is used in international recommendations for wind turbine noise emission measurements. (For example, IEC International Standard 61400-11 Wind turbine generator systems - Part II - Acoustic Measurement Techniques). The height h the wind speed υ_h is calculated as follows (p.4, para 1):

$$\upsilon_h = \upsilon_{ref} \log(h/z) \log(h_{ref}/z).$$

This equation is an approximation of the wind profile in the turbulent boundary layer of a neutral atmosphere, when the air is mixed by turbulence resulting from friction with the surface of the earth. During daytime thermal turbulence is added, especially when the heating of the earth surface by the sun is significant. At night-time a neutral atmosphere, characterised by the adiabatic temperature gradient, occurs under heavy cloud and/or at relatively high wind speeds. However when there is some clear sky and in the absence of strong winds the atmosphere becomes stable because of radiative cooling of the surface. The wind profile changes and can no longer be adequately described by the above equation.

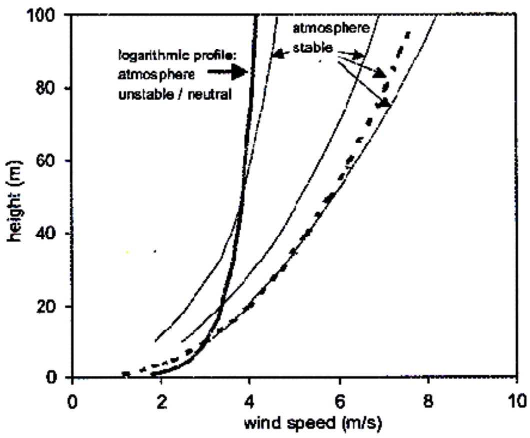

Fig. 2. Measured wind profiles (thin lines, [6]) and wind profile according to TA Luft (dotted line, [8]) in a stable atmosphere, and wind profile according to logarithmic model of formula 2 with $z = 3\,\mathrm{cm}$ (bold line).

The effect of the change to a stable atmosphere is that, relative to a given wind speed at 10m height in daytime. At night there is a high wind speed at hub height and thus a higher turbine sound power level; also there is a lower wind speed below 10m and thus wind-induced sound in vegetation.(p.4, para 2)

It is important to note that the above does not imply that the noise from the turbines is 14dB or 18dB noisier as such.

What is being said is that the wind profile at night when the measured velocity at standard height of 10m (the usual basis for noise prediction) is say 2 or 3 m/s, then the velocity at hub level due to the night wind profile may be 8 m/s, thus the turbines are near maximum noise level. This also implies that a situation can arise with little wind at a residential premises, and thus there would be hardly any masking noise by foliage, at the same time the turbines produce near maximum noise levels.

During the day for a velocity 2 or 3 m/s (at 10m reference height), then due to the different day wind profile the velocity of air going through the turbine will only be about 4 m/s and the noise from the turbines will be much lower.

The author also noted that wind speed at 10m height is not a suitable indicator of turbine noise had previously been put forward by E. Rudolphi ("Wind noise emission. Wind speed measurements blow hub height give poor accuracy", Proceedings of the Nordic Acoustical Society, Stockholm 1998). This showed for a 58m hub height, wind noise at night was 5dB louder than expected

Now, Mr van den Berg also noted that sound from the wind park contains repetitive pulses, *unlike the sound in the daytime* (my emphasis). According to the long term auditory observation of residents the pulse like characters or "thumping" is more pronounced at high turbine rotational speed.

The author further states "A pulse like character was not expected, eg in a recent Dutch report (14) it was stated that turbines do not produce impulsive noise. However, when measurements are made at a single turbine, as is usual, no pulses will be audible according to the explanation given above".(p.14, para 2)

Finally "Pedersen et al (15) have investigated the annoyance around wind turbines in the south of Sweden. Their paper gives preliminary results and definitive results have yet to be published (personal communication Pedersen by Mr van den Berg). They found highly annoyed residents at (calculated) sound levels as low as 32.5 - 35dB(A)".(p.14, para 4) Mr van den Berg attributes the high percentage of complaints due to the level being higher at night due to the errors associated from predicting noise from tall tower windfarms.

SUMMARY ON WINDFARM NOISE

1. The work by G.P. van den Berg shows that noise from wind turbines, for low wind speeds (when assessed at 10m height), can at night be up to 15 to 18dB higher than expected.

2. The work also showed that at large distances from groups of wind turbines that the noise at night, unlike in the daytime, can have a pulse-like or thumping character. This is contrary to the argument included in many documents on wind parks. These claim "as observer distance increases from the turbine, the rhythmic swishing becomes less pronounced" (ETSU-R-97) or "at

a distance, due to propagation effects, any noise that would be heard would exhibit less rhythmic variations" (MDA Report 03147).

3. The work also showed that at night that there could be a very light wind near the ground, even when the turbines are at high power. The contrast between the turbine noise and the ambient sound is therefore higher at night. This implies that any criterion that compares the ambient noise with the turbine noise must have regard to the significant difference between daytime and nighttime (and in particular during stable atmospheric conditions).

4. The work also concluded that the prediction of noise emission at night from wind turbines is under estimated and the problem gets worse the taller the wind turbine.

5. For residents, the only time noise from the wind park will be an issue is when it is loudest and most annoying. This will generally only occur in the later afternoon or at night, with the wind in the direction from the source to the receiver. Therefore to correctly assess the noise from the wind turbines for each receiving point, it will be necessary to measure the noise under these worst case conditions. This should be the sole basis of the assessment.

   Any assessment procedure that measures the noise during the day, when the imission levels are low, and averages these results with the night results, when levels are high, (particularly under stable atmospheric conditions) will misrepresent the true the level of noise to the residents.

6. According to Mr van den Berg, the character of noise from the windfarm can vary significantly. If a resident complains that noise at night has a "thumping sound", then to determine if a character correction is required it will be necessary to investigate the noise under conditions when the complaint occurs. At this time it would appear that character adjustments must be made on a subjective basis.

   This highlights, however, that any approach for compliance measurement that only uses logging apparatus that can only register the A-weighted level is far too simplistic. The only way to properly assess the noise is to use some form of recording device that can be later analysed for level versus time and character. If occasional wind gusts, or other extraneous noise interferes with the level, then the extraneous noise shall be removed from the analysis. This procedure has been used in the application of both SEPP N-1 and SEPP N-2 for over 20 years and 10 years respectively with no criticism from acoustical engineers and scientists about its reasonableness.

7. The use of logging equipment for the assessment of background noise levels is considered appropriate, however to specify a background level, the time of day for the background, the wind direction, as well as the wind speed, must all be considered. Birds in the early morning and late afternoon can have a significant affect on background levels, for example

   The background noise level can be very sensitive to seasonal variations. Cicadas in summer, crickets in late summer and autumn, etc. all elevate the background noise. Any assessment of background noise must also have regard to the source of the background. Indeed any background measurement should enable the source of the background noise to be identified.

8. Background noise measurements must be made with equipment capable of measuring down to very low levels, say 20dB(A). If monitoring equipment which has a high noise floor is used, such as 26dB(A), then any limit based on the background level will be artificially elevated. In the case

of The New Zealand Standard for wind farms, or the South Australian Guidelines for wind farms, the equation of best fit regression curve of background will be distorted thereby allowing a higher (distorted) noise limit.

NOISE LIMITS FOR WINDFARMS

The attached Table shows various nighttime noise limits, both international and local, concerning windfarms. As can be seen, there is a wide range of recommendations. Clearly it is beyond the brief of this report to recommend noise limits, and these should only be set after additional noise assessment into windfarms is carried out.

However the following need to be considered:

Low Wind Speeds

The ETSU-R-97 requirement of a higher level for nighttime than daytime for low wind speeds does not agree with requirements for any other type of noise emission. Ther also does not appear to be any reasoned basis for the daytime criterion. The criterion should be viewed with caution.

The European requirements are typically in the range of 35dB(A) to 45dB(A). Being L_{eqs}, if windfarms are measured as L_{90} or L_{95} levels, the range would be typically 32 to 42dB(A). The Netherlands requirement is strictly for windfarms and has a range of 40dB(A) to 50dB(A), depending on wind speed. These are given as "LAr, LT [dB(A)] it is presumed these are L_{eq} levels.

The New Zealand Standard has a "low wind" limit of 40dB(A) $L_{90,\ 10}$. It must be emphasised that the Standard is a guide and nothing in the Standard prevents "The Territorial Local Authority from specifying an alternative compliance level .....".

The South Australian requirement is for a level of 35dB(A), $L_{90,\ 10}$.

The Victorian EPA Guidelines for Country Victoria publication N3/89 provides a "variable" minimum level dependent on the background level. The following table shows the range of background levels, and noise limits, and compares them with the South Australian requirement. For the purpose of comparison, the EPA Guidelines have been adjusted to $L_{A90,\ 10}$ levels.

Publication N3/89			S.A. Limit, L_{A90}
Night Background	Night Limit, L_{eq}	*Approx. Night Limit, L_{A90}	
Low	32dB(A)	29.5dB(A)	35dB(A)
25dB(A)	35dB(A)	32.5dB(A)	
27dB(A)	36dB(A)	33.5dB(A)	
29dB(A)	37dB(A)	34.5dB(A)	
30dB(A)	39dB(A)	36.5dB(A)	

*Assumes L_{A90} about 2.5dB(A) less than the Leq

This table shows that the Victorian and South Australian South Australian requirements for low wind speeds are quite similar. It is recognised that the EPA method of assessing background levels is based on the arithmetic average of 1 hourly levels, rather than 10m measurements favoured by other wind turbine noise standards.

Consideration should be given to the use of the EPA guidelines as an interim measure for the assessment of wind turbines noise at low wind speeds. This would ensure all industries in Victoria would be on a "level playing field" when assessed for noise. Thus the wind turbine industry and the other power generating industries would be required to meet the same limits.

Further as the Victorian limits would be similar to the South Australian limits, there would be no significant difference between states.

Limits for High Wind Speeds

The work by G. P. Van den Berg indicates that noise emission levels at night for a particular wind speed at 10m measurement height are much higher during the night under "stable" atmospheric profiles, than during the day or at night with unstable or neutral atmospheric conditions.

As residents are only annoyed by noise from industry when it is loudest, the only time when appropriate measurements of noise from a wind turbine park can be made is at night when the atmosphere is stable.

The New Zealand Standard and the South Australian Guidelines suggest similar procedures for the assessment of wind turbines at higher wind speeds (i.e. when the background foliage becomes intrusive). As discussed previously, the procedure compares the best fit regression curve of the background noise levels at the residential premises with the best fit regression curves of the background noise levels plus wind turbine noise. This procedure is only valid under identical weather conditions. For the procedure to have any basis then:

- The background noise data and wind speed data pairs are to be divided into wind direction arcs
- Each data set is be further divided into day and night
- The night data set is to be further divided "stable" and "unstable" conditions.

The data that will be most appropriate for analysis will be under the following conditions:

- Night-time
- "Stable" air
- Wind from source to receiver

It is noted that the New Zealand Standard suggests that the wind speeds should be made at hub height. This has technical advantages and disadvantages. At this stage, measurements should continue to be made at 10m height as wind speed at this height relates slightly more reliably to the background foliage noise than wind speed measurements at hub heights.

In the analysis of noise of the turbine using the regression curve approach, the data pairs must be based on the noise level and wind speed at all times when the turbines are operating above cut-in. If the data pairs are based on 10m height wind speeds to define cut-in, then those data pairs at night, then the turbines are well above cut-in and producing significant noise will be excluded from the analysis. Based upon Mr van den Berg's work, the data sets that are most important would be deleted from the assessment.

NOISE CHARACTER CORRECTIONS

Impulse

The work of Mr van den Berg has shown that the long held view that windfarms emit noise with very little impulse character is not correct. Clearly, some form of noise character correction must be applied to imissions.

At this stage there appear to be no character adjustments developed specifically for wind farm noise.

However, as a wind farm is really a power station, the character corrections recommended under SEPP N-1 for industrial premises would appear appropriate.

This requirement is contained in A4. Measurement procedures specific to minor premises. The adjustments are as shown below:

- When the impulsive character of the noise is just detectable then Aimp = + 2dB.
- When the impulsive character of the noise is prominent then Aimp = + 5dB.

The above are somewhat arbitrary and as such will result in some disagreement. A more satisfactory response is to adopt the provisions for major premises included under: A3. Measurement procedures specific to major premises, 1. Measurement of impulsive noise.

This procedure uses the "I" time weighting for impulsive noises.

Low frequency noise

Early wind turbines exhibited low frequency noise that caused, the vibration of windows and doors, and also generated very low frequency noise within dwellings, mainly due to excited room mode resonance. An inspection of a house near a recent windfarm in Gippsland (Toora) showed repetitive low frequency noise was audible in certain rooms in the house. The turbines were only idling and no measurements of this phenomenon were made.

It would be prudent to require windfarm noise imissions to meet the requirements contained in "Physical Characteristics and Perception of Low Frequency Noise from wind Turbines" K.P. Shepherd and H.H. Hubbard, N.C.E.J., Jan-Feb 1991) at residential premises.

The graph of vibration limits are shown below:

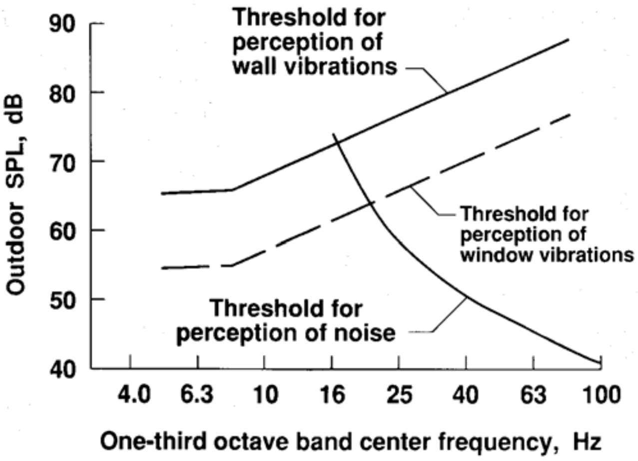

Figure 12. Noise and vibration thresholds

Alternatively, or additionally, the low frequency imissions from wind farms are not dissimilar from those generated by entertainment noise premises. Experience has shown that the SEPP N-2 criterion provides an appropriate measure for entertainment noise, and by adopting the same criterion for wind farms would ensure a "level playing field" between industries and businesses which have noise imissions having the same character.

The night time requirements of SEPP N-2 are as follows, modified for wind farm use:

> The noise limit for wind farms (indoor venues) is L_{oct90} + 8dB
>
> The assessment point shall be either directly outside or inside a habitable room normally used for the purpose of sleeping.
>
> The effective noise level for the night period shall be determined as L_{oct10} values of selected octave bands from the range of selected octave bands, with the centre frequencies of 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, and 4kHz. The octave bands selected shall be those for which the wind farm (music) noise contributes significantly to the octave and sound pressure level. Measurements shall only be taken when the selected octave band level correlates with the music noise.
>
> The base noise limits for the night period are specified in the table below.

Frequency (Hz)	63	125	250	500	1k	2k	4k
Base noise limit (dB)	40	30	20	20	15	10	10

> The background level shall be....the L_{oct90} level for the night period, that represents the background level at the time when the effective noise level was measured.

The background level shall be measured within the noise sensitive area a or at another point where the background level is representative of the of the background level occurring in the noise sensitive area.

The background level means the noise level of the aggregate sound s received at a specified measurement point in the absence of contributions of wind farm (music) noise, measured as....L_{oct90} according to the procedures in Schedule B

SUMMARY

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9. Background noise measurements must be made with equipment capable of measuring down to very low levels, say 20dB(A)

Prepared by James B. Fowler, B.E., M.A.A.S., Associate
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Comparison of Noise Limits

Standard or Code	"Low" Wind Speed	"High" Wind Speed	Comment
Victorian EPA Publication. No. N3/89	Night Background / * Night Limit Low / 32dB(A), L_{eq} 25dB(A) / 35dB(A), L_{eq} 27dB(A) / 36dB(A), L_{eq} 29dB(A) / 37dB(A), L_{eq} 30dB(A) / 39dB(A), L_{eq}	None (?)	Industry noise measured 3 times over 30 days. Results average. * Assuming fully residential
South Australia Windfarm requirements	35dB(A), L_{90}	Regression curve: $L_{A90,\ 10}$ + 5	
ETSU-R-97	Night limit: 43dB(A), $L_{90,10}$ Day limit: 35dB(A), L_{90} or 40dB(A), L_{90}	Regression curve: $L_{A90,\ 10}$ + 5 As above	1. Required day and night to be separately assessed. 2. Difficult to explain why night limit is higher than day limit.
New Zealand Standard NZS6808: 1998	40dB(A), $L_{90,\ 10}$	Regression curve: $L_{A95,\ 10}$ + 5	1. Levels are a guide, can be changed by Territorial Local Authority. 2. May be necessary to correlate background sound levels with different wind directions and/or different time of day.
Denmark	Dwellings 45dB(A), L_{eq} Sensitive 40dB(A), L_{eq}	As for low (?)	
Germany	Standard Residential 40dB(A) Pure Residential 35dB(A)	As for low (?)	
France	Background +3dB(A)		Measurements made when wind at turbines 8 m/s at 10m height.
Netherlands	Wind dependant curve: Night: 40-50dB(A)	As for low	