The effect of a common wind shear adjustment methodology on the assessment of wind farms when applying ETSU-R-97

by

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Executive summary

This research paper has been commissioned by MAS Environmental Ltd. It challenges many of the commonly accepted assumptions on the influence of wind shear on wind turbine noise introduced by an article published in 2009. The article outlined changes to the assessment of wind shear reasoning that by altering background noise levels for wind shear, permitted turbine noise limits would be lowered.

The 2009 article method for assessing wind shear was not based on research and was developed following some widely stated, but now shown to be incorrect, assumptions about the effects of wind shear.

This paper investigates the differences in turbine noise assessment as recommended in the article method and as recommended in ETSU-R-97, the current UK guidance for assessing wind farm noise. Using data measured at a number of wind farm sites around the country comparison is made between the difference in margin between predicted turbine noise level and associated limits as calculated by the article method and by the application of ETSU-R-97 as written. This paper explores whether there are any benefits to using the article method, however small, and reviews the consequences for local communities in adopting this change.

The study concluded that the desired benefit using the article method at all wind speeds, and especially at 5-7m/s where the article method was expected to perform best, is not realised. Where standardised wind shear conditions as implemented by the article, which do not relate to those conditions causing complaint, were substituted for the actual wind shear conditions likely to cause complaint more turbine noise was allowed. Further, the comparison showed that in all cases analysed there was a loss of community protection when adopting the article method.

Outline of the paper

In part I I discuss the background and some of the issues arising with the two wind shear methods most commonly in use.

In part II I set out the steps and some of the differences between the two methods.

In part III I provide the detailed analysis of the individual site data and issues relating to individual sites.

In part IV I analyse the results of the data comparisons and report the findings of the cumulative analysis.

In part V I provide conclusions and recommendations.

PART I

Introduction, background and discussion

In the UK it planning policy supports the use of ETSU-R-97 to rate and assess noise from wind farms. The method was reported in 1997 when wind turbines were of a height about 30m to the hub. At 30m the effect of wind shear on the relative decibel level of noise at a given 10m wind speed was small. Now turbines have hub heights of 80m the effect of wind shear can be significant. ETSU-R-97 compares either a set decibel limit (e.g. 35 dB LA90) or the prevailing background noise level plus 5dB over a range of 10m height measured wind speeds against the actual or predicted wind turbine noise level.

In 2003 Prof. Frits van den Berg of Groningen University highlighted the problems of wind shear in relation to the predicted noise output from modern tall turbines in a paper presented to the Euronoise conference. This was followed by a number of other papers expanding on the issues.

At first his findings were rejected by many involved in wind farm assessment but are now widely accepted. Following debate over how to address this issue, six years later in 2009 a group of acousticians published[1] an alternative method to that set out in ETSU-R-97 for assessing noise impact from wind turbines. The result is a change in methodology in the way background noise levels and the setting of limits

[1] Bowdler, D. et al (2009) "Prediction and assessment of wind turbine noise", *Acoustics Bulletin*, March/April 2009: p.35

are determined which differs to that set out in ETSU-R-97[2]. It was argued this addressed wind shear. The alternative method was not based on supporting research or empirical evidence and appeared to be founded on a number of assumptions over the effects of wind shear[3].

In this paper I refer to this alternative method as the "article method". This paper explores critical conflicts created by the article method that are now commonly accepted by planning authorities and inspectors at appeals. Many acousticians refer to the article method as "best practice" even though it appears to have no more status than an idea of a number of acousticians that was put forward as "recommendations" in an article. The article method is in conflict with the established "best-practice" under ETSU-R-97.

Introduction to wind shear

Wind shear is described in various documents. To avoid confusion the description below is extracted from a recent Defra report[4] considering wind farm nuisance.

Wind shear is the phenomenon whereby wind speed varies at different heights above the ground, typically with wind speed increasing at higher altitudes. Generally, the greater the wind shear the more noise the turbine may generate compared with lower shear conditions [for a given 10m wind speed].

Wind shear can also refer to a change in wind direction with height.

The effect of wind shear is twofold:

> It can affect the propagation of sound.
>
> It allows a range of turbine noise emission levels to be possible for a given 10m height wind speed. The range of turbine noise emission levels depends on the variation in wind shear between 10m height and turbine hub height.

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[2] There appears to have been some debate whether the method still meets the requirements of ETSU-R-97 but it now seems generally accepted it is a change. This is confirmed by the article itself and a reading of the actual recommendations of the ETSU working party which are set out in the draft planning obligation within the ETSU document.

[3] The assumptions were set out in a number of papers presented at seminars by some of the authors of the article. IoA one day seminar on wind farm noise January 2009. Epuk seminar 2009.

[4] Department for Environment, Food and Rural Affairs (2011) *Wind Farm Noise Statutory Nuisance Complaint Methodology*. Kent: Aecom.

In this paper I do not consider the effects of wind shear on the propagation of sound through the atmosphere as this is a separate issue. There are also wind shear effects in the highly complex wind field within a wind farm created by wake and turbulence interactions and reduced wind speeds; these issues are also outside the scope of this paper. It is however, worth considering, in a simplistic form, how it can affect sound turbine emission levels.

In sunny weather there are rising air thermals and mixing of the atmospheric layers as a result. This leads to higher friction in the air and a reduced difference between wind speeds near the ground and those at elevated heights[5]. In other words it leads to windier conditions near the ground when there are significant winds at the same level as the hub of a tall turbine. This is generally called statically unstable conditions. This in turn leads to some upward refraction, or reduced downward refraction, of sound energy and general scatter of the emitted sound from a turbine. As a consequence the received sound downwind from the turbine is less than experienced under other more stable atmospheric states even when the wind speed at hub height is the same.

In the period following sunset and when there has been solar gain (sunny weather), typically when there is little cloud cover, rapid cooling of the earth occurs leading to inversion conditions[6]. This causes the cessation of thermals and atmospheric mixing effectively stops. As time progresses the atmosphere becomes layered and frictional effects due to upward thermals reduce such that wind energy is no longer transferred down to the ground. The consequence is the cessation of wind near the ground but continuation of wind at the turbine hub. This is a "stable" atmospheric state leading to high wind shear. High wind shear can also arise as a consequence of topographical features such as forests that are many kilometres away but affected the wind profile, mainly downwind.

Another consequence of stable conditions is a drop in background noise levels as there is much reduced foliage noise and other wind-generated noise near ground level.

In relation to atmospheric sound propagation effects, when downwind of the source the sounds are refracted downwards due to the faster moving air that occurs with increased height. There is also much reduced scatter of noise in the atmosphere. This leads to increased sound energy from the turbines at locations nearer the ground but which are at more distant locations.

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[5] For further information see for example Stull, R.B. & Ahrens, C.D. (2000). *Meteorology for scientists and engineers*. 2nd Ed. (Belmont: Brooks/Cole).
[6] The air is cooler near the ground than in the layers of air directly above.

Thus in two separate situations where there is the same wind speed at the turbine hub height, one will lead to greater sound propagated towards ground level listeners and the other reduces sound propagated towards them even though they are both downwind. It can be seen from this simple analogy that different resulting sound levels can arise for the same hub height wind speed depending on the stability of the atmosphere.

Note: Wind shear affects the level of turbine noise experienced at a given wind speed, i.e. it is predictions of turbine noise and associated impact that are changed by the influence of wind shear. ETSU-R-97 does not address wind turbine noise prediction. When the authors of the article method began devising a method for wind shear assessment there was arguably a strong basis for no change to the ETSU-R-97 procedures but scope for changes in the method of assessing turbine noise prediction.

DECC Report by Dr McKenzie on ETSU-R-97[7]

In the report to DECC published in July 2011, Dr A McKenzie effectively undertook a review of the application of ETSU-R-97. At paragraph 5.36 he recognised that predicted turbine noise would occur at lower 10m height wind speed under conditions of increased wind shear than originally predicted without allowing for wind shear. At paragraph 5.37 he noted that this shift could be accounted for in two separate ways. Dr McKenzie identified the two separate methods of addressing wind shear, which are those compared in this paper, stating:

> *5.37 This can be accounted for in two ways in a wind turbine noise assessment. Where background noise is referenced to wind speed at 10 metres height, a correction has to be made to the turbine noise to allow for varying conditions of wind shear at the site. This means that some assumption has to be made as to the wind shear at the site, often derived from measurements at two or more heights on the site.*
>
> *5.38 Alternatively, background noise can be referenced to wind speed at hub height and 'standardised' to 10 metres height in the same way that source noise level is 'standardised' to 10 metres height. In terms of a comparison between turbine noise and background this second method is essentially the same as referencing both to hub height wind speed and means that turbine*

[7] Department for Energy and Climate Change. (2011) - *Analysis of How Noise Impacts are Considered in the Determination of Wind Farm Planning Applications* Research Project 01.08.09.01/492A

noise is compared with the derived background noise as it occurs for the conditions under which the turbines are operating without any need for a further correction to account for wind shear. It also means that variation in atmospheric stability is taken into account in the averaging of the background noise data in deriving the prevailing background noise as it varies with wind speed which is likely to produce more scatter and reduce the correlation between background noise and wind speed. Although this method was identified as an agreed practice in the Institute of Acoustics Bulletin article referred to at Paragraph 2.4 (above) and means that limits specified in planning conditions can be set relative to wind speeds measured at hub height such that compliance with such limits can be predicted without making any assumptions about wind shear at the site, there is still some debate about the principles of the method and whether it should be universally applied.

5.39 There are a number of variations within the two methods identified such as the way wind shear for the site is quantified in the first method, given that it is not possible to model every possible wind shear condition occurring at the site, and the way hub height wind speed is determined in the second method. The individual site reviews will summarise the way this has been dealt with in each case.

In response to an email seeking clarification of the DECC report Dr McKenzie confirmed the two methods are different and so are not like for like procedures. In the report he recommended a review of the "article" recommendations[8]. This research paper effectively achieves part of that review by comparing the two methods, using sites where both 10m measured and calculated hub height data was available.

The DECC report identified increasing use of the article method. It is suggested the findings of this paper should be considered by any parties seeking to rely on the article method.

At about the same time as the article was published, at MAS Environmental (MAS) I was undertaking assessments of wind farm noise under stable atmospheric conditions arising from a number of wind farms in the UK. There were three reasons for my exercise, firstly, wind speeds near the ground were low during stable conditions which meant there was limited risk of wind interaction noise over the meter's microphone assembly during measurements. Secondly, background noise levels tended to be lower during stable atmospheric conditions and thirdly, and

[8] E.g. paragraph 7.4 of the DECC report.

most importantly, because stable atmospheric conditions were being associated with the occurrence of significant amplitude modulation caused by wind farms. During this exercise I compared measured and predicted noise levels. My work indicated that the article method was likely to understate impact under the conditions I was examining which in turn led to my reservations over the proposal.

Introduction to the article method

The article method has been described by some people in the field as illogical for trying to incorporate wind shear changes into the background noise analysis rather than a change to the turbine noise, a description I support. Wind speed at hub height affects the wind turbine noise generated at hub height; it has no direct influence on background noise level which is largely determined by 10m height wind speed or other environmental sources. It was apparent to us at MAS that the article method would theoretically allow more turbine noise but was unlikely to lead to a corresponding lowering of decibel limits. However, there was no direct empirical field evidence to demonstrate either way.

A paper by Dick Bowdler, one of the authors of the article method, published in June 2009[9], shortly after the article method was published in the Institute of Acoustics 'Acoustics Bulletin', described the effect of wind shear assessment on wind turbine noise. In this paper Bowdler outlines the differences between wind shear assessment using the article method and assessment of wind shear still following ETSU-R-97 as written, referred to here on as the "ETSU method". It is stated that the effect of adjusting wind shear using either the article method or the ETSU method is the same[10].

Some authors of the article method have presented short addresses at seminars depicting a scenario where the article method simply shifted the turbine limits to the right, horizontally along the 'x' axis, on a graph of wind speed (x axis) versus decibel limits[11]. In effect they suggested a lower turbine noise limit was therefore applied at each wind speed resulting from a lowering of the prevailing background noise level due to wind shear effects. This in turn supported an argument that turbine noise

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[9] Bowdler, D (2009). *Wind Shear And Its Effect On Noise Assessment Of Wind Turbines*.
[10] See the Introduction to the paper and text under figure 3.
[11] For example, see Hoare Lea Acoustics & Hayes McKenzie (2009) *Wind Farm Noise - Wind Shear and the IoA Bulletin Agreement* [Online] Available from: http://www.google.co.uk/url?sa=t&source=web&cd=3&ved=0CCoQFjAC&url=http%3A%2F%2Fwww.hayesmckenzie.co.uk%2Fdownloads%2FEversheds%2520-%2520Talk%25205(a)%2520-%2520Wind%2520Shear%2520amd%2520the%2520IoA%2520Bulletin%2520Agreement.pdf&rct=j&q=IoA%20Bulletin%20article%20method%20wind%20shear&ei=f-uKTseBKaTT0QXM7NHmBQ&usg=AFQjCNHG1_LuXSYr_PsBQc7Vx6Tc8JedJg&cad=rja

limits were lowered when using the article method. The effect is shown pictorially below in two steps and this paper aims to analyse whether this actually occurs in practice.

Step 1:

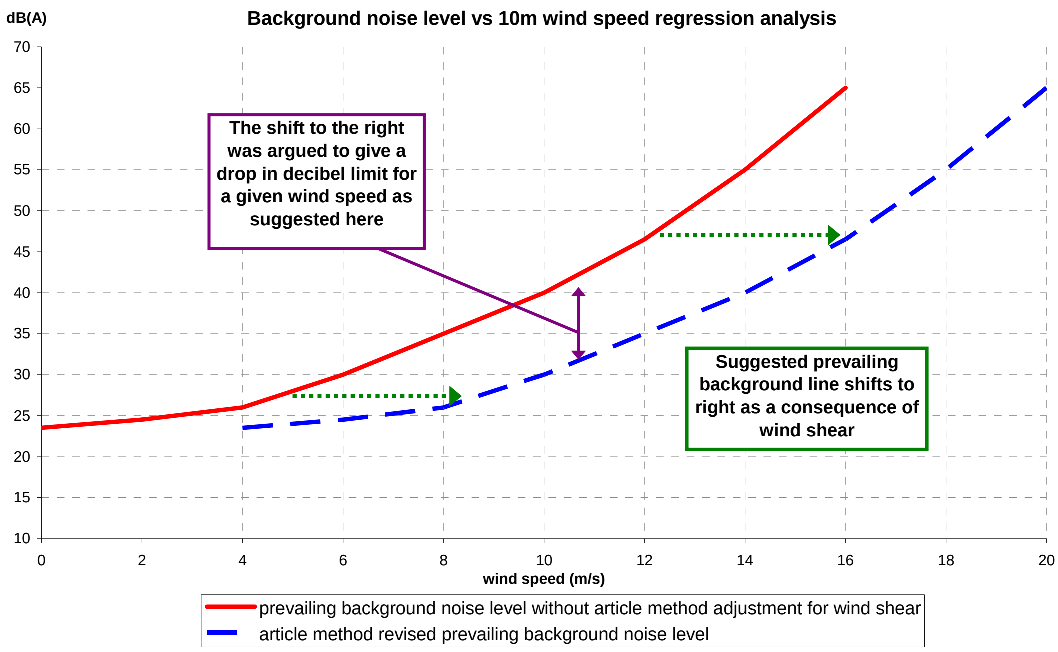


Chart 1 - Theoretical change suggested by some to prevailing background noise curve due to incorporation of wind shear.

The ETSU method for obtaining a prevailing background noise level plots the measured background noise level against 10m measured wind speed with the aim of correlating increasing background noise level with increasing wind speed. The ETSU method plots background noise level against 10m measured wind speed as wind speed at this height is likely to reflect the wind speed close to the ground which is controlling wind generated background noise. The ETSU method prevailing background noise curve is shown as the red line in chart 1.

Rather than relating prevailing background noise levels to 10m measured wind speed the article method relates the background noise level to a 10m "standardised" wind speed. This is a 10m measured wind speed that has been converted to hub height and then re converted to 10m height using a different formula that accounts for a standard ground roughness. It is argued that this adjusts the background noise level for wind shear. This adjusted prevailing background noise curve is shown by the blue dashed curve in chart 1 above.

Step2: It was then suggested that if you introduced the ETSU-R-97 threshold limits[12] applied to wind farms it merely shifted limits above the threshold to the right, further restricting the amount of permitted noise (lowered decibel limit) based on the average short term wind shear occurring at the site. See illustrative diagram below.

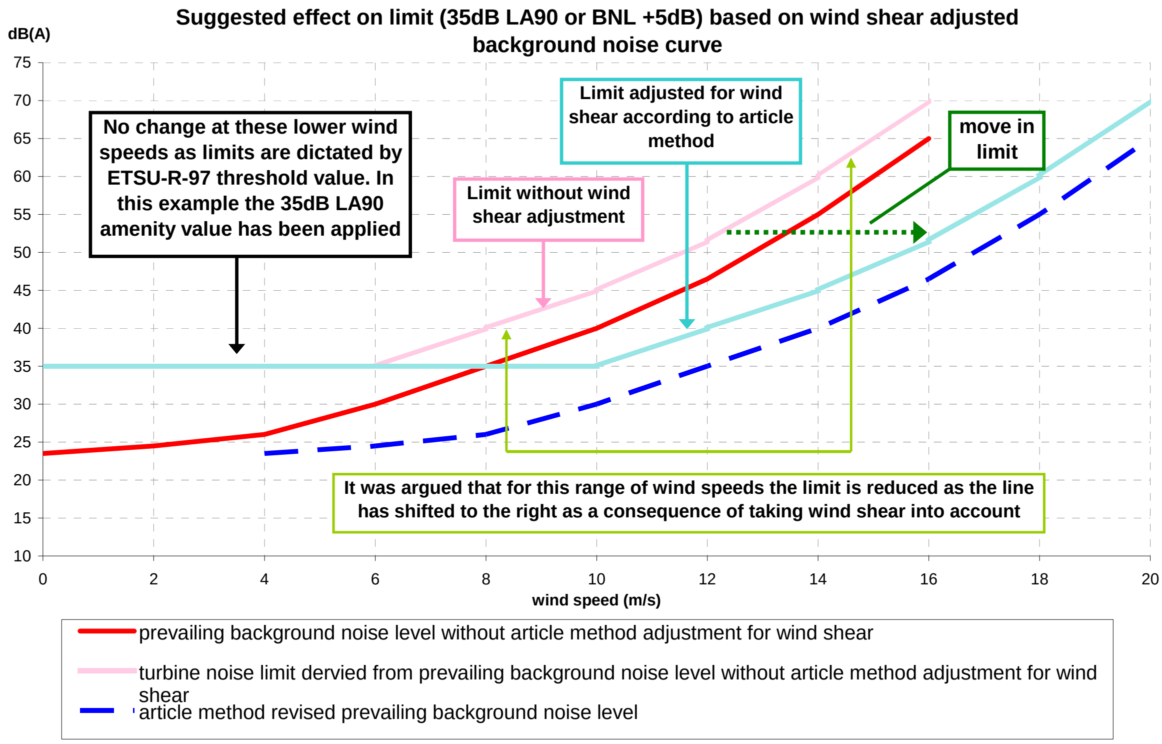


Chart 2 - Theoretical change in limit suggested by some due to incorporation of wind shear.

On its face this appeared an attractive change but it is now clear from the results presented in this paper that this simplified shift does not occur and the assumptions applied did not follow the actual relationship now found to exist between wind shear and wind speed. There is not a linear relationship and in some respects there is not a clearly defined relationship at all due to a large number of variables.

Furthermore, it appeared from a theoretical perspective that the limit line should not shift to the right but rotate about an axis with lower decibel limits for the lower wind speed range arising and increased limits for the higher wind speeds. This theoretical change was expected as stronger

[12] ETSU-R-97 assesses wind turbine noise in quiet daytime periods and night time periods. Quiet daytime applies to all evenings from 6pm to 11pm, Saturday afternoons from 1pm to 6pm and all day Sunday from 7am to 6pm. Night time is defined as 11pm to 7am. The lower daytime permitted turbine noise limit is defined as 35-40dB LA90 or 5dB above the prevailing background noise level. At night time a lower limit of 43dB LA90 or 5dB above the prevailing background is applied.

winds are often associated with lower wind shear values[13], resulting in higher wind shear for lower 10m measured wind speeds than higher 10m measured wind speeds. This effect is presented below[14].

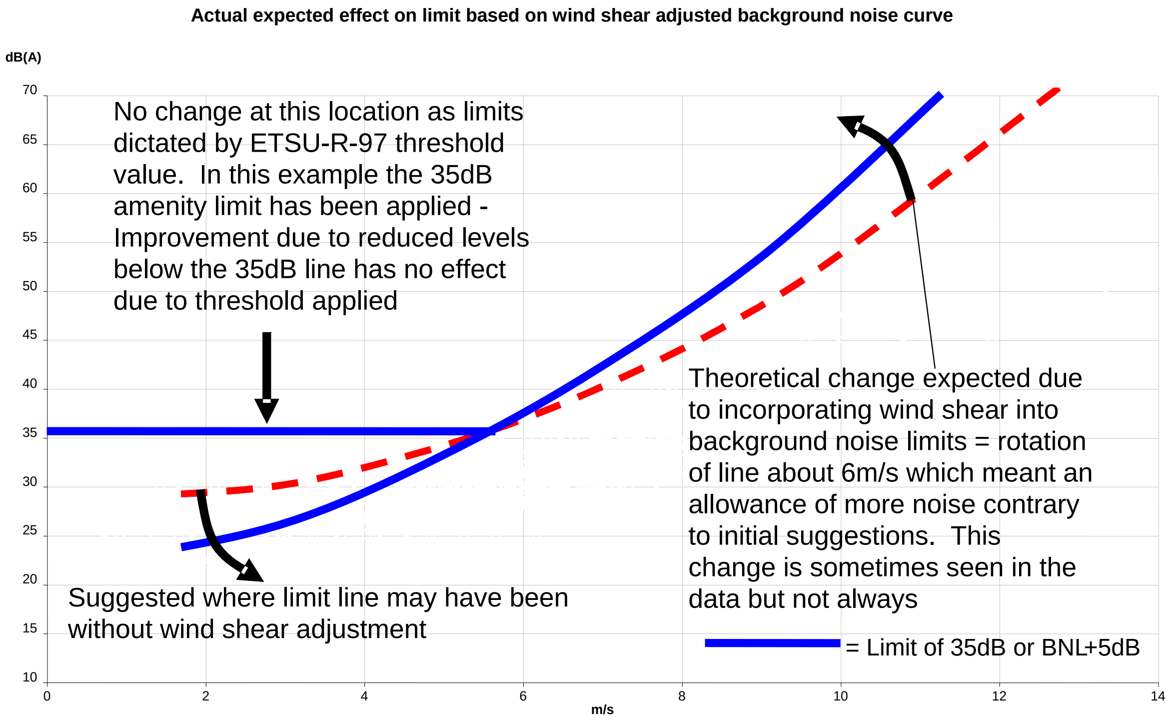


Chart 3 - Shows the theoretical change expected by MAS due to differential relationship of wind shear and wind speed. This was only sometimes seen to occur.

The type of change shown in Chart 3 would mean that for low wind speeds in practice there was no benefit to the article method compared to the ETSU-R-97 method as written because normally the ETSU-R-97 threshold limits applied. Any reduction further below the 35-40dB threshold during amenity periods or 43dB at night would result in no change. However, conversely the increase at higher wind speeds, typically above 6m/s led to more noise being allowed. Thus, following the theory relating to wind shear it was expected the adoption of the article method would allow more noise than when following ETSU-R-97 as written, the "ETSU method".

In summary, it was expected that any theoretical benefit at lower wind speeds was likely to be lost as it would fall below the ETSU-R-97

[13] See again Hoare Lea Acoustics & Hayes McKenzie (2009) *Wind Farm Noise - Wind Shear and the IoA Bulletin Agreement* as referenced in footnote 11.
[14] In practice the data demonstrated that sometimes the limit line rotated counter-clockwise but in other cases a range of different shifts in the line were experienced. In some cases there is virtually no shift at all and the lines lay almost over each other.

thresholds. Conversely at higher wind speeds more noise would be allowed.

Some authors of the article method have argued overall there is a small benefit at the most critical wind speeds which are between 5-7m/s where they considered most compliance issues arose. Thus it was argued if the method provided a benefit, however small, at these wind speeds there was merit in its use.

The only clear way to conclude whether there was a real benefit and the extent of any harm was to compare a number of sites using the two methods. This approach is more complex than first appears; few sites provide both 10m measured data from which it is possible to accurately calculate the hub height wind speed and the standardised 10m values needed for the article method.

It is possible to calculate the 10m height wind speed values using the same data gathered to calculate the hub height wind speed. However, this 10m calculated wind speed would not follow a strict application of ETSU-R-97 and hence would not provide a direct comparison of the two methods. Thus, this paper only compares the actual 10m measured wind speed with the 10m standardised values determined using the article method.

PART II

Reason for change in the wind turbine assessment method

It was argued that changes to assessment procedures were required in order to address the effects of wind shear arising from increases in turbine height, when compared to the situation when ETSU-R-97 was introduced in 1997. At the time of ETSU-R-97 the tallest turbine was 32m to its hub and wind shear effects could only lead to relatively small errors. Typically turbines now have hub heights of 80m and above.

The consequence is that the difference in wind shear effects between the reference height of 10m (used for determination of background noise levels that are compared to the wind speed) and hub height has changed. The error in the change in wind speed between 10m and 32m for high wind shear conditions was much smaller than compared to the difference for 10m versus 80m heights.

How the methods differ in their incorporation of wind shear

The differences in the two methods are not necessarily readily apparent. I have therefore set them out in the table below with some description in the following paragraphs along with notes of some of the key issues arising from the different processes.

Table 1 - Comparison of how the article method and ETSU-R-97 method as written (ETSU method) work.

Usual process steps			
Pre development acceptability assessment			
	Process step	**Article method**	**ETSU method**
1	Measure long term anemometry to determine wind energy potential	Ignore data	Use data to determine wind shear statistics for the site but this is not critical as you could apply typical or expected wind shear values. *Note: Long term data is not subject to chance variations and errors tend to cancel out.*
2	Background noise survey	Use anemometry from different heights	Measure 10m wind speed which

		(typically 40 and 50m) during the noise survey to calculate / approximate hub height wind speeds which correspond with the measured background noise levels. *Note1: Relies on the accuracy of calculating the hub height values and degree of errors in two measurement heights.* *Note2: Background noise levels are affected by multiple averaging effects from differences in decibel level caused by wind direction, other environmental noise sources and adjustments made for a range of wind shear conditions. Even though wind shear does not influence background noise level, it will increase the scatter of background noise data and further adversely impact the averaging effects of the regression analysis.*	corresponds with measured background noise levels during the survey. *Note: Relies only on accuracy of one measurement height = reduced error risk.* *Note2: Background noise levels are only affected by the averaging effects from differences in decibel level due to wind direction and other environmental noise sources such as increases and decreases in road traffic noise.*
3		Convert to approximate hub height wind speeds. *Note: Formula assumes both measurement points lie on the same perfect exponential curve*	N/A
4		Convert hub height values to a "standardised" 10m value assuming a wind shear exponent (ɑ)of 0.16[15]. *Note1: This ignores actual wind shear effects as the change is unrelated to actual wind shear exponent* (ɑ) *but is assumed constant. In reality it*	N/A

[15] The wind shear exponent of 0.16 equates to a ground roughness value of 0.05m when applying the logarithmic formula in ETSU-R-97. By converting to a wind shear exponent it allows direct comparison. The logarithmic formula in ETSU-R-97 ignores atmospheric states.

		compares hub height wind speed with background noise; this ignores the change in wind speed between hub height and 10m height which actually determines background noise.	
5	Noise data analysis	Exclude noise data affected by extraneous noise. *Note: Process identical for both methods.*	Exclude noise data affected by extraneous noise.
6		Compare 10m "standardised" wind speeds with decibel levels to produce "*best fit*" curve (prevailing background noise level). *Note: Comparing artificial 10m value with background noise. Effectively looks at the relationship between hub height wind speed and background noise level; this is based on the false premise that there is a relationship between the background noise level and hub height wind speed.*	Compare measured 10m wind speeds with decibel levels to produce "*best fit*" curve (prevailing background noise level). *Note: Comparing actual 10m value with background noise. Looks at the relationship between 10m height wind speed and background noise level; this is based on the assumption that background noise level correlates with 10m height wind speed.*
7	Derive limits	Add ETSU-R-97 threshold values or background plus 5dB to get limits. *Note: Process identical for both methods.*	Add ETSU-R-97 threshold values or background plus 5dB to get limits.
8		Plot predicted wind turbine noise levels for wind speeds based on α=0.16. *Note: Process step made easier as manufacturers provide data for this wind shear exponent although stated as a ground roughness value. Ignores the actual wind shear and so plots turbine noise levels based on α=0.16 which primarily relates to daylight / sunny conditions*	Plot predicted wind turbine noise levels based on long term measured wind shear values found to occur or typical night / daytime values. *Note: This replicates the actual effect of different wind shear values on wind turbine noise. Wind shear is included at this stage as it relates to the level of wind*

		and not those normally found in the evenings and at night.	*turbine noise that will be generated as a result of the wind shear difference.* *Wind shear is not averaged with other effects on noise sources as it only influences to the turbine noise level.*
9	Determine likely compliance	Determine compliance by comparison of limits and best fit lines. *Note: Process identical for both methods.*	Determine compliance by comparison of limits and best fit lines.
Post development complaint investigation (See ETSU-R-97 pages 102-103)			
10	Data acquisition	Determine or measure hub height wind speed and wind direction during periods of complaint. *Note: This cannot meet the requirement to relate measured turbine noise with the actual measured 10m wind speed causing the problem; 10m measured wind speeds are never referenced or referred to in this method.* *"Standardised" wind speeds are substituted for actual conditions.* *Method is unable to factor in the effect of actual wind shear occurring during the complaint and measures noise at hub height wind speeds regardless of wind shear effects.*	Measure 10m height wind speed and direction during periods of complaint. *Note: Follows procedure as written in ETSU-R-97 and measures 10m wind which is the main cause / influence of background noise at the same time as measuring turbine noise.* *Most problems are when turbine decibel levels are high and background noise is low = high wind shear conditions. Only these conditions would be assessed as determined by the turbine power output and meteorological conditions during the complaint.*
11		Determine power output of turbines during complaint periods. *Note: Power output should be relatively stable for a given wind speed as standardised wind speeds relate to hub height wind speed which in turn relates to power extracted.*	Determine power output of turbines during complaint periods. *Note: Power output will vary helping to identify the level of wind shear occurring. A low wind speed at 10m height will relate to low power output when the wind shear is low and higher*

			power output when the wind shear is high.
12		Measure noise at dwellings during same hub height wind speeds and power output. Approximately 20-30 data points are measured at the relevant 10m wind speed. *Note1: The 20-30 data points equates to 200-300 minutes which typically requires one or two evenings. Complaints are most likely to be during evening hours when higher wind shear most often occurs.* *Note2: Using this approach it does not matter what the actual conditions are at 10m height or what the effects of wind shear are as it assumes a wind shear exponent of 0.16 and so when there is high power output and low background noise it ignores this situation and applies a higher 10m wind and its related decibel limit. It thus ignores the conditions causing complaint.* *This protection as originally applied by ETSU-R-97 is now lost.*	Measure noise at dwellings during same 10m measured wind speeds and power output. Approximately 20-30 data points are measured at the relevant 10m wind speed. *Note1: The 20-30 data points equates to 200-300 minutes which typically requires one or two evenings. These need to reflect the conditions causing complaint. Complaints are most likely to be during evening hours when higher wind shear most often occurs.* *Note2: Using this approach it replicates the conditions causing complaints and impact will generally depend on the level of wind shear occurring which will affect how low the background noise is.* *This process means the actual 10m measured wind speeds and background noise levels relate to what actually happens within community locations and there is no substituting of an artificial wind speed value.* *The protection as originally applied by ETSU-R-97 remains and compliance is based on a comparison with the actual conditions rather than an artificial situation.*
13	Determine if a breach	The remaining procedures are relatively unchanged	

The procedural differences are perhaps better understood by the diagrammatic example and explanation given below.

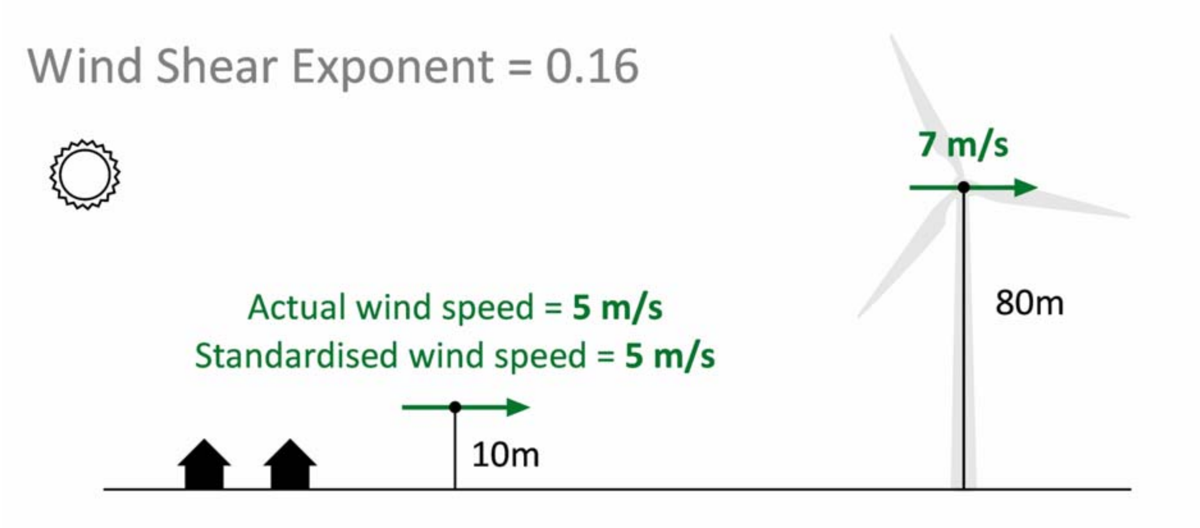


Figure 1 - Typical daytime conditions. The two methods are more likely to agree as low wind shear values arise when there is higher solar gain. Actual 10m and 80m wind speeds are closer with only a 2m/s difference.

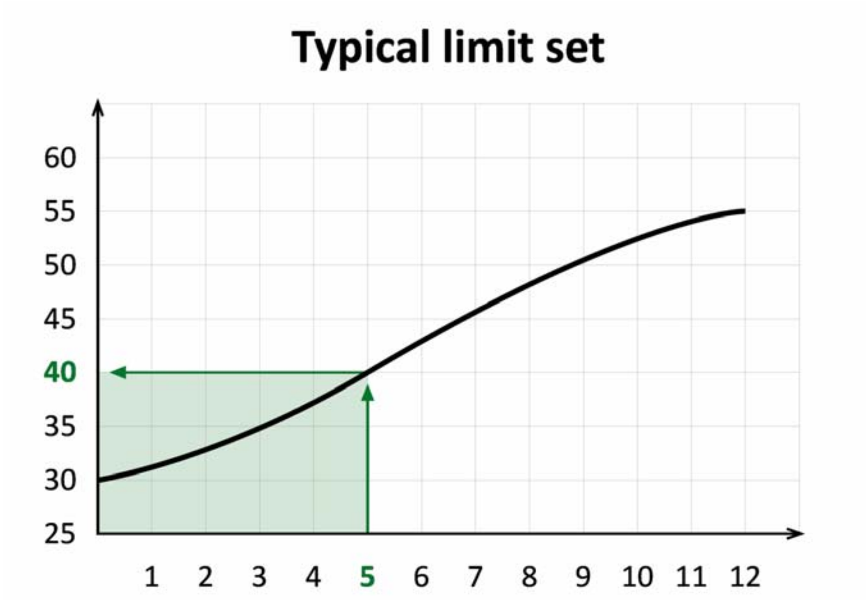


Figure 2 - How the decibel limits are compared to actual levels of wind speed. It can be seen in this case as per figure 1 that where the resulting limits for the two methods are the same, it is because the daytime wind shear exponent is about 0.16, giving almost identical results.

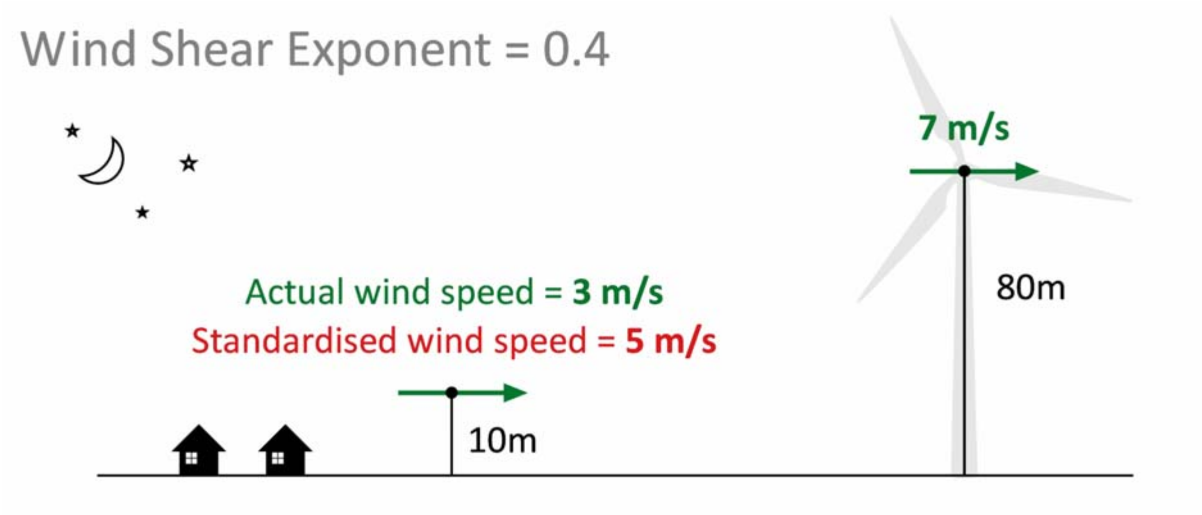


Figure 3 - Typical evening (after sunset) or night time condition. Under these conditions the methods are more likely to disagree[16]. This is because higher wind shear values commonly arise under these conditions and at these times as there is no solar gain and radiative cooling is taking place. The actual 80m and 10m wind speeds diverge much more with a difference of 2 m/s for the standardised assessment and double that at 4m/s for a wind shear exponent of 0.4. The resulting difference in levels is shown in Figure 4 below.

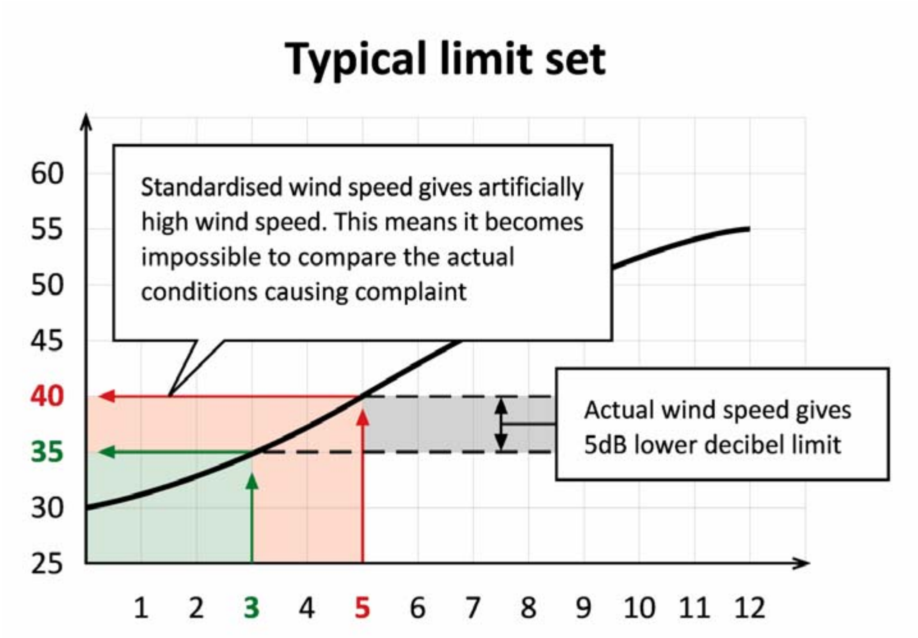


Figure 4 - How the decibel limits are compared to wind speed. In this example (compare to Figure 2) it can be seen different results now arise. The "standardised" wind speeds give an artificially high wind speed

[16] Note: The article method still assumes a wind shear exponent of 0.16.

value than actually found at 10m measured height. This means it becomes impossible to compare the actual conditions causing complaint when using the "standardised" approach.

Discussion on wind shear method differences

In the illustrative scenario provided above comparing limits, it is demonstrated that the "standardised" wind speeds ignore the actual effect of wind shear variations as a function of atmospheric stability, constantly assuming $\alpha=0.16$, at the time of noise impact but when using 10m measured wind speeds, actual wind shear will accordingly adjust the limit applied.

In figure 1, during the day when the wind shear is low a decibel limit of 40dB is derived with either method. Figure 3 shows the situation when the wind shear has increased to a commonly occurring wind shear value. In this scenario the article method assumes a higher 10m wind speed which is still at 5m/s and as found during the daytime. However, in the actual circumstances the 10m measured wind speed has dropped to 3m/s due to a wind shear increase to an exponent of 0.4. Using the 10m measured approach a lower decibel limit applies. This is a simple example of the mechanism which allows the article method to apply higher decibel limits.

Position of MAS Environmental as to the change

It is important to identify that at MAS Environmental we have always been opposed to the changes introduced which followed the article in the Institute of Acoustics bulletin in April 2009 for the reasons already identified. Further, the article was not peer reviewed and was not supported by any research. A major reason for opposition was simply that ETSU-R-97 sets limits on maximum turbine noise arising under any typical conditions that arise. The limits are either based on the threshold value (35-40dB LA90 during the day or 43dB LA90 at night) or the average background noise level LA90 plus 5dB at a particular 10m wind speed.

The premise of ETSU-R-97 and planning guidance[17] was simply that as the wind at 10m height increased so did the noise from trees rustling and wind effects around buildings that are at a similar height. The logic applied was that as this 10m height wind speed increased, the

[17] See Companion Guide to PPS22 which states as such.

background noise levels increased at a faster rate and to a greater extent than did the turbine noise level.

As ETSU-R-97 applies limits to 10m measured reference heights and differences in wind shear do not influence background noise level, there was no consequence of introducing taller turbines to the ETSU-R-97 complaint assessment methodology. The turbine noise limit remains the same whatever the turbine height.

There is no basis for changing the level of noise that a community should experience because the turbine height changed. This appeared to be the consequence of the change introduced by the article method which adjusts background noise levels, in turn adjusting permitted turbine limits. However, the change needed to account for taller turbines was not in the setting of limits but in the prediction of wind turbine noise and the range of turbine noise levels that could be generated for a specific 10m wind speed.

Prima facie there was no requirement for change to any of the procedures in ETSU-R-97. For example, the hub height wind speed at 80m could range from 3-8m/s when the 10m wind speed was only 3m/s because of differences in wind shear. This would mean the wind turbine noise level could vary from 0dB at cut in wind speed to its maximum noise level at approximately 8m/s with no change in background noise level. The realisation of wind shear effects suggested that the only change required was to determine the range of wind turbine noise levels for a given 10m height wind speed and its corresponding background noise level due to different degrees of wind shear.

Another concern with the article method is that factoring the wind shear into the background noise level data creates an artificial situation compared to that which actually happens in reality; it is the wind turbine noise that is altered and not the background noise. As noted above, Dick Bowdler, one of the authors of the article method, implicated that the application of changes to the background levels rather than turbine noise levels was similar in terms of total effect and therefore the change could be accounted for by either incorporating effects into an adjustment of limits or predicted turbine noise.

I understand that in the light of the assumed similarity those supporting the article method opted for a change in the background noise determination procedure and future reliance on an artificial 10m wind speed which they termed “standardised” 10m wind speeds.

PART III

Method of comparative analysis applied

To avoid any bias in the results we have used the data and procedures as set out in the respective Environmental Statements (ES) accompanying each wind farm application reviewed in this paper. The only change is in the way wind shear has been accounted for in the data. The best comparison is achieved where 10m measured wind speeds are available as well as the calculated hub height wind speed and this has been the focus of this paper.

A common turbine noise prediction and data exclusion process has been applied for both the article and ETSU method[18] which in most cases was as applied in the planning application details or as reviewed during the planning process. This process was not transparent in all cases and in those circumstances identical adjustments have been made to ensure like for like data inclusion.

For those unfamiliar with the procedural and methodological differences between the two approaches, it may be hard to comprehend how significant the differences are when compliance or exceedance is determined. It is not only the derived limits which differ between methods but the predicted turbine noise levels respective to a particular wind speed are also different. There are two simultaneous changes.

In the comparative analysis within this paper we have focused on assessing the differences in procedures by comparing the outcomes in terms of what level of noise is permitted when using the two methods. They are not "like for like" processes as the article method averages wind shear during the noise survey. As a consequence it is reliant on whatever wind shear conditions happen to arise during the survey[19]. The 10m measured method which follows ETSU-R-97 as written (ETSU method) considers the wind shear effects under the conditions expected to lead to complaints by residents. This is typically when there is higher wind shear. Higher wind shear values than 0.4 are expected to give a greater margin in favour of the ETSU method but have been excluded to ensure only typical / commonly occurring conditions are assessed rather than considering the less common conditions. In view of this it is necessary to select representative wind shear values which reflect commonly occurring wind shear conditions.

[18] For example, removal of rain affected data

[19] This may be limited to 7-14 days of wind shear data during which meteorological conditions do not reflect those likely to generate complaints from wind farm noise.

Wind shear values used

Detailed examination of the wind shear data suggests a typical range of wind shear exponents between α=0.1-0.6 and occasionally beyond these values. Where α=0.6 this represents a rapid change of wind speed with height and is typically found in very stable[20] atmospheric conditions often with little wind even at hub height. Unstable atmospheric conditions are represented by α=0.16 as used for standardised wind speeds[21] in the article method. Wind shear of α=0.16 normally only occurs on sunny days when there is thermal mixing in the atmosphere and equates to a statically "unstable" atmosphere.

A statically "neutral" atmosphere is the limited period of transition between unstable and stable atmospheres and typically has a wind shear exponent "α" of 0.22[22]. An "α" of 0.4 equates to moderate or very stable conditions. This is clarified in the table below which provides an overview of atmospheric conditions and the corresponding wind shear exponent, reproduced from a paper by Prof. Frits van den Berg[23].

Pasquill class	name	shear exponent
A - B	(very - moderately) unstable	$m \leq 0.21$
C	near neutral	$0.21 < m \leq 0.25$
D - E	(slighlty - modertaely) stable	$0.25 < m \leq 0.4$
F	very stable	$0.4 < m$

Table 2 - corresponding wind shear exponent and atmospheric conditions

[20] "Stable" refers to static vertical stability in terms of vertical wind or air movement within the atmosphere. Unstable refers to a situation where thermals rise in the atmosphere mixing air and leading to friction such that wind speeds experienced at greater heights are transferred nearer the ground. As a consequence the wind shear exponent is low and typically about 0.16 in an unstable atmosphere. When there is horizontal layering in the atmospheric boundary layer and decoupling of the greater height winds from the air nearer the ground then the atmosphere is described as statically stable. This in turn leads to high wind shear typically above an exponent of 0.25. Other factors can cause a high wind shear other than stable atmospheric conditions, including topographical features such as forest.

[21] The "standardised" wind shear value is usually stated as a ground roughness adjustment but equates to a wind shear exponent of 0.16.

[22] See G.P van den Berg (2006). *The sound of high winds - the effect of atmospheric stability on wind turbine sound and microphone noise*. PhD These, Rijksuniversiteit Groningen, Netherlands. p. 32.

[23] G.P van den Berg (2006). *The sound of high winds - the effect of atmospheric stability on wind turbine sound and microphone noise*. PhD These, Rijksuniversiteit Groningen, Netherlands

Thus comparison of the article method against the ETSU method with the latter assessed using wind shear exponents of 0.25 and 0.4 to determine the wind turbine noise level at a measured 10m wind speed provides a common comparison and not worst case. The percentage of time each of these wind shear exponent values was exceeded has been calculated and is highlighted in the results tables.

Two commonly occurring wind shear conditions have been selected for use in the prediction of turbine noise levels; wind shear exponent "α" of 0.25 and 0.4. The percentage of time these exponent values arise in the data for each site assessed has been considered to test the appropriateness of their selection for comparison with the article method. Furthermore in one of the cases used in the study the average wind shear exponent during the night time and amenity periods was found to closely match the values of 0.25 (slightly stable) and 0.4 (very stable) separately selected for the study. The average α at night was 0.42 and during the amenity period it was 0.24 in the case analysed.

The compliance testing procedure according to ETSU-R-97 requires that measurements of wind turbine noise be undertaken in the same conditions that caused the noise complaint. Thus, measurements of wind turbine noise should be made in the same meteorological conditions, and hence wind shear conditions, as those that caused the complaint. When applying the article method, it is not possible to account for the actual wind shear that occurs during compliance checks as when calculating the 10m wind speed from the hub height values it assumes a standard value of α=0.16.

The procedure adopted in the article method for determining the prevailing background noise levels is also largely neglectful of actual wind shear. The wind shear values assumed to determine prevailing background noise levels and turbine noise limits are limited to and dependent on the weather conditions experienced during the survey. These wind shear values may or may not relate to the typical wind shear experienced at a site. The ETSU method can usually be related to long-term wind shear data collected at the site which increases confidence in assessing turbine noise impact under conditions likely to occur at the site.

The “standardised” 10m wind speed limits used for comparison were derived using the procedures identified in the site’s ES or the data provided with the planning application and processed using the article method. This relies on a wind shear adjustment of α=0.16.

The original raw data was used in each case and the procedures replicated as far as possible to ensure the same results as presented in the ES or as modified during the planning process but also to confirm whether the methodology reported in the ES was reasonably accurately applied. Where discrepancies arose[24] following processing of the data then the results were based on an identical approach to data inclusion and *best fit* curve adjustment in each of the two respective methods.

As identified, to avoid discrepancy an identical wind turbine noise propagation prediction methodology was also used as set out in the relevant ES. This meant the only variable was the way wind shear was incorporated into the analysis.

As discussed, the two methods produce two changes; different limits and different predicted turbine noise levels. The "standardised" method is based on an artificial comparison; the ETSU-R-97 method is based on conditions and wind shear values that actually arise at the site. As the actual levels experienced will vary depending on the wind shear at the time of adverse impact, it is reasonable to compare more than one wind shear exponent.

[24] Discrepancies were usually small and in most cases appear to arise due to adjustments to the regression curve to try to make it appear to better fit the data. This usually meant levelling off the line at lower and higher wind speeds. This anomaly arises as the regression analysis in some cases predicted anomalous results such as reducing decibel levels at higher wind speeds and increasing decibel levels at lower wind speeds. This reliance on a best fit curve that does not actually fit the data is a separate issue for debate and not considered in this study. As a consequence the data manipulations applied in the relative ES documents were generally accepted. Where the information is not available or reliable then no adjustment has been applied to the data in both methods. In this way it leads to a direct comparison of methods as the same approach was adopted for each.

Comparisons made in this paper

For the purposes of this paper and in providing a uniform comparison process of the two methods, it does not matter what limits were actually applied or proposed for an individual site provided a uniform approach to comparison was adopted.

The critical issue is which method provides a lower margin between turbine noise and limits or greater exceedance when compared to a particular limit. Whichever method provides a lower margin between the predicted turbine noise and turbine noise limit or greatest exceedance of the limit also provides the greatest level of protection to communities. This is explained in the charts below.

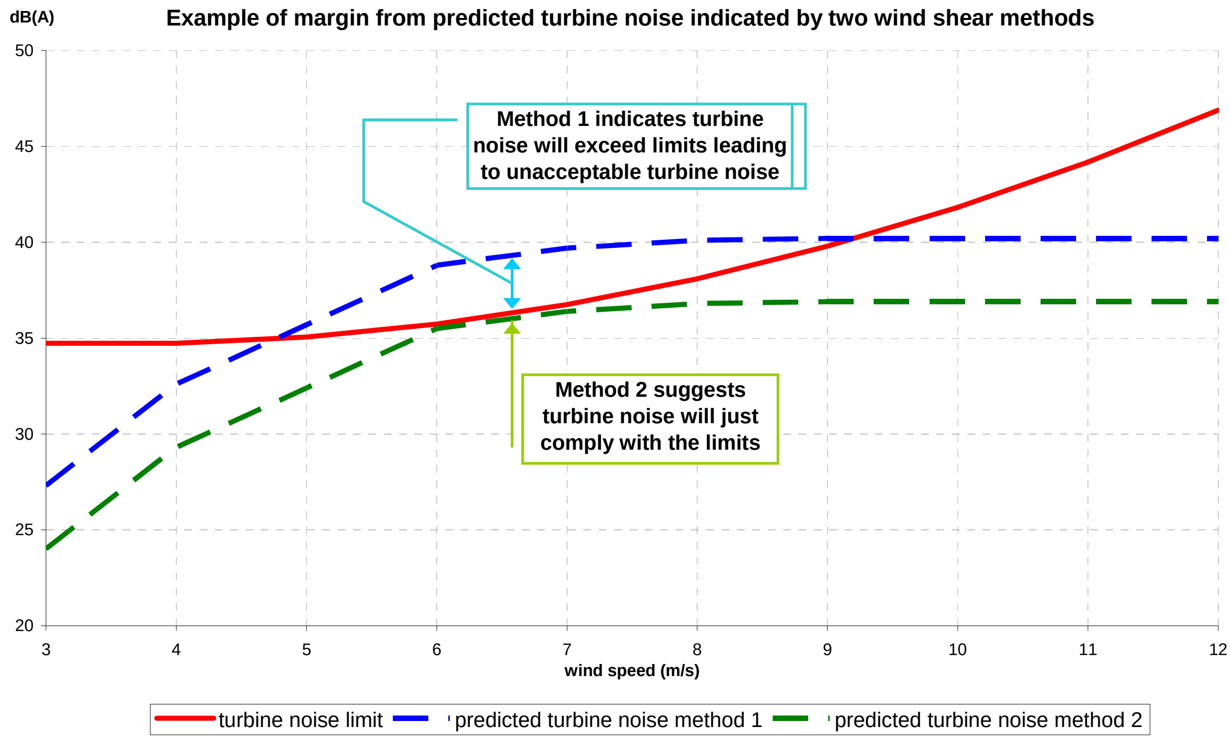


Chart 4 - Method 1 predicted turbine noise will exceed the limit, method 2 predicts that turbine noise will comply.

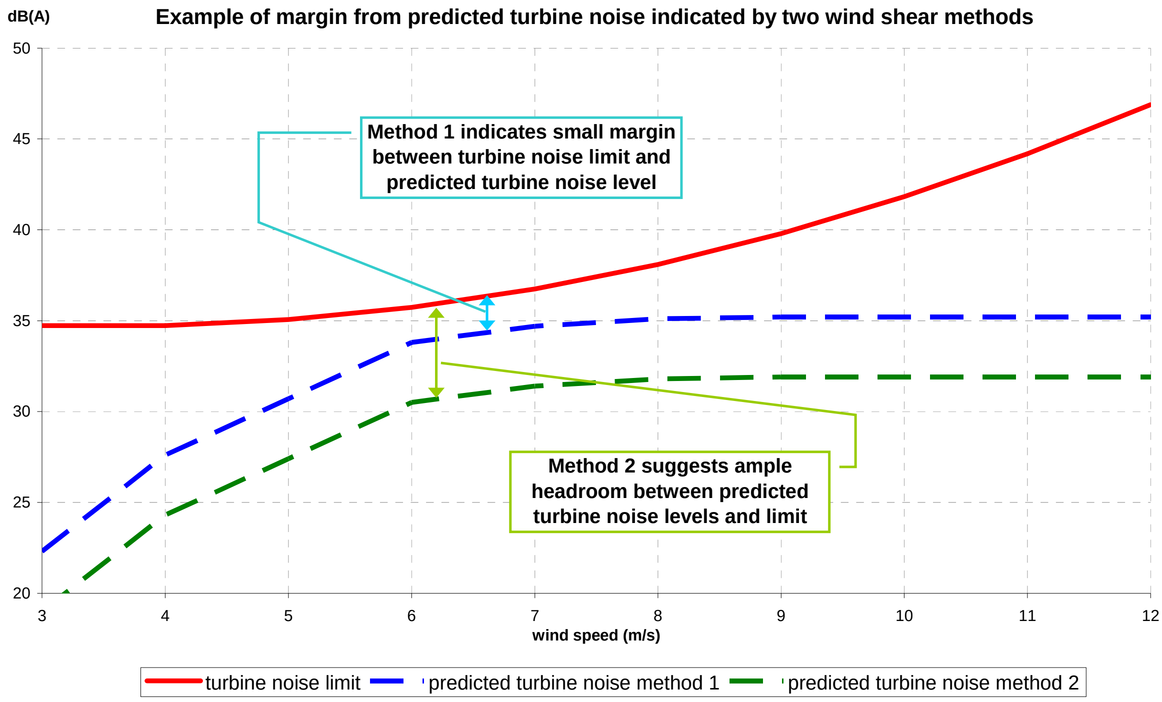


Chart 5 - Method 1 predicts that turbine noise is closer to the limit than method 2.

In the above examples it can be seen that method 1 provides better protection to communities as it is more likely to indicate unacceptable turbine noise. Method 2 is better for developers as it is more likely to suggest that turbines will comply with the limits.

To render comparison easier to see, the differences in margin or exceedance between the two methods were compared by subtracting the "standardised" decibel results from the ETSU method results. Negative values in the resulting bar graphs and tables included below identify cases where the article method provides greater protection than the ETSU method as there is less implied margin between turbine levels and limits. Positive values indicate the ETSU method provides greater protection.

This comparative margin has been presented in tables and charts below. To provide additional clarity the comparative tables / charts work as follows:

> When the ETSU method provides a decibel level that is nearer to the ETSU-R-97 derived limit than the article method but does not exceed it then there is a positive value in the tables representing the difference in values between the two methods.

When the ETSU method provides a decibel level above the ETSU limit and which exceeds it more than the article method value, or when the ETSU method provides a decibel level above the ETS limit, the article method does not exceed the limit at all then again there is a positive value in the tables equal to the difference between the results of the two methods.

When the article method provides a decibel level nearer to the ETSU derived limit than the ETSU method there is a negative value in the tables and charts. Similarly if the article method provides a decibel level above the limit which exceeds the amount the ETSU method exceeds the limit then you get a negative value.

In summary any positive values in the tables means ETSU provides greater protection of communities as it predicts less headroom or margin in the tables / chars between turbine levels and limits and the converse is the case for negative values. The table values identify the extent of difference in protection between the two methods with a higher value denoting a greater level of protection of one method over the other.

To determine the original comparative values, a daytime (amenity) threshold limit of 35dB LA90 or prevailing background plus 5dB (whichever is the highest) was applied. At night a threshold of 43dB or prevailing background plus 5dB (whichever is the highest) was applied. These are the most common limits applied but it would not matter if other limits were applied as it is a comparison of the results.

Note: In reality "standardised" wind speeds of 1-2m/s and sometimes 3m/s are theoretical as the turbines do not cut in until the standardised wind speed exceeds about 2.5-3m/s. This is because using the standardised method there will be insufficient wind speed at hub height to operate the turbines. Whilst some of these values are provided in the tables they have not been used in the comparison. Analysis at 3m/s has been included as in practice it is common for turbines to be operating and emitting noise for 10m height wind speeds of 3m/s.

The only purposes I can conclude for including 1-3m/s values in the respective Environmental Statements is either to provide an illusion that turbine noise is controlled at these standardised wind speeds or because those presenting the data have not appreciated that the "standardised" wind speeds introduced by the article method do not apply at the low values.

For additional comparison, part of the analysis is restricted to wind speeds of 5-7m/s. At these wind speeds turbines will be operating regardless of the method applied. This wind speed range has also been separately considered to test the suggestion outlined above that the article method would offer most benefit at wind speeds of 5-7m/s.

Detailed analysis of the site data

Below the tables and bar charts show the loss or gain of protection at each wind speed obtained by comparing the margin between turbine noise and turbine limit afforded by the two methods.

The results are summarised in the following tables with four possible outcomes as detailed below. There are two tables for each site: one comparing the article method (α=0.16) against the ETSU method assuming α=0.25 and one comparing the article method (α=0.16) against the ETSU method assuming α=0.4. Night time and amenity periods have been assessed in accordance with ETSU-R-97. Headings, e.g. '93' or 'College Farm', relate to individual premises where background noise measurements were taken.

> **No gain.** Where there is no gain from using the article method this is the combination of '0' values (no difference) and positive values (loss of protection using the article method, advantage to using the ETSU method).
>
> **Gain to using the article method.** Negative values are cases where the article method provides greater control over noise levels, i.e. where there is an advantage to using the article method.
>
> **No difference.** Where there is no difference between the two methods the value is 0 hence neither positive or negative.
>
> **Loss of protection using the article method**. Positive values are cases where the ETSU method provides greater protection; the greater the value the greater the protection. This is where the ETSU method is more advantageous and there is a loss of protection from using the article method.

The charts show the level of margin between predicted turbine noise and turbine noise levels afforded by each method. Where bars are positive there is a loss of protection using the article method. Negative bars indicate there is a gain to using the article method. The 'y' axis gives the individual premises where background noise levels were taken. Each bar represents a wind speed; hence, there are ten bars for each background noise monitoring location for wind speeds of 3-12m/s.

As discussed, results are excluded below 3m/s as turbines do not operate under these conditions when applying "standardised" wind speeds and were excluded in the Environmental Statement. In reality impact can arise at these wind speeds and theoretically it should be included. Its exclusion limits comparison to the more common situations that arise.

Site specific results

Biggleswade wind farm

In this case data for 10m measured wind speeds and the calculated hub height wind speed using the article method were both available enabling direct comparison.

Measurements at this site were obtained during a very cold winter period when there was high wind shear and limited data for upper wind speeds. Residential properties assessed are subject to noise from the A1 dual carriageway on the eastern side of the site and which is very close to them. Only distant noise from the A1 affected measurements on the other side of the proposed wind farm. As a consequence many of the prevailing background noise curves reflecting properties close to the A1 dual carriageway are relatively flat with little increase in values when there is a corresponding increase in wind speed. This is because of the influence of road traffic noise on external measurements.

Prevailing background curves did rise at dwellings on the western side of the proposed wind farm away from the A1 dual carriageway. It was assumed this would lead to circumstances best favouring the article method. When compared to the other sites assessed this was partially found to be the case. Notwithstanding this finding, the article method still permitted substantially more noise than the ETSU method. The outcome was that predictions of compliance were changed to a prediction of a breach of limits at some properties. However, the relevant part of the analysis for this exercise was the degree of change in noise permitted at different wind speeds.

At the Biggleswade site, for the wind shear exponents of $\alpha=0.25$ & $\alpha=0.4$ and between the wind speed range of 3-12m/s[25], there is no gain or improved decibel margin between predicted levels and limits using the article method in 77% of all cases. In 64% of cases there is a loss of

[25] The loss of margin increases if 2m/s is included but this is a far less common scenario and so has been excluded.

protection using the article method. In the 23% of cases where there is a gain in using the article method, the gain ranges between 0.1-2.8dB with an average gain of 0.9dB. Where there is a loss in margin (i.e. a gain in using the ETSU method) this ranges from 0.1-36.5dB[26] with an average loss of 5.1dB.

Between the critical wind speeds of 5-7m/s, where the article method was expected to provide best protection, 98% of cases resulted in no gain or improved decibel margin between predicted levels and limits using the article method. In 96% of cases there was a loss of protection using the article method. Where there was a loss of margin (i.e. a gain in using the ETSU method) the advantage provided by using the ETSU method ranged between 0.1-5dB and on average provided better protection of 2dB.

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.25 Shear)

wind speed (m/s)	Night-time							Amenity						
	93	BF	BC	BH	G	HH	WW	93	BF	BC	BH	G	HH	WW
2	0.0	-0.2	-0.2	0.3	0.0	0.1	0.0	-0.4	-0.7	0.2	0.3	0.0	-0.8	-0.4
3	0.0	-0.2	0.0	0.2	0.0	0.2	0.0	-0.5	-0.5	0.0	0.3	-0.1	-0.3	-0.1
4	4.5	4.4	4.6	4.6	4.5	4.5	4.5	4.1	4.2	4.3	4.8	4.4	4.5	4.6
5	3.5	3.5	3.7	3.5	3.5	3.5	3.5	3.4	3.5	3.2	3.6	3.3	3.7	3.7
6	1.0	1.0	1.2	0.7	1.0	1.0	1.0	1.3	1.2	0.8	1.0	0.7	1.3	1.2
7	0.4	0.5	0.5	-0.2	0.4	0.4	0.4	1.4	0.9	0.3	0.2	0.0	0.7	0.4
8	0.1	0.4	0.1	-0.8	0.1	0.1	0.1	2.0	1.0	0.3	-0.4	-0.5	0.3	-0.1
9	0.0	0.4	-0.2	-1.3	0.0	0.0	0.0	3.0	1.2	0.5	-0.9	-0.8	-0.1	-0.6
10	0.0	0.5	-0.4	-1.8	0.0	0.0	0.0	4.2	1.6	0.9	-1.3	-1.0	-0.4	-1.1
11	0.0	0.7	-0.8	-2.3	0.0	0.0	0.0	5.7	2.1	1.4	-1.7	-1.2	-0.9	-1.8
12	0.0	0.9	-1.1	-2.8	0.0	0.0	0.0	7.4	2.5	2.1	-2.2	-1.4	-1.4	-2.5

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.4 Shear)

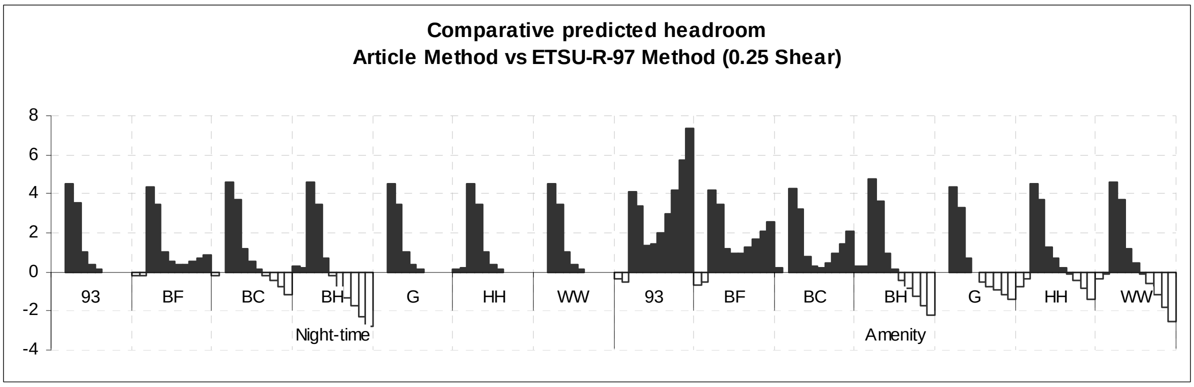
wind speed (m/s)	Night-time							Amenity						
	93	BF	BC	BH	G	HH	WW	93	BF	BC	BH	G	HH	WW
2	0.0	-0.2	-0.2	0.3	0.0	0.1	0.0	-0.4	-0.7	0.2	0.3	0.0	-0.8	-0.4
3	36.5	35.3	33.9	34.6	31.2	33.6	31.9	36.0	35.0	33.9	34.7	31.1	33.1	31.8
4	9.4	9.3	9.5	9.5	9.4	9.4	9.4	9.0	9.1	9.2	9.7	9.3	9.4	9.5
5	4.8	4.8	5.0	4.8	4.8	4.8	4.8	4.7	4.8	4.5	4.9	4.6	5.0	5.0
6	1.4	1.4	1.6	1.1	1.4	1.4	1.4	1.7	1.6	1.2	1.4	1.1	1.7	1.6
7	0.5	0.6	0.6	-0.1	0.5	0.5	0.5	1.5	1.0	0.4	0.3	0.1	0.8	0.5
8	0.1	0.4	0.1	-0.8	0.1	0.1	0.1	2.0	1.0	0.3	-0.4	-0.5	0.3	-0.1
9	0.0	0.4	-0.2	-1.3	0.0	0.0	0.0	3.0	1.2	0.5	-0.9	-0.8	-0.1	-0.6
10	0.0	0.5	-0.4	-1.8	0.0	0.0	0.0	4.2	1.6	0.9	-1.3	-1.0	-0.4	-1.1
11	0.0	0.7	-0.8	-2.3	0.0	0.0	0.0	5.7	2.1	1.4	-1.7	-1.2	-0.9	-1.8
12	0.0	0.9	-1.1	-2.8	0.0	0.0	0.0	7.4	2.5	2.1	-2.2	-1.4	-1.4	-2.5

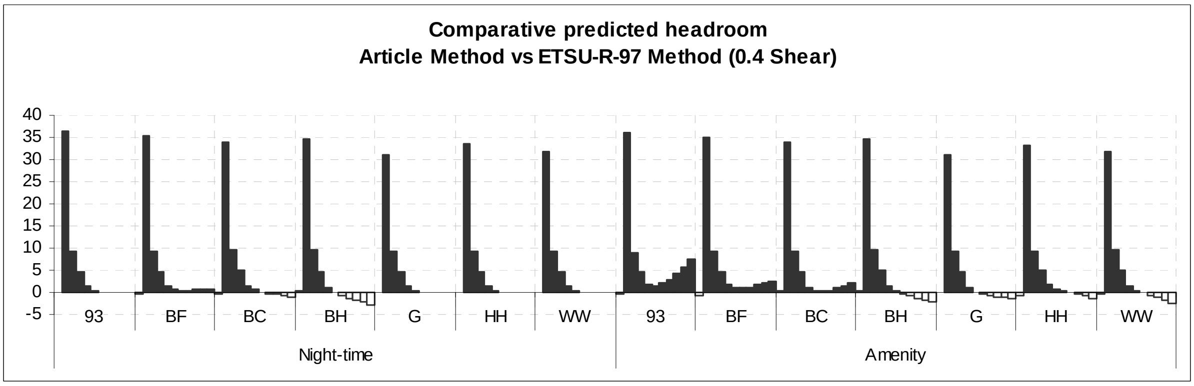
[26] Very high differences of 36.5dB are not expected in practice as the prevailing background noise polynomials as used in the various statements do not represent a true reflection of the background noise environment. However the difference is substantial as identified when only the middle range within the data of 5-7m/s is used.

Positive values in the bar chart indicate a loss of protection when adopting the article method. Negative values in the bar chart indicate a potential benefit to using the article method[27].

The bar charts show that even in this case when noise data was collected during a period of high wind shear, the article method provides substantially less margin to decibel limits than ETSU-R-97 as written for the wind shear conditions.

In the majority of conditions (night, amenity, 0.25 or 0.4 shear exponent) there is no benefit of note at any wind speed when using the article method. Where there is a potential benefit to using the article method this is often a benefit of less than 1dB. In a few isolated cases the benefit increases up to 2dB typically at wind speeds above 11m/s. These high winds are not those where problems are considered to arise. Conversely at the important lower wind speeds there was a consistent loss of margin.





It is to be remembered that the article method does not recognise that high levels of wind farm noise can be emitted at low wind speeds and it

[27] This is only considered a potential benefit as the ETSU-R-97 approach applies a true wind speed to impact assessment which will be lower than the value in the article method. Thus a potential benefit at say 8m/s for the article method could be argued should be compared to a lower wind speed when using 10m measured approach.

substitutes standardised values. The ETSU-R-97 method follows reality where high wind speeds at hub height, leading to higher noise emissions, can occur when the wind speeds at 10m height are below 5m/s.

Cotton Farm Wind Farm

For both wind shear exponents of 0.25 & 0.4 and between the wind speed range of 3-12m/s at this site, there is no gain or improved decibel margin between predicted levels and limits using the article method in 90% of all cases. In 86% of cases there is a loss of protection using the article method. In the 10% of cases where there is a gain to using the article method, the gain ranges between 0.1-1.3dB with an average gain of 0.4dB. Where there is a loss in margin (i.e. a gain in using the ETSU method) this ranges from 0.1-6.8dB with an average loss of 1.8dB.

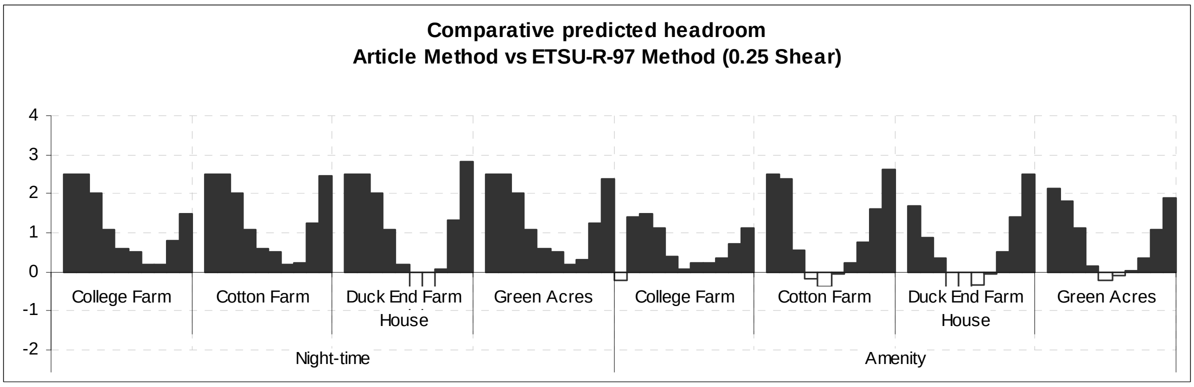
Between the critical wind speeds of 5-7m/s, where the article method was expected to provide best protection, 88% of cases resulted in no gain or improved decibel margin between predicted levels and limits using the article method. In 85% of cases there was a loss of protection using the article method. Where there was a loss of margin (i.e. a gain in using the ETSU method) the advantage provided by using the ETSU method ranged between 0.1-3.6dB and on average provided better protection of 1.4dB. In the few cases where there was a gain in using the article method this ranged between 0.1-1.3dB and on average provided better protection of 0.4dB.

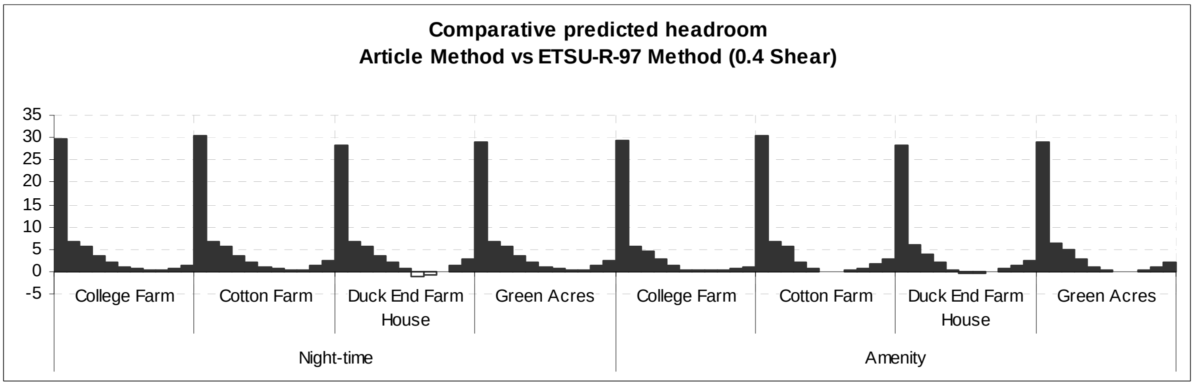
Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.25 Shear)

	Night-time				Amenity			
wind speed (m/s)	College Farm	Cotton Farm	Duck End Farm House	Green Acres	College Farm	Cotton Farm	Duck End Farm House	Green Acres
2	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0
3	2.5	2.5	2.5	2.5	1.4	2.5	1.7	2.1
4	2.5	2.5	2.5	2.5	1.5	2.4	0.9	1.8
5	2.0	2.0	2.0	2.0	1.1	0.5	0.4	1.1
6	1.1	1.1	1.1	1.1	0.4	-0.2	-0.4	0.2
7	0.6	0.6	0.2	0.6	0.1	-0.4	-0.7	-0.2
8	0.5	0.5	-1.3	0.5	0.2	-0.1	-0.3	-0.1
9	0.2	0.2	-0.8	0.2	0.2	0.2	0.0	0.0
10	0.2	0.2	0.0	0.3	0.3	0.8	0.5	0.4
11	0.8	1.2	1.3	1.2	0.7	1.6	1.4	1.1
12	1.5	2.4	2.8	2.4	1.1	2.6	2.5	1.9

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.4 Shear)								
	Night-time				Amenity			
	College Farm	Cotton Farm	Duck End Farm House	Green Acres	College Farm	Cotton Farm	Duck End Farm House	Green Acres
wind speed (m/s) 2	29.6	30.5	28.3	29.1	29.4	30.5	28.3	29.1
3	6.8	6.8	6.8	6.8	5.7	6.8	6.0	6.4
4	5.6	5.6	5.6	5.6	4.6	5.5	4.0	4.9
5	3.6	3.6	3.6	3.6	2.7	2.1	2.0	2.7
6	2.0	2.0	2.0	2.0	1.3	0.7	0.5	1.1
7	1.0	1.0	0.6	1.0	0.5	0.0	-0.3	0.2
8	0.5	0.5	-1.3	0.5	0.2	-0.1	-0.3	-0.1
9	0.2	0.2	-0.8	0.2	0.2	0.2	0.0	0.0
10	0.2	0.2	0.0	0.3	0.3	0.8	0.5	0.4
11	0.8	1.2	1.3	1.2	0.7	1.6	1.4	1.1
12	1.5	2.4	2.8	2.4	1.1	2.6	2.5	1.9

In the majority of conditions (night, amenity, 0.25 or 0.4 shear exponent) there is no benefit of note at any wind speed when using the article method. There are very few cases where a potential benefit to using the article method is found.





Reeves Hill Wind Farm

For both wind shear exponents of 0.25 & 0.4 and between the wind speed range of 3-12m/s at this site, there is no gain or improved decibel margin between predicted levels and limits using the article method in 83% of all cases; considering amenity periods only this increases to 100%. In 77% of cases there is a loss of protection using the article method and again, considering amenity periods 100% of cases show a loss of protection using the article method. The 18% of cases where there is a gain to using the article method are all during night time periods where the gain ranges between 0.1-3.8dB with an average gain of 1.2dB. Where there is a loss in margin (i.e. a gain in using the ETSU method) this ranges from 0.1-12.0dB with an average loss of 4.3dB.

Between the critical wind speeds of 5-7m/s, where the article method was expected to provide best protection, 100% of cases resulted in a loss of protection using the article method. Where there was a loss of protection (i.e. a gain in using the ETSU method) the advantage provided by using the ETSU method ranged between 1.4-5.5dB and on average provided better protection of 2.9dB.

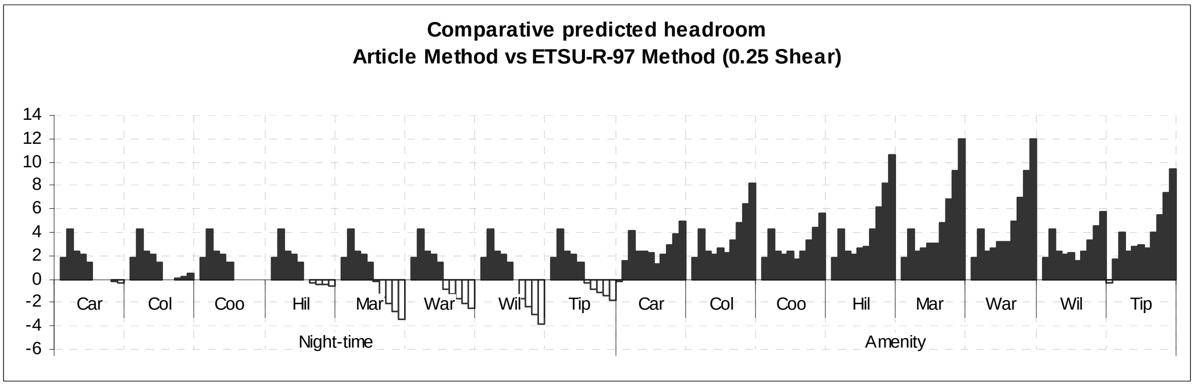
Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.25 Shear)

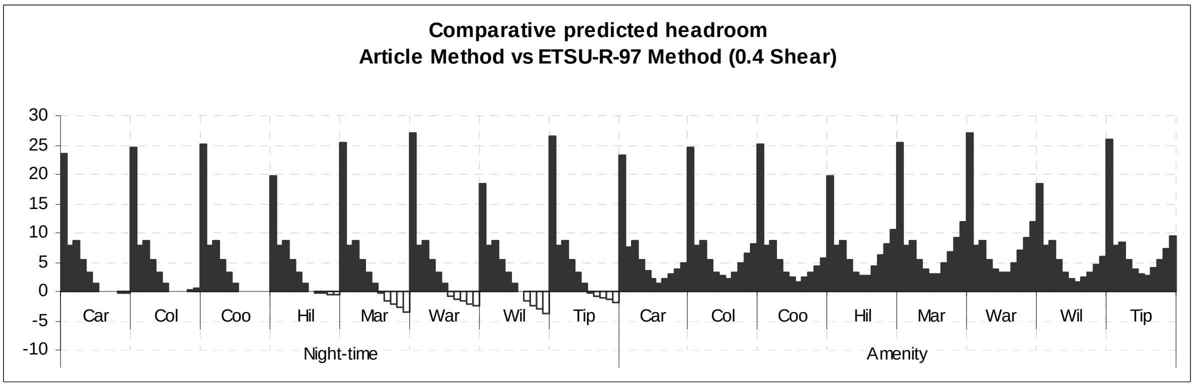
wind speed (m/s)	Night-time								Amenity							
	Car	Col	Coo	Hil	Mar	War	Wil	Tip	Car	Col	Coo	Hil	Mar	War	Wil	Tip
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.3
3	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.6	1.8	1.8	1.8	1.8	1.8	1.8	1.7
4	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.1	4.3	4.3	4.3	4.3	4.3	4.3	4.0
5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
6	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.4	2.1	2.1	2.1	2.7	2.6	2.1	2.7
7	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.2	2.6	2.4	2.7	3.1	3.2	2.3	2.9
8	0.0	0.0	0.0	0.0	-0.2	-0.8	0.0	-0.3	1.4	2.2	1.7	2.7	3.1	3.2	1.6	2.6
9	0.0	0.0	0.0	-0.3	-1.6	-1.3	-1.7	-0.8	2.1	3.4	2.4	4.3	4.8	4.9	2.4	3.9
10	-0.1	0.1	-0.1	-0.4	-2.1	-1.7	-2.3	-1.1	2.9	4.8	3.4	6.1	6.9	6.9	3.4	5.5
11	-0.2	0.3	-0.1	-0.5	-2.7	-2.0	-3.0	-1.4	3.8	6.4	4.4	8.2	9.3	9.3	4.5	7.4
12	-0.3	0.4	0.0	-0.6	-3.4	-2.4	-3.8	-1.8	4.9	8.2	5.6	10.6	12.0	11.9	5.8	9.4

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.4 Shear)

wind speed (m/s)	Night-time								Amenity							
	Car	Col	Coo	Hil	Mar	War	Wil	Tip	Car	Col	Coo	Hil	Mar	War	Wil	Tip
2	23.4	24.7	25.2	19.6	25.5	26.9	18.4	26.4	23.2	24.7	25.2	19.6	25.5	26.9	18.4	26.1
3	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.7	7.9	7.9	7.9	7.9	7.9	7.9	7.8
4	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.5	8.7	8.7	8.7	8.7	8.7	8.7	8.4
5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
6	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.5	3.2	3.2	3.2	3.8	3.7	3.2	3.8
7	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.2	2.6	2.4	2.7	3.1	3.2	2.3	2.9
8	0.0	0.0	0.0	0.0	-0.2	-0.8	0.0	-0.3	1.4	2.2	1.7	2.7	3.1	3.2	1.6	2.6
9	0.0	0.0	0.0	-0.3	-1.6	-1.3	-1.7	-0.8	2.1	3.4	2.4	4.3	4.8	4.9	2.4	3.9
10	-0.1	0.1	-0.1	-0.4	-2.1	-1.7	-2.3	-1.1	2.9	4.8	3.4	6.1	6.9	6.9	3.4	5.5
11	-0.2	0.3	-0.1	-0.5	-2.7	-2.0	-3.0	-1.4	3.8	6.4	4.4	8.2	9.3	9.3	4.5	7.4
12	-0.3	0.4	0.0	-0.6	-3.4	-2.4	-3.8	-1.8	4.9	8.2	5.6	10.6	12.0	11.9	5.8	9.4

In the majority of conditions (night, amenity, 0.25 or 0.4 shear exponent) there is no benefit of note at any wind speed when using the article method. Where there is a potential benefit to using the article method this is only above 1dB typically at wind speeds above 9m/s.





Spaldington Airfield Wind Farm

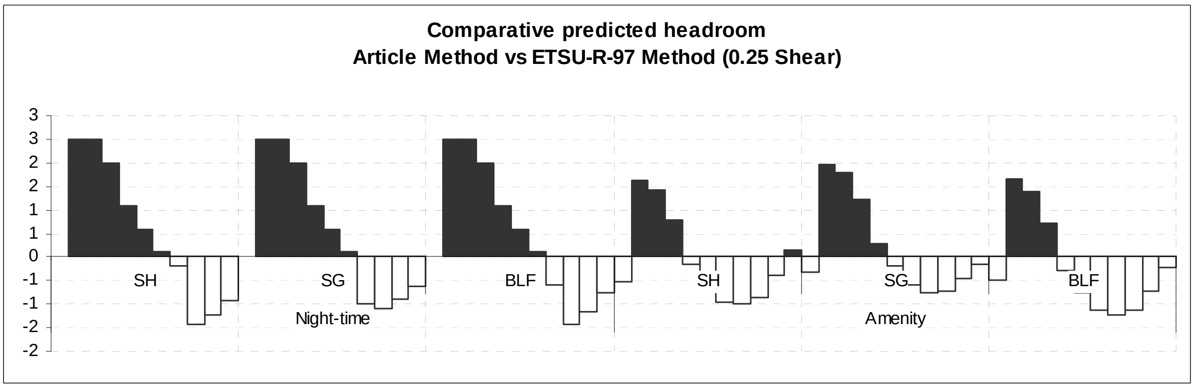
For both wind shear exponents of 0.25 & 0.4 and between the wind speed range of 3-12m/s, there is no gain or improved decibel margin between predicted levels and limits using the article method in 60% of all cases. In 58% of cases there is a loss of protection using the article method. There are 40% of cases where there is a gain in using the article method. The gain ranges between 0.1-1.4dB with an average gain of 0.7dB. Where there is a loss in margin (i.e. a gain in using the ETSU method) this ranges from 0.1-6.8dB with an average loss of 2.2dB.

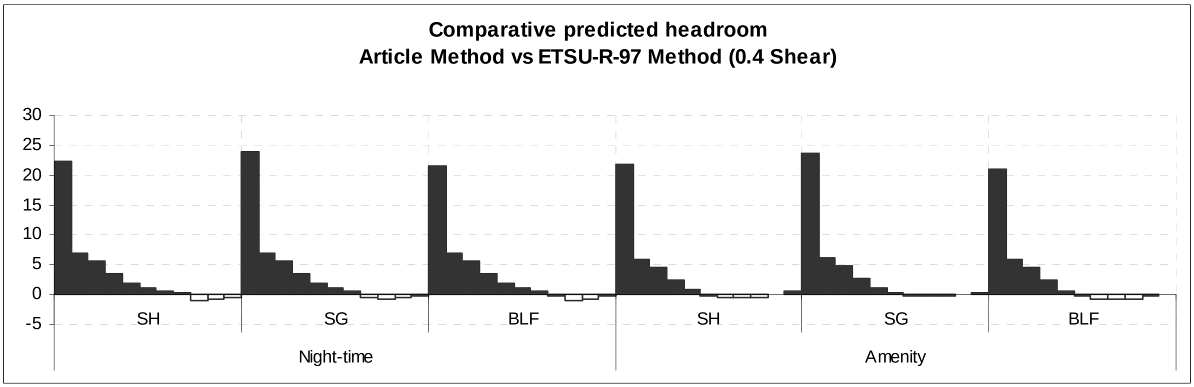
Between the critical wind speeds of 5-7m/s, where the article method was expected to provide best protection, 89% of cases resulted a loss of protection using the article method. Where there was a loss of protection (i.e. a gain in using the ETSU method) the advantage provided by using the ETSU method ranged between 0.2-3.6dB and on average provided better protection of 1.5dB. In 11% of cases there was a gain in using the article method ranging from 0.2-0.8dB and on average providing a gain of 0.4dB.

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.25 Shear)						
	Night-time			Amenity		
wind speed (m/s)	SH	SG	BLF	SH	SG	BLF
2	0.0	0.0	0.0	-0.5	-0.3	-0.5
3	2.5	2.5	2.5	1.6	2.0	1.6
4	2.5	2.5	2.5	1.4	1.8	1.4
5	2.0	2.0	2.0	0.8	1.2	0.7
6	1.1	1.1	1.1	-0.2	0.3	-0.3
7	0.6	0.6	0.6	-0.6	-0.2	-0.8
8	0.1	0.1	0.1	-1.0	-0.6	-1.1
9	-0.2	-1.0	-0.6	-1.0	-0.8	-1.2
10	-1.4	-1.1	-1.4	-0.8	-0.7	-1.1
11	-1.2	-0.9	-1.2	-0.4	-0.5	-0.7
12	-0.9	-0.6	-0.8	0.2	-0.1	-0.2

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.4 Shear)						
	Night-time			Amenity		
wind speed (m/s)	SH	SG	BLF	SH	SG	BLF
2	22.3	24.0	21.4	21.8	23.7	20.9
3	6.8	6.8	6.8	5.9	6.3	5.9
4	5.6	5.6	5.6	4.5	4.9	4.5
5	3.6	3.6	3.6	2.4	2.8	2.3
6	2.0	2.0	2.0	0.7	1.2	0.6
7	1.0	1.0	1.0	-0.2	0.2	-0.4
8	0.5	0.5	0.5	-0.6	-0.2	-0.7
9	0.2	-0.6	-0.2	-0.6	-0.4	-0.8
10	-1.0	-0.7	-1.0	-0.4	-0.3	-0.7
11	-0.8	-0.5	-0.8	0.0	-0.1	-0.3
12	-0.5	-0.2	-0.4	0.6	0.3	0.2

The bar charts show that considering a wind shear of 0.25 there is approximately a 1dB benefit to using the ETSU method. In reality this benefit will be greater in terms of impact as the article method is typically only better at higher wind speeds where turbine impact is less likely to be a problem due to the nature / behaviour of wind shear. During higher wind shear of 0.4 the article method offers little or no benefit and the ETSU method is clearly favourable.





Site A[28]

For both wind shear exponents of 0.25 & 0.4 and between the wind speed range of 3-12m/s, there is no gain or improved decibel margin between predicted levels and limits using the article method in 81% of all cases. In 81% of cases there is a loss of protection using the article method. There are 19% of cases where there is a gain to using the article method. This gain ranges between 0.1-4.3dB with an average gain of 1.4dB. Where there is a loss in margin (i.e. a gain in using the ETSU method) this ranges from 0.1-37.8dB with an average loss of 7.1dB.

Between the critical wind speeds of 5-7m/s, where the article method was expected to provide best protection, 92% of cases resulted a loss of protection using the article method. Where there was a loss of protection (i.e. a gain in using the ETSU method) the advantage provided by using the ETSU method ranged between 0.3-4.1dB and on average provided better protection of 1.7dB. In 8% of cases there was a gain in using the article method ranging from 0.1-1.7dB and on average providing a gain of 0.7dB.

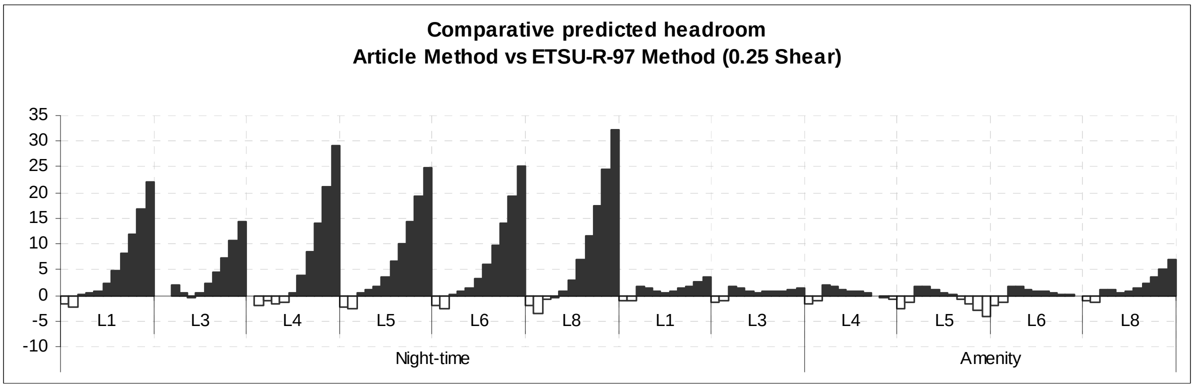
Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.25 Shear)

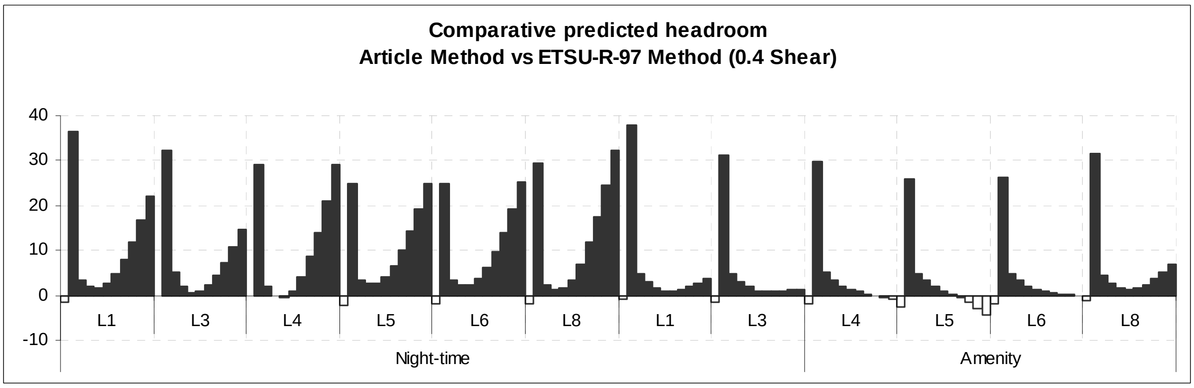
	Night-time						Amenity					
wind speed (m/s)	L1	L3	L4	L5	L6	L8	L1	L3	L4	L5	L6	L8
2	-1.6	0.0	0.0	-2.3	-2.1	-2.1	-1.0	-1.5	-1.8	-2.6	-2.0	-1.1
3	-2.3	0.0	-1.9	-2.5	-2.5	-3.4	-1.0	-1.1	-1.1	-1.5	-1.4	-1.3
4	0.2	2.1	-1.1	0.4	0.2	-0.9	1.6	1.7	1.9	1.8	1.7	1.2
5	0.3	0.5	-1.7	1.0	0.7	-0.4	1.3	1.5	1.8	1.8	1.6	1.0
6	0.8	-0.3	-1.3	1.8	1.4	0.7	0.7	0.9	1.2	1.2	1.1	0.6
7	2.2	0.5	0.6	3.6	3.2	3.0	0.5	0.6	0.7	0.5	0.7	0.7
8	4.8	2.3	4.0	6.6	6.2	6.9	0.9	0.8	0.6	0.1	0.7	1.5
9	8.0	4.5	8.5	10.1	9.8	11.7	1.3	0.8	0.3	-0.7	0.6	2.5
10	11.9	7.2	14.1	14.3	14.1	17.4	1.8	0.9	-0.1	-1.7	0.3	3.6
11	16.7	10.6	21.0	19.3	19.3	24.4	2.7	1.1	-0.4	-2.8	0.1	5.2
12	22.1	14.5	29.0	24.9	25.3	32.3	3.6	1.4	-0.9	-4.3	-0.3	7.0

[28] Identity protected due to sensitivity of data.

Comparative predicted headroom - Article Method vs ETSU-R-97 Method (0.4 Shear)												
	Night-time						Amenity					
	L1	L3	L4	L5	L6	L8	L1	L3	L4	L5	L6	L8
wind speed (m/s) 2	-1.6	0.0	0.0	-2.3	-2.1	-2.1	-1.0	-1.5	-1.8	-2.6	-2.0	-1.1
3	36.5	32.3	29.1	25.0	25.0	29.3	37.8	31.2	29.9	26.0	26.1	31.4
4	3.3	5.2	2.0	3.5	3.3	2.2	4.7	4.8	5.0	4.9	4.8	4.3
5	1.9	2.1	-0.1	2.6	2.3	1.2	2.9	3.1	3.4	3.4	3.2	2.6
6	1.7	0.6	-0.4	2.7	2.3	1.6	1.6	1.8	2.1	2.1	2.0	1.5
7	2.7	1.0	1.1	4.1	3.7	3.5	1.0	1.1	1.2	1.0	1.2	1.2
8	4.9	2.4	4.1	6.7	6.3	7.0	1.0	0.9	0.7	0.2	0.8	1.6
9	8.0	4.5	8.5	10.1	9.8	11.7	1.3	0.8	0.3	-0.7	0.6	2.5
10	11.9	7.2	14.1	14.3	14.1	17.4	1.8	0.9	-0.1	-1.7	0.3	3.6
11	16.7	10.6	21.0	19.3	19.3	24.4	2.7	1.1	-0.4	-2.8	0.1	5.2
12	22.1	14.5	29.0	24.9	25.3	32.3	3.6	1.4	-0.9	-4.3	-0.3	7.0

The bar charts reflect the high proportion of cases where there is a loss of protection using the article method. Although the ETSU method tends to offer greater protection at the higher wind speeds where adverse impact is less likely to occur, it still offers a consistently better approach of good margin at mid and lower wind speeds.





Part IV

General results

All wind speeds 3-12m/s

The tables below give the percentage of cases for all wind speeds between 3-12m/s during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site when and on average, where there is:

- no gain from adopting the article method
- a gain from adopting the article method,
- no difference between the two methods and
- a loss of protection from using the article method (i.e. a gain in adopting the ETSU approach).

% cases where no gain from adopting article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	84	66	86	73	High wind shear during measurements
Cotton Farm	95	80	95	90	
Reeves Hill	65	100	65	100	Measurements during different periods
Spald. Air	63	57	63	57	High wind shear during measurements -
Site A	82	77	93	73	
Average	**78**	**76**	**80**	**79**	

Table 3 – The table above details the percentage of cases during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is no gain from adopting the article method.

The results provide a very strong case for supporting that there is no gain in using the article method. On average the percentage of cases where there is no gain is high. Spaldington Airfield gives the lowest values but still provides an overall average well above 50%, confirming there is no gain from using the article method. On average there is little difference between amenity and night time periods and wind shear exponents; the results therefore indicate that there is consistently no gain from using the article method.

% cases where there is a gain in adopting the article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	16	34	14	27	
Cotton Farm	5	20	5	10	
Reeves Hill	35	0	35	0	
Spald. Air	37	43	37	43	
Site A	18	23	7	27	
Average	**22**	**24**	**20**	**21**	

Table 4 – The table above details the percentage of cases during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is a gain from adopting the article method.

This table analyses the percentage of cases where there is a positive gain (as opposed to no gain) in adopting the article method. On average in all conditions the percentage of cases where there is any gain is small. All percentages are below 50% and the overall average for each condition (night time, amenity, α=0.25 and α=0.4) is below 25%.

% cases where no difference between methods					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	29	3	23	0	
Cotton Farm	3	5	3	8	
Reeves Hill	11	0	11	0	
Spald. Air	0	3	0	3	
Site A	2	0	0	0	
Average	**9**	**2**	**7**	**2**	

Table 5 – The table above details the percentage of cases during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is no difference between the two methods.

With the exception of Biggleswade the percentage of cases where no difference between the two methods is observed is very low. Including Biggleswade the highest percentage of cases suggesting no difference between the methods is only 29%. The most cases during which there is no difference between the methods are found during night time hours with as little as 2% of cases during amenity hours.

% of cases where a loss of protection adopting article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	56	63	63	73	
Cotton Farm	93	75	93	83	
Reeves Hill	54	100	54	100	
Spald. Air	63	53	63	53	
Site A	80	77	93	73	
Average	**69**	**74**	**73**	**76**	Loss is substantially above half and approximates to ¾

Table 6 – The table above details the percentage of cases during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is a loss of protection from using the article method (i.e. a gain in adopting the ETSU approach).

This table represents cases where community protection is reduced through adopting the article method. The average loss approximates to ¾ of the cases analysed. This excludes cases where there is no difference between the methods and hence there is a definite and measurable disadvantage to adopting the article method. There is no obvious distinction between loss of protection for amenity periods, night time periods, wind shears of α=0.25 or α=0.4 and hence the loss of protection is consistent across conditions.

Critical wind speeds - 5-7m/s

The tables below give the percentage of cases for all wind speeds between 5-7m/s during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site when and on average, where there is no gain from adopting the article method, where there is a gain from adopting the article method, where there is no difference between the two methods and where there is a loss of protection from using the article method (i.e. a gain in adopting the ETSU approach). This critical wind speed range is where the article method was considered by some of the authors likely to provide most benefit.

Critical range 5-7m/s - % cases where no gain from adopting article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	95	100	95	100	High wind shear during measurements
Cotton Farm	100	58	100	92	
Reeves Hill	100	100	100	100	Measurements during different periods
Spald. Air	100	78	100	78	High wind shear during measurements -
Site A	78	100	89	100	
Average	**95**	**87**	**97**	**94**	

Table 7 – The table above details the percentage of cases between 5-7m/s during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is no gain from adopting the article method.

With the exception of Cotton Farm during amenity hours and a wind shear of α=0.25, there are a very high percentage of cases where there is no gain from adopting the article method. On average across all wind shear exponents and day / night time there is an extremely high percentage of cases supporting that there is no benefit to adopting the article method.

Critical range 5-7m/s - % cases where there is a gain in adopting the article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	5	0	5	0	
Cotton Farm	0	42	0	8	Improved benefit in 0.25 amenity band but lost at 0.4 wind shear exponent
Reeves Hill	0	0	0	0	
Spald. Air	0	22	0	22	Benefit in 0.25 amenity but substantial loss overall
Site A	22	0	11	0	
Average	**5**	**13**	**3**	**6**	

Table 8 – The table above details the percentage of cases between wind speeds of 5-7m/s during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is a gain from adopting the article method.

With the exception of Cotton farm amenity hours and wind shear of α=0.25, there is very little support in the above data to suggest that the article method provides any advantage. Out of the above twenty conditions only four indicated a gain in adopting the article method at or above 22% of cases. For the majority of conditions and sites there was 11% or less of cases supporting use of the article method.

Critical range 5-7m/s - % cases where no difference between methods					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	0	5	0	0	
Cotton Farm	0	0	0	8	
Reeves Hill	0	0	0	0	
Spald. Air	0	0	0	0	
Site A	0	0	0	0	
Average	**0**	**1**	**0**	**2**	

Table 9 – The table above details the percentage of cases between wind speeds of 5-7m/s during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is no difference between the two methods.

In all cases / conditions there was a very small percentage of cases, and in the majority no cases, where there was no difference between the two methods.

Critical range 5-7m/s - % of cases where a loss of protection adopting article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	95	95	95	100	
Cotton Farm	100	58	100	83	
Reeves Hill	100	100	100	100	
Spald. Air	100	78	100	78	
Site A	78	100	89	100	
Average	**95**	**86**	**97**	**92**	Substantial loss of protection at critical wind speed range.

Table 10 – The table above details the percentage of cases during night time and amenity periods for wind shears of α=0.25 and α=0.4, at each site and on average, where there is a loss of protection from using the article method (i.e. a gain in adopting the ETSU approach).

This table (10) and table 8 are perhaps the most important outcome of the study. There is an overwhelming loss of protection for communities at these critical middle wind speeds when adopting the article method but was the range where some potential gain was considered possible.

Maximum decibel loss / gain

The tables below look at the maximum loss or gain in decibels by adopting the article method between all wind speeds (3-12m/s) and the critical wind speed range (5-7m/s).

Maximum decibel loss in protection across all wind speeds adopting the article method (i.e. gain to using ETSU method)					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	4.6	7.4	4.6	36.0	
Cotton Farm	2.8	2.6	6.8	6.8	
Reeves Hill	4.3	12.0	8.7	12.0	
Spald. Air	2.5	2	6.8	6.3	
Site A	32.3	7.0	36.5	37.8	

Table 11 – Maximum loss in decibel protection 3-12m/s. The table above shows the maximum loss in decibel protection when adopting the article method at each site during night time and amenity periods and for wind shears of $\alpha=0.25$ and $\alpha=0.4$.

The loss of protection is generally above 6dB when adopting the article approach; this is a substantial loss of protection.

Maximum decibel gain in protection across all wind speeds adopting the article method					
Wind Farm	Wind shear exponent 0.25		Wind shear exponent 0.4		Comments
	Night	Amenity	Night	Amenity	
Biggleswade	2.8	2.5	2.8	2.5	
Cotton Farm	1.3	0.7	1.3	0.3	
Reeves Hill	3.8	n/a	3.8	n/a	
Spald. Air	1.4	1.2	1	0.8	
Site A	3.4	4.3	0.4	4.3	

Table 12 – Maximum gain in decibel protection 3-12m/s. The table above shows the maximum gain in decibel protection when adopting the article method at each site during night time and amenity periods and for wind shears of $\alpha=0.25$ and $\alpha=0.4$.

At best the article method provides a gain of 4.3dB. The majority of decibel gains are less than 3dB.

Maximum decibel loss of protection between 5-7m/s adopting the article method (i.e. gain to using ETSU method)					
Wind Farm	Wind shear exponent 0.25		Wind shear exponent 0.4		Comments
	Night	Amenity	Night	Amenity	
Biggleswade	3.7	3.7	5.0	5.0	
Cotton Farm	2.0	1.1	3.6	2.7	
Reeves Hill	2.4	3.2	5.5	5.5	
Spald. Air	2.0	1.2	3.6	2.8	
Site A	3.6	1.8	4.1	3.4	

Table 13 – Maximum loss of decibel protection 5-7m/s. The table above shows the maximum loss in decibel protection when adopting the article method at each site during night time and amenity periods and for wind shears of $\alpha=0.25$ and $\alpha=0.4$. This range of wind speeds is where the article method was expected to perform best.

In most cases / conditions the loss of protection is greater than 2.7dB.

Maximum decibel gain of protection between 5-7m/s using the article method					
Wind Farm	**Wind shear exponent 0.25**		**Wind shear exponent 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	0.2	n/a	0.1	n/a	
Cotton Farm	n/a	0.7	n/a	0.3	
Reeves Hill	n/a	n/a	n/a	n/a	
Spald. Air	n/a	0.8	n/a	0.4	
Site A	1.7	n/a	0.4	n/a	

Table 14 – Maximum gain in decibel protection 5-7m/s. The table above shows the maximum gain in decibel protection when adopting the article method at each site during night time and amenity periods and for wind shears of α=0.25 and α=0.4. This range of wind speeds is where the article method was expected to perform best.

The decibel benefits are generally a fraction of a decibel with only one case above 1dB. In many conditions there is no gain to adopting the article method. Compare to the loss of protection identified in Table 11 with a loss between 1.1-5.5dB.

Summary of results

	All wind speeds (3-12m/s)		Critical wind speeds (5-7m/s)	
	α=0.25	α=0.4	α=0.25	α=0.4
% no gain from adopting article method	77	80	91	96
% gain from adopting article method	23	21	9	5
% no difference between methods	6	5	1	1
% loss of protection adopting article method	72	75	91	95

Table 15 - Overall results. The above analysis indicates that across the data there are very few cases where there is a benefit to adopting the article method; this is especially the case at the critical wind speeds of 5-7m/s.

Wind shear analysis

Percentage wind shear exponent occurring as a proportion of total time					
Wind Farm	**Wind shear exponent exceeding 0.25**		**Wind shear exponent exceeding 0.4**		**Comments**
	Night	Amenity	Night	Amenity	
Biggleswade	62	45	24	16	Very high wind shear
Cotton Farm	45	27	11	8	
Reeves Hill	45	30	13	8	
Spald. Air	76	58	40	27	Very high wind shear
Site A	78	40	54	21	Very high wind shear

Table 16 – Wind shear exponent exceedances. This table demonstrates that the values of 0.25 and 0.4 wind shear exponent used for comparison purposes arise for statistically important periods for all sites and show the expected relationship where wind shear values are higher at night than during daytime amenity periods.

General findings

Two general patterns emerge from the data. There is a substantially higher proportion of cases where there is a loss of protection as a result of using the article method compared to cases where there is a gain. There is also significantly greater loss in the decibel level of protection for communities, which in turn provides substantially more headroom for wind farm developments, when adopting the article method. In the small number of cases of gain using the article method the decibel gain is typically only a fraction of a decibel. This equates to substantial losses in terms of the overall decibel level of protection.

Contrary to expectations, data only occasionally followed assumed theoretical changes[29] and the outcome is generally unpredictable in situations when the article method is adopted, except in the conclusion that more noise will generally be allowed.

There is a small minority of cases where a slight gain in adopting the article method is suggested. However, even these do not equate to a benefit as it is coupled with the future adoption of compliance checks under "standardised" conditions and not those which relate to the higher wind shear that actually occurs and are likely to be identified as the conditions causing complaints.

The impact of adopting the article method is worst at the wind speed range 5-7m/s, where there was expected to be greatest benefit.

Overall use of the article method represents a substantial loss in the protection of communities compared to that as originally intended by ETSU-R-97. It changes many cases from apparent non-compliance to one of compliance. This outcome provides a major incentive for developers to adopt the method and its acceptance is a loss of protection for communities.

There is the additional problem revealed when adopting the article method of no longer being able to relate compliance checks to the specific conditions giving rise to complaints. This is a further incentive for developers to adopt this method. It removes the basic protection mechanism set out in ETSU-R-97 at pages 102 – 103 and replaces it with a "standardised", artificial mechanism that is incapable of replicating limits for the meteorological conditions likely to be responsible for any complaints.

[29] For example, the changes in shape to the prevailing background noise curve.

The acceptance of this procedure may be responsible for communities experiencing excess noise in the future that they would have previously been protected against and results in a two-tier system of control with different results depending which is adopted. This does not appear to provide fairness in administration of planning policy and it means communities reliant on controls based on the article method are afforded significantly less protection than those considered prior to the method's use or in those cases where it has not been applied.

Summary findings and implications from comparing the two wind shear methods

There is considerable strength and consistency in the data results which demonstrates the article method allows substantially more noise impact upon communities than applying ETSU-R-97 as written. As it suggests that there is greater margin between turbine noise levels and limits it allows wind farms to be built closer to communities than the ETSU-R-97 rationale intended. This was the consistent finding for all the sites where the article method was applied. The situation reversed for some limited wind speeds in some locations but rarely. Where it did it restricted noise only marginally more than the ETSU method. Conversely the ETSU method restricted decibel limits substantially more at the majority of wind speeds and locations.

The apparent slight benefit in a small percentage of circumstances for some wind speeds which is not accounted for in practice. This occurs as there is a shift where the ETSU method identifies greatest turbine noise versus lowest background at lower wind speeds than the article method. This means limits at lower wind speeds become more important when using ETSU-R-97 as written than compared to the article method. The two methods produce their worst case predicted noise impact at slightly different wind speeds. This arises as wind shear causes a shift in the background noise data when using the article method and thus the point of probable greatest noise impact versus background noise is different for both.

In practice therefore the data demonstrates that there is rarely or almost never any benefit in terms of community protection when adopting the article method but conversely considerable harm is predicted over most wind speeds.

The wind speed range of 5-7m/s has been considered a critical range where exceedance is most likely and hence where greatest control is required. It has been argued in some cases this is the range where the article method assists the most with a possible overall benefit. Crucially at these important wind speeds, in all the cases examined it did not benefit. Almost universally it allowed more noise at these wind speeds than ETSU-R-97 intended. Decibel losses in protection are also consistently higher than any decibel gain afforded by adopting the article method.

Further, when the article method is applied the balance between where the predicted turbine noise lies in comparison to the prevailing background noise and turbine noise limits is shifted to a point where it becomes difficult to exceed the limits even when turbine noise is more than 5dB above the background. This is because the meteorological conditions where exceedance is likely are replaced with “standardised” wind speed conditions which then assume a "standardised" and unrealistic wind shear for the times when problems are experienced and higher decibel limits apply.

On the face of the data the article method appears to have failed its intent and leaves the public exposed to greater risk of adverse noise impact whilst at the same time removing the main control mechanism set out in ETSU-R-97 that was used to prevent excess noise under the specific characterised wind speed conditions when the excess noise was commonly identified.

The consequence of adopting the article method is that it prevents the increased turbine noise occurring under high wind shear conditions, first identified by Prof. Frits van den Berg, being controlled. It becomes impossible to control, as you are required by the article method to assume a standardised wind shear exponent of 0.16 regardless of the true wind shear. The assumed gain by a shift of limits is not found to occur.

PART V

Conclusions

Adoption of the article method increases the permitted impact from noise upon communities that was not intended by ETSU-R-97.

The increase in noise impact was significant in all cases analysed.

When the article method is compared to ETSU-R-97 as written it consistently permits increased noise and as a result allows turbines to be located closer to dwellings in al situations assessed.

There is a loss of protection both at mid and low 10m wind speeds using the article method which represent the most important amenity periods.

The article method does not replicate or reasonably reflect the changes in decibel limits that were assumed to arise by its authors.

Adoption of "standardised" wind speeds prevent assessment of compliance as intended in ETSU-R-97 at pages 102-103.

Any individual combination of wind speed and location where the article method shifts the limit downwards slightly is outweighed by much larger upward shifts in permitted noise for the majority of circumstances.

Recommendations

ETSU-R-97 should be followed as written and wind shear effects equated into the predicted turbine noise levels.

Use of wind shear exponents of 0.25 and 0.4 are likely to provide a reasonable analysis of typical effects of wind shear at a site but where possible an analysis of the long term wind shear range should be undertaken to help inform on the likely impact at a site.

At approved sites where 10m measured and determined hub height wind speed data is available and the article method has been used for impact assessment analysis of the loss of protection arising from use of the article method, as undertaken in this paper, should be quantified.

All historical cases where the article method has been applied and as a consequence results in a loss of protection of the community in effect means that the only recourse to protection is through the application of nuisance provisions (where applicable) or through the voluntary restriction of turbines by the operators.

In all cases where it is proposed to record anemometry both 10m measured and higher position wind speeds which permit the calculation of approximate hub height values should be obtained to allow comparison.

POST SCRIPT

Why different levels of protection result

There are many facets to this question. The difference between levels of protection is not uniform and could not be determined by a formula as there are many external variables which influence or moderate the outcome of turbine noise impact to different degrees in each case.
These external influencing factors include:

Factors affecting the background noise that are unrelated to wind speed such as road traffic noise, other human activities and bird song.

The use of an averaging procedure when measuring background noise so that for a specific wind speed, a range of wind shears are included regardless of their effect on turbine noise impact.

How representative the measured wind shear exponents during the background noise survey compared to the long term wind shear at the site are. Also the typical or average wind shear arising at a specific wind speed will differ to the typical or average wind shear experienced at other winds speeds during the background noise survey. Further, a background noise survey conducted during a period of proportionally higher wind shear, relative to the typical wind shear for a site, will result in a limit slightly nearer the limits derived using ETSU.

The difference between the predicted turbine noise level compared to the cut-off (threshold) value applied i.e. 35-40dB LA90 during the day and 43dB LA90 at night, for low wind speeds. When the predicted turbine noise level exceeds the threshold values i.e. is higher than 35dB during the day then the method chosen has a greater effect at low 10m wind speeds. This is the typical case where the article method would permit development but if measured in accordance with ETSU-R-97 it would give rise to an exceedance.

What is evident is that the effects of external influencing factors are greatest at lower wind speeds. These factors moderate the influence of wind shear with most impact when incorporated into an adjustment of the prevailing background noise levels and resulting derived limits rather than when incorporated into the wind turbine noise level.

The hidden loss of protection

The change in protection does not only manifest itself as a visible shift in favour of development; there is a second change which potentially has a far greater effect in removing protection from communities that was not identified by the authors of the article method.

The change from actual measured 10m wind speeds to 10m "standardised" wind speeds removes the main cornerstone protection built into ETSU-R-97 and generally applied in planning conditions on noise. This relates to what constitutes a breach. As with noise controls in general, ETSU-R-97 seeks to prevent excessive noise under any conditions where they might arise, deeming the existence of noise above a certain level as unacceptable unless occurring in a de-minimus way, for example for negligible periods.

It describes the procedure for assessing this at pages 102-103 in ETSU-R-97.[30] In summary the affected resident identifies the conditions under which they complain of excessive noise and testing is designed to match these to replicate and measure the noise they complain of.

In all probability the likely conditions leading to a complaint will arise when background noise levels are lowest and turbine noise levels are highest. This in turn is most likely to occur when there is high wind shear during the late evening following a sunny day.[31] Provided there is reasonable wind speed at hub height the turbines will emit significant noise but the background noise levels will drop as there are little wind induced noise effects near the ground.

In these conditions if ETSU-R-97 was applied as written in most cases the 35-40dB LA90 threshold limit will apply and the background noise level may be well below 30dB LA90. Assuming a threshold limit of 35dB LA90, any exceedance of 35dB LA90 by the turbine noise would be a breach. In these conditions, using the article method a "standardised" wind speed is applied and the true conditions at 10m height are ignored (See figure 4 above). For example, with an 80m hub height wind speed of 8.4m/s the standardised 10m wind speed is automatically assumed to be 6m/s even

[30] The working party decided to set out their main recommendations in a draft Section 106 planning agreement and thus their proposed controls and procedures are found by referring to this part of the document.

[31] This arises as lack of cloud cover means high heat gain at the Earth's surface followed by rapid heat loss (radiative cooling) as the sun starts to set. The air temperature drops slower than the Earth's temperature leading to a loss of thermal rise as the temperature at ground level becomes lower than that of the air above. There is then a de-coupling between the greater winds at height and the atmosphere near the ground. The 10m wind speeds drops but wind speeds continue at hub height. The lack of wind at 10m height leads to a reduction in background noise but wind turbine noise remains high.

though in a high wind shear case it will be substantially less. An actual 6m/s wind speed at 10m height is likely to cause significant contribution to the background noise due to trees rustling etc. This influences the background noise limit more than the periods of high wind shear effects when there is not the same amount of wind generated background noise. The consequence of using a "standardised" wind speed is that a much higher background noise limit which relates to hub height wind speed is used compared to the background noise level experienced and the actual conditions leading to complaint.

In summary, an artificial limit is always applied when using the article method that does not reflect the actual conditions causing complaint. It is no longer possible to assess compliance under the actual conditions that caused complaint using the article method as “standardised” conditions are substituted. Put another way, the permitted turbine noise limit relates not to the actual conditions under which noise may be perceived but to how much turbine noise is generated with the limit increasing as the turbine noise level increases as opposed to the turbine limit increasing with increasing background noise as originally intended by ETSU-R-97.[32]

[32] This concept is identified both in ETSU-R-97, PPS22 and its Companion Guide.