centre for sustainable energy

Common concerns about wind power (2nd edn)

Chapter 14
Wind turbines and noise

This is one of a series of chapters of evidence-based analysis drawing on peer-reviewed academic research and publicly funded studies.

For other chapters, see
www.cse.org.uk/concerns-wind-power-2017

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Common concerns about wind power (2nd edn)

Chapter 14
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The first edition of Common Concerns about Wind Power was published in 2011 to provide factual information about wind energy, in part to counter the many myths and misconceptions surrounding this technology.

Since 2011, much has changed in the legal and economic sphere, and a second edition became necessary. Research has been carried out for this edition since 2014. Therefore, this edition is formatted as a series of individual chapters available for download at www.cse.org.uk/concerns-wind-power-2017

All chapters written and researched by Iain Cox.

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Chapter 14
Wind turbines and noise

Summary

Wind turbines rely on mechanical operations to generate electricity. The movement of the blades through the air inevitably creates noise, and the increasing size of medium-to-large turbines (typically 2.3–3.6 MW rating, standing 65–105m tall) has prompted concern that they will generate an unacceptable level of noise for nearby residents.
In the UK, this phenomenon has been studied by a government working group, and detailed guidelines form part of UK planning regulations to prevent undue noise pollution. These, coupled with the quieter design of modern turbines, mean that the noise levels generated by wind farms are comparable to outdoor background noise. Studies have found topography and changing wind patterns at night can accentuate this noise in specific locations, but understanding this process means it can be correctly assessed during planning to ensure that properties that might be prone to these effects are not affected.

People may hear the same noise, but experience quite different impressions of it. Excepting those instances where nuisance noise can clearly and objectively be demonstrated, controversies over wind turbine noise reveal the shortcomings of the planning process. Evidence suggests that some residents negatively perceive wind turbine noise and suffer annoyance due to the technocratic and opaque way in which many wind farms are developed in Britain, and are rightly aggrieved when their concerns are dismissed by developers who are then accused of hiding behind what some observers increasingly see as inadequate, arbitrary and out-of-date guidelines. This brings the legitimacy of wind power into question, shaping perceptions of future developments and increasing the likelihood that more residents will consider that they have suffered loss of amenity. Lessons from Europe, in particular Germany, suggest that early participation, and local ownership, or favouring social enterprises, are far more successful ways to implement wind power. Experience has shown that residents' negative perceptions of noise are reduced when communities are actively engaged in the planning process and enjoy some direct financial benefit from wind farms, rather than ignoring concerns, presenting last-minute 'consultations' and doggedly adhering to prescriptive and inflexible noise limits as a defence when challenged.

What is this based on?

Any large device that has moving parts will create some noise, and wind turbines of any size are no exception. The sounds generated by wind turbines are either mechanical or aerodynamic. Modern turbine designs have resulted in progressively quieter mechanical operation, to the extent that mechanical noise will not exceed aerodynamic noise under normal operation.[1] The aerodynamic sounds are caused by the turbine blades moving through the air as the wind is blowing, and are usually classed as tonal, low-frequency, broadband and impulsive.

These sounds are the result of changes in wind speed experienced by the blades at different heights as they go through a complete revolution, the blades interacting with atmospheric turbulence, and the deflection of air due to the blade aerofoil itself (the aerofoil, or airfoil, is the cross-section of the blade, which determines how air passes around the blade and aerodynamic force is generated).[1,2]

Table 14.1, below, demonstrates the levels of noise commonly associated with utility-scale turbines (1.0–3.6 MW), with typical noise output ranging between 97 and 107 dB(A).[3]

Table 14.1. Sound power level for Vestas V90-3.0MW (80m Hub)

U_Sm/s	4	5	6	7	8	9
Lw dB(A)	97.9	100.9	104.2	106.1	107.0	106.9

U_Sm/s is the wind speed in m/sec at a standardised anemometer height of 10m. Lw is sound power level re 10^{-12} watts

It is apparent from this that wind turbines cannot be sited too close to residential dwellings. The World Health Organization (WHO) has stated that excessive 'community noise', defined as noise from traffic, industries, construction works, and the urban environment, can create a host of adverse effects on human health.[4] Noise levels encountered in everyday situations are given in Table 14.2. Note that noise levels are measured using an 'A-weighting' that emphasises those frequencies to which the human ear is most sensitive, hence sound pressure levels are given in dB(A) (decibels with A-weighting). The A-weighting helps ensure measured sound levels are close to the perceived sound levels of the human subject. The dynamic range of human hearing is discussed in more depth in the section on low-frequency sounds (section 15).

As the wind energy sector began to expand in the early 1990s, UK planning authorities recognised that guidelines were needed that adequately cover the use of increasingly large, utility-scale wind turbines. In 1996, the Energy Technology Support Unit (ETSU) set up a Noise Working Group to carry out research on behalf of the government so that the lower limits for noise emissions from wind farms could be defined. The recommendations were published as ETSU-R-97 and then incorporated into national planning guidelines the following year.[5,6]

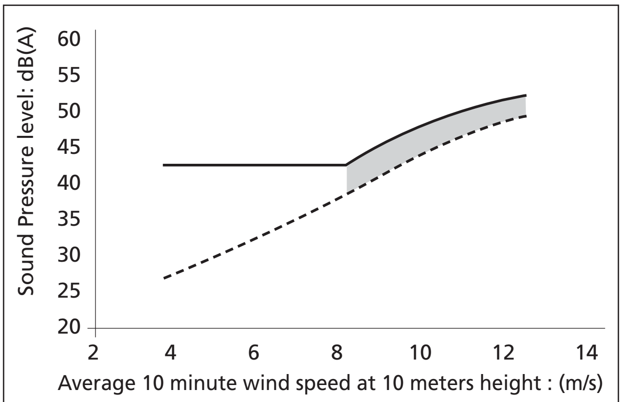
These guidelines provide a general rule that day and night noise levels should be a maximum of 5 dB(A) above ambient background noise. For example, if background noise levels are 50 dB(A), then the permitted noise level due to a wind farm is 55 dB(A). However, there is also a fixed *lower* threshold for background ambient noise, below which developers do not have to adhere to the +5dB(A) rule. These thresholds are 35–40 dB(A) for daytime noise levels and and 43 dB(A) nighttime noise levels.[5] What this means is that, should a particular location have a nighttime background noise measurement of 25dB(A), the noise from the wind farm is not limited at 30dB(A) (which is 25 +5 dB(A)), but would actually be acceptable under ETSU-R-97 as high as 43dB(A) (the fixed lower threshold for night-time noise) (see Figure 14.1).

The ETSU-R-97 report is still in use today. Despite this longevity, ETSU-R-97 has been the subject of criticism for some time.[7] To begin with, the authors of the report themselves aired the view that the report should be revised after two years. Twenty years on, no revision has been forthcoming. Given how much the average wind turbine has increased in size since the 1990s, this is quite surprising. It is especially puzzling in light of the fact that wind turbine noise continues to be reported as an annoyance factor for a significant minority of residents living near wind farms.[8–10]

Table 14.2 Indicative noise levels for situations commonly experienced in normal life.

Source	Noise level in dB(A)
Jet aircraft at 150m	105
Pneumatic drill at 150m	95
Truck at 30mph at 100m	65
Busy general office	60
Car at 40mph at 100m	55
Wind farm at 350m	**35-45**
Rural night-time background	20-40
Quiet bedroom	20
(Threshold of pain = 140 dB(A))	

Figure 14.1 Graphical representation of ETSU recommended noise limits for night time.



The way in which wind turbine noise is compared against background noise levels has also been criticised.[7] The ETSU-R-97 report took much of its inspiration from the widely used British Standards, BS4142 ('Method for rating industrial noise…').*[11] This set of standards stipulated that measurements of background noise be representative of the period, and include the quietest part of said period. However, on this point ETSU-R-97 departed from BS4142 by recommending sound pressure level measurements that do not include the quietest period and are averaged across the entire period (see p.60 of ref. 5, 'the LA90 descriptor is also being proposed for the turbine noise').[5] The upshot of this decision is that, when compared with good practice laid out in BS4142, actual wind turbine noise may effectively be 7 dB(A) above background levels, rather than 5 dB(A), but still fall within the permitted limits proposed by ETSU-R-97.

Perhaps most contentious of all is that ETSU-R-97 permits higher noise levels at night than during the day – the only guidelines on noise to do so anywhere in the world.[7,12] At certain sites, wind turbine emissions were found to be unexpectedly loud at night time, and it is now known that meteorological conditions that occur more commonly at night contribute to the apparent loudness.[2,13] Thus, noise emissions from wind turbines can be problematic even when planning guidelines are

* In 1996, this standard was BS4142:1990, which was superseded in 1997 by BS4142:1997 'Method for rating industrial noise affecting mixed residential and industrial areas'. The current standard is BS4142:2014.

adhered to. A recent good practice guide, published by the Institute of Acoustics, on how to apply ETSU-R-97 to wind farm proposals incorporates the effect of meteorological conditions on sound propagation.[14] The central tenets of the ETSU report, however, remain unchanged.

Although ETSU-R-97 guidance has some shortcomings, it is important to note that the evidence of a direct link between wind turbine noise, annoyance and sleep disturbance continues to be conflicting.[9] One crucial aspect, and one that ETSU makes no allowance for, is the non-acoustic element of noise disturbance, that is, the meaning that humans attach to perceived sounds.[7] Despite evidence that particular acoustic characteristics of turbines are more intrusive than previously thought, especially the phenomenom of 'amplitude modulation',[15,16] studies also show that the context plays a major role in self-reported disturbance and even in objectively measured sleep patterns.[17–20] Negative attitudes towards wind turbines can be a strong predictor of annoyance, independent of the actual sound levels experienced by residents due to wind turbine noise. Awareness of the source of the noise, and also the benefit that an individual receives personally from a wind farm, can have a significant effect.[8,17,20–23]

What is considered noise can be highly subjective and may largely depend on the attitudes of the person receiving the sound. National planners and wind energy developers have been reluctant to concede that non-acoustic factors can add layers of meaning to a sound, which may be why noise from the same wind farm can seemingly be both 'undetectable' and 'unbearable' to different residents.[7] Unfortunately, this has also nurtured the belief that wind turbine noise is somehow uniquely damaging, giving rise to various health scares that have little basis in fact. [24,25] Pernicious myths like 'wind turbine syndrome' (see chapter 15) do a disservice to those individuals experiencing ordinary, but intrusive, noise from wind turbines.

What is the current evidence?

Aerodynamic noise

Thanks to improvements in gearbox design and machining, the use of anti-vibration mountings and couplings to limit structure-borne noise, and other features such as acoustic damping of the nacelle and liquid cooling of the generator, mechanical noise generated by modern wind turbines is minimal.[2,26] Although the original turbine blade designs sought to optimise aerodynamics using knowledge from aeronautics, which meant little attention was paid to sound, blade design has since been refined to be aerodynamically designed for maximum energy generation and minimum noise.[1,27]

As we have seen, aerodynamic noise from wind turbine blades can still be significant, and research into quieter designs is still ongoing, especially given increasing noise constraints as wind power continues to expand. Already, blade manufacture is often adapted to suit a particular wind farm, and researchers are looking at low-computational methods that can allow design to be improved on a site-by-site basis, with optimal trade-off between annual power production and noise.[28] This demonstrates that it is possible to mitigate aerodynamic noise, which, as will be discussed below, is especially important at low wind speeds when background noise is diminished but wind turbines are still capable of operating; the most efficient generation still occurs at higher wind speeds when background noise masks wind turbine noise.[29]

The aerodynamic noise generated by wind turbines during operation takes a variety of forms, usually classed as tonal, low-frequency, broadband and impulsive.[1,2] Tonal sounds typically arise from mechanical parts (e.g. gears meshing) and are also a notable feature of blade aerofoils in small kilowatt turbines, but tonal sounds are not an issue for utility-scale turbines used on wind farms.[26] There is a great deal of misunderstanding and misinformation on the nature and impact of low-frequency sound, which, along with 'infrasound', is blamed as the cause of a multitude of health complaints. This is discussed in detail in chapter 15, which concludes that there is simply no evidence for these health complaints. As mentioned above, the persistence of these 'myths' is an unhelpful distraction from the real problem of wind turbine noise.[24]

Amplitude modulation – swishing and thumping

It is acknowledged that the problem of wind turbine noise lies with the broadband and impulsive emissions caused by the rotating blades. This is because these sounds are subject to amplitude modulation.[1]

Broadband sound – so called because the sounds cover a wide range of frequencies anywhere from 18 to 2,000 Hz – is generated by the front of the blade (the leading edge) pushing through turbulent air and by the back of the blade (the trailing edge) interacting with turbulent air that has just passed across either side of the blade itself. The key feature here is that sound waves generated by the force of these interactions are pushed along in the direction that the blade is travelling. This gives the sound an unusual directivity.[26] A listener on the ground will hear this broadband sound most clearly each time a blade passes a certain position whereby the sound is 'pushed', or projected, in their direction. Thus, to this listener, the sound rises and fades in a rhythmic fashion, i.e. the amplitude modulates up and down.[30]

This rhythmic amplitude modulation is generally described onomatopoeically as a ‘swish’, ‘swoosh’ or ‘whistle’. The ‘swish’ is the characteristic sound of wind turbines, and can be an annoyance factor if especially audible, which might happen in rural or semi-rural areas.[8,21] In particular, there appears to be a threshold of around 40 dB(A) at an affected residence where the sound is prominent (though not necessarily annoying, since context affects this).[31,32] Of more concern is the phenomenon at times of high activity of a ‘thumping’ noise (sometimes described as a roar or rumble), which is experienced as a more intrusive sound.[13,21] The cause of the ‘thump’ has been a matter of some debate, but it is now thought to be the sound generated by the trailing edge of the blade that is reinforced at times by local atmospheric conditions.[26] Since the thumping sound varies rhythmically in a similar fashion to the swishing sound, it too is a form of amplitude modulation.[1] What makes thumping a concern is that the conditions that cause it are not well understood, so it is more difficult to predict and mitigate; the amplitude modulation can be relatively large, more than 6 dB rather than the usual 1–2 dB for swish; and there is an increased low-frequency component that contributes to the unusual and insistent nature of the sound in the ears of the listener.[13,21,26,30]

Both the Institute of Acoustics and the main industry body for wind power (RenewableUK) are investigating further the incidence of impulsive amplitude modulation. At the end of 2013, RenewableUK released findings† that suggest ‘transient stall’ of the blades may be a cause of thumping, and may occur independently of atmospheric conditions.[33] Since the onset of stall can be minimized by adjustments to blade pitch (and possibly changes to blade design), this recent research suggests that it is possible to reduce the risk of amplitude modulation that results in thumping.

In addition, and what is a welcome move considering the existing guidance under ETSU-R-97 has remained unchanged since 1997, RenewableUK put forward a proposal for a penalty scheme to account for amplitude modulation.‡ This proposal builds on RenewableUK’s research programme to develop a robust metric to describe the level of amplitude modulation (essentially, the ‘depth’ of modulation, i.e. how much the modulation causes noise levels to go up and down above the level of background noise), and how that might relate to annoyance levels.[33] Once modulation depth is at a level that is likely to induce annoyance, a ‘penalty’ of 3–5 dB(A) is added on a sliding scale to the measured turbine noise level, meaning that measured noise levels from the turbine must be this much lower to compensate for the intrusive nature of the ‘thump’.

† See references in [34]. Findings summarized in: D. Fiumicelli, ‘Summary of research into amplitude modulation of aerodynamic noise from wind turbines’, Temple (London; 13 December, 2013).

‡ See in [34]: ‘Template Planning Condition on Amplitude Modulation: Noise Guidance Notes’, RenewableUK (London; 16 December 2013).

The Institute of Acoustics, which did not incorporate amplitude modulation in its 2013 good practice guide, released a statement in 2014 saying it is carrying out its own investigations to provide guidance on how to rate amplitude modulation when applying ETSU-R-97 to wind farm developments. The Institute has not officially endorsed RenewableUK’s penalty scheme.[34] The Institute is yet to release its official guidance (as of early 2016), but is assessing various methods that can be used to effectively monitor and rate amplitude modulation.[35]

Limitations of noise guidelines

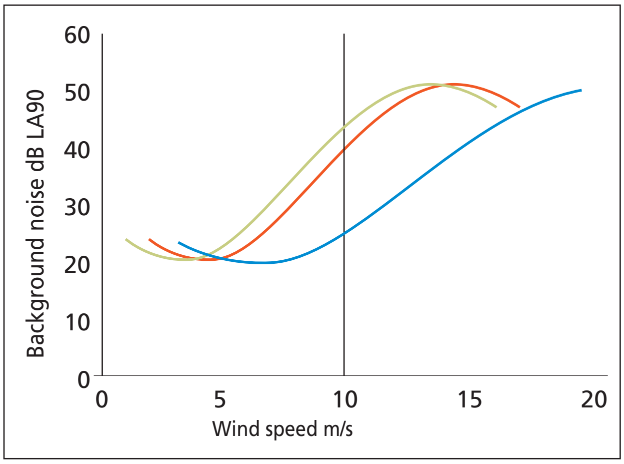
Despite recent moves on the part of the wind industry to address the issue of problematic noise from turbines due to amplitude modulation, existing guidelines are still based on ETSU-R-97, which, it has been noted, has several shortcomings.

Wind speed

A 2011 report into the way ETSU had been applied to noise assessments for wind farm developments highlighted the variable nature of these assessments when submitted to planning authorities.[36] Prior to 2009, slightly more than half of assessments reviewed were found to inconsistently account for meteorological conditions (e.g. temperature, humidity, barrier attenuation) when predicting noise levels. In particular, the phenomenon of wind shear was not addressed. Wind shear is the variation in wind speed with height from ground level; apart from some rare circumstances, wind speed increases with height. This relates to one of the fundamental problems when assessing wind turbine noise, that is, wind turbines only generate noise when rotating, which only occurs when the wind is blowing, itself a source of noise.[37] This is why assessments of wind turbine noise use background noise levels plotted against different wind speeds.

Let us remind ourselves how wind speed affects turbine operation. Megawatt-rated wind turbines do not spin the moment there is a breeze – instead, wind turbine output follows a power curve (see Figure 5.1 in chapter 5) that is dependent on the wind speed at the turbine’s hub (in metres per second, m/s). The *cut-in speed*, is typically 3–4 m/s (roughly 7–9 mph), at which point the turbine can extract useful energy from the wind; below 3 m/s the turbine does not operate. Once the cut-in speed is reached, power output and wind speed are related through a cubic relationship, which means a small change in wind speed can result in a large change in power output. At 7 m/s (15.7 mph) wind speed, a turbine will be generating roughly 40%–50% of its

Figure 14.2 This is an idealised graph showing how wind speed measurements at different heights can affect the derived background noise level.§ The three best-fit lines use the same noise data plotted against: measured 10 m wind speed (blue line), standardised 10 m wind speed (red), and measured hub height wind speed (green). Note when wind speed at hub height reaches 10 m/s, background noise L_{A90} is still below 30 dB. The standardised wind speed, however, suggests background L_{A90} is almost 40 dB. Under these conditions, the turbine is likely to be operating at 80%–90% capacity.



maximum rated output. By the time wind speed is up to 12 m/s (26.8 mph), the turbine will be operating at 100% of its rated output. For the protection of structural and electrical components, a wind turbine will cut out when wind speeds reach about 25 m/s, or 56 mph.[38]

Following ETSU-R-97, Institute of Acoustics guidance recommends the area being assessed for wind turbine noise should include at least the area predicted to exceed 35 dB L_{A90} (more on the use of L_{A90} below) at wind speeds up to 10 m/s (22 mph) due to sound generated from all existing and proposed turbines.[14] One should note that wind speed in this measurement is usually derived from turbine's electrical output and power curve, and it is the adjusted wind speed at a reference height of 10 metres, which typically incorporates a factor relating to ground conditions. Using a reference height enables useful comparisons between assessments and is standard practice when measuring wind turbine noise.[2] The problem is that using standardised readings in this way shifts the background noise level in relation to wind speed, so that background noise appears to be higher than it actually is in relation to the wind speed at hub height. This is easier to visualise graphically, as seen in Figure 14.2.

At hub height wind speeds that correspond to significant operational output (recall turbines go from roughly 50% capacity to 100% between 7 and 12 m/s wind speed) there is a disparity between the derived background noise levels. When hub height wind speed is 10 m/s, the standardised wind speed readings suggests a background noise level approximately 10 dB(A) higher than what may actually be the case, which would underestimate how audible wind turbine sounds are in the context of background noise levels. This is one factor that can lead to misleading assessments of the impact of wind turbine noise when using ETSU-R-97.[37]

Background noise

Contrary to Germany, the Netherlands and Denmark, which set limits on the maximum sound pressure level permitted when turbines are operating, ETSU-R-97 guidelines follow the logic that a maximum permitted +5 dB increase be allowed on top of background LA90, as well as including a fixed lower limit, which we have previously seen can lead to permitted levels of wind turbine noise that are considerably more than 5dB(A) above background levels. (see Figure 14.1). And, as we have just seen, the risk of underestimating background noise levels to start with makes the UK guidelines prone to allowing a much greater disparity between wind turbine noise levels and background noise levels. Permitting a fixed minimum limit at night-time that is higher than daytime can also result in notable incongruences[7] – one might have a situation where a wind farm in an area close to a major road will operate at or near the 43 dB(A) level but be comfortably within 5 dB of the background noise level, whereas a similar development in a very quiet rural area may see the same operational noise limit be 10 dB or more above the background level of noise (quiet rural areas frequently have background levels around 25–30 dBA). Clearly, the impact of the latter development is significant, but ETSU-R-97 would see them as the same.

Use of L_{A90} is itself questionable. Industrial noise assessments use two types of metrics when monitoring environmental noise impacts, the equivalent continuous noise level (Leq) and the noise level that is exceeded 90% of the time (L_{90}). Since noise assessments use A-weighting, these metrics are notated as LAeq and L_{A90}.

The L_{Aeq} is useful for continuous sound levels that fluctuate over a given period. An L_{Aeq} measurement is the average of sound pressure levels over a period of interest, presented in decibels (technically, this makes the L_{Aeq} a logarithmic average because decibels are a logarithmic scale, but this does not change the basic principle). For example, monitoring night-time noise levels at a location may see measurements as low as 25 dB(A) at the quietest moments, but levels as high as 60 or 70 dB(A) when there is passing traffic (or, for that

§ Although presented as an idealised graph, this is based on a plot of real data found in: R. Bowdler, 'ETSU-R-97. An alternative view', www.dickbowdler.co.uk/content/publications/ETSU-R-97_-_The_Alternative_-_Incl_figures.pdf, c. 2016 Dick Bowdler.

matter, when it is very windy). The LAeq over this period shows the average noise level a listener is subjected to. The WHO note that 24-hour exposure to 70 dB LAeq will not cause hearing impairment,[4] and daily occupational exposure is limited by UK law to 85 dB(A).**

The L_{A90} is commonly used for background noise levels, notably in BS4142.[39] For example, a reading of 30 dB L_{A90} for a 10 minute period (L_{A90},10min) means that noise levels are 30 dB(A) or above for 9 of those 10 minutes (not necessarily 9 consecutive minutes). In industrial noise assessments, background noise levels are L_{A90} (usually L_{A90},15min for night-time readings) and the source noise (i.e. the equipment or premises that is creating the noise impact) is rated as L_{Aeq}. The rated source L_{Aeq} is then compared to the background L_{A90}. The BS4142:2014 advises that, *'depending on the context'*, a difference of 10 dB(A) indicates 'a significant adverse impact', 5 dB(A) 'an adverse impact', and between 0 and 5 dB(A) is 'less likely' to have an adverse impact. Despite citing BS4142 as a useful model for assessing noise impact, ETSU-R-97 applied the L_{A90} to the 'source' noise, in other words, wind turbine noise is measured using L_{A90} and compared directly to background L_{A90}.[5] The issue here is that the difference between L_{A90} and LAeq is about 2 dB.[2] In effect, when wind turbine noise is 5 dB L_{A90} above background levels as per ETSU-R-97, the LAeq is 7 dB above background according to BS4142, which indicates 'an adverse impact'. Furthermore, the ETSU-R-97 night-time minimum limit of 43 dB(A) is the L_{A90}, meaning the continuous noise level permitted at night averaged over an eight hour period could be 45 dB(A) even when background levels are only around 30 dB L_{Aeq} (28 dB L_{A90}).

Compounded by misleadingly high background noise levels in some cases (as explained above), is it any wonder that some residents complain of noise disturbance even when the conditions of ETSU-R-97 have been met?[7,24] People's perception of intrusive noise is often based on what can be heard at quietest times, not what is heard on average.

Amplitude modulation

The same 2011 report that highlighted inconsistencies in noise assessments submitted to planning authorities also revealed that around 37% of assessments had not addressed amplitude modulation at all.[36] This is not surprising, as ETSU-R-97 does not address amplitude modulation either (it does include tonal sounds).[5,14] As discussed already, RenewableUK released its own guidance on the issue in December of 2013.[33] The Institute of Acoustics is carrying out its own research prior to releasing official guidance. Whilst the RenewableUK guidance is a much needed and transparent process, there is some evidence that the analysis method suggested by RenewableUK leads to an underestimation of the effect.[35] In addition, there is still a reliance on L_{A90} as a measure of wind turbine noise when applying the amplitude modulation 'penalty', the limitations of which have been discussed in the preceding section. Although not official guidance, the Institute of Acoustics has recommended that RenewableUK's method of characterising amplitude modulation could be improved by filtering noise recordings (a band-pass filter) to account for the lower frequencies inherent in the thumping sound.[35]

When the peculiar characteristics of wind turbine noise were becoming known, it was hypothesised that meteorological conditions and the topography could be a major contributing factor for the unexpectedly high noise emissions, especially at night.[13] In particular, a meteorological condition known as a temperature inversion can result in relatively low noise exposure close to the turbine (within 200 metres), called a 'shadow zone', but higher noise levels further out from the shadow zone. Wind speed can have a similar effect, especially when wind shear is more pronounced.[2] Furthermore, cross-winds have been found to increase the depth of amplitude modulation, so that even if sound levels from a wind farm are lower overall the more pronounced swish caused by cross-winds makes the sound more recognisable.[30] These contributing factors, such as wind shear are addressed in the recent guidance from the Institute of Acoustics, in addition to RenewableUK's own efforts to tackle amplitude modulation.

Unfortunately, the prescriptive nature of ETSU-R-97 means that some noise complaints relating to wind farm developments from the 1990s and 2000s have been dismissed, simply because the ETSU guidelines were met. This has meant that the small number of residents with a genuine grievance who have pointed out wind turbine noise may be annoying and intrusive have not had their concerns adequately addressed.[7,24] This has led to increasing opposition to new renewable energy developments, with residents no longer trusting the intentions of developers or the government's renewable energy strategy, and gifting opposition groups a ready supply of controversial talking points.[40–42] This brings us to what is perhaps the most important part of the debate over wind turbine noise: the meaning that neighbours of wind farms attach to what they can hear.

Psychology – the 'meaning' of wind farm noise

For all that has been discussed up to this point, there is one important element still remaining. It is a simple fact that many residents do not like wind turbines intruding in their local environment. Although this fact is simple

** Control of Noise at Work Regulations 2005.

enough, what gives rise to it is a very complex interaction between value judgements that are informed by psychological and social cues. The context of a wind farm development within a community – its politics, its perceived 'winners' and 'losers' – is as vital a part of the annoyance factor (or lack thereof) as any objective measure of sound levels. These issues are discussed in detail in chapter 8, 'Public acceptance and community engagement', but here we will relate some of the issues specific to reports of annoyance, noise disturbance and wind turbines.

Complaints about wind turbine noise are not new.[43] The discovery that a small but significant proportion of residents find audible emissions annoying and intrusive was initially surprising, as levels of noise were found to be within accepted limits for ambient background noise.[15,44] Effects such as amplitude modulation are now better understood, and help explain some of the initial theories that perhaps the characteristics of aerodynamic noise from wind turbines may be perceived differently depending on the sensitivity of individual residents.[45] After visual impact, noise is most frequently cited as the reason for complaints by nearby residents relating to wind farms, and a feature common to most studies into intrusive noise is that negative attitudes toward the siting of wind farms plays a large part in any individual subject's response to noise.[8,15,19]

Familiarity with and proximity to wind turbines can elicit more of a response if the context, i.e. the perceived intrusion, is negative.[22,46] Likewise, familiarity combined with positive attitude towards wind turbines has a significant effect on how wind farms are viewed.[8,21,47–50] Context and individual attitudes is key, something that even the BS4142 acknowledges with respect to industrial noise.[39] When assessing the impact of a wind farm, planners and developers must consider both visual and auditory aspects of wind turbines in relation to residents' experience of quiet areas. Where existing developments may have engendered negative attitudes already, further developments may be met with greater opposition.[51] Given the characteristics of wind turbine noise, although objectively measured sound levels may show that levels are not excessive compared with other environmental sources of noise, it is likely that perceptually relevant information will be a strong influence.[52]

Therefore, an unsympathetic approach to wind farm developments, especially where complaints of noise have been dismissed in the past, introduces a new problem for wind power that goes beyond the objective level of noise to a situation where noise from wind turbines, *when identified as such,* has a lower annoyance threshold for certain people. Awareness of the source is a relevant aspect for noise perception. Studies suggest that when wind turbine noise is unidentified it is perceived no differently from road traffic noise, which is interesting in light of data from early surveys where wind turbines were singled out as annoying despite traffic noise being at comparable levels.[13,15,46] This 'acoustical recognition factor' has been experimentally demonstrated for wind turbine sounds. It is clear that subjective experience is likely to become more relevant with the recognition of wind turbine noise.[46,53]

A person's evaluation of the sound is affected by the social process between themselves and the operator of the source.[54] Researchers into the peculiar noise characteristics of wind turbines and their effect on annoyance and disturbance have pointed out that if residents feel disconnected from decisions made by local government, or are generally unhappy with changes to their community space, then they are much more likely to be affected once a wind farm is installed. Residents who enjoy a personal benefit from a neighbouring wind farm (e.g. direct payments or community improvements from revenue) do not experience the same feelings of annoyance despite being exposed to the same level of noise.[8,20,21] Wind turbine noise shows a clear association with self-reported incidences of annoyance, but the link between annoyance and exposure to wind turbine noise is not linear, and frequently breaks down when other factors – such as economic benefit – are analysed.

In this context, although studies show annoyance and stress are correlated with subjects reporting they are disturbed by turbine noise, it is not clear if annoyance with wind turbine noise is a result of stress or vice versa. A poor experience with wind developers during the planning phase of a wind farm can lead a stressed individual to appraise wind turbine noise as a threat to their psychological well-being and be annoyed by it, regardless of objective sound levels.[20,31]

It is possible to find that sleep disturbance is highly correlated to annoyance, but sleep disturbance is not correlated to turbine noise level, even though annoyance alone is correlated to wind turbine noise.[20] Similarly, measuring quality-of-life indicators through questionnaire surveys of residents living anywhere from 7 miles away to within 250 metres of a wind farm fails to show any direct relationship between between quality-of-life effects and exposure to wind turbine noise.[18]

A recent pilot study across several different wind farms in Canada used objective measurements of sleep disturbance along with self-reported questionnaires, and did not show any relationship between sleep disturbances (including diagnosed sleep disorders) and exposure to wind turbine noise up to 46 dB(A).[17] Findings such as these may explain the contextual relationship between wind turbine noise and annoyance. Negative expectations can affect how wind turbine noise is perceived by individuals.[46,55] The converse may also be true: inducing positive expectations can mitigate or reduce levels of annoyance, even in noise-sensitive subjects.[50,56]

The provision of benefits can be a tricky area. Even well-intentioned developers may be caught out by locals' ambivalence towards the nature of benefits, which can easily be perceived as a form of bribery.[40] In the UK, most benefits are the result of bilateral negotiations between developers and affected communities once a proposal is announced, which speaks volumes about the UK's lack of tradition in alternative energy for grassroots movements, local co-ownership and early participation in infrastructure projects that characterises much of the discourse between planners and communities in countries like Germany.[57–60] Local authorities can be valuable intermediaries in the negotiation process, but the historically top-down approach that has sought to impose few limits on wind power developments, led inevitably by large power companies, means that the dictates of central planning too often trump the efforts of local planning authorities.[42,57,61,62] This may change with the introduction in June 2015 of a planning requirement that wind developments can only be brought forward where there is an allocated site in a local or neighbourhood plan[††]. Such allocated sites can be reasonably broad and, if used well, this provision could allow for better and earlier local engagement about the need for (and appropriateness of) potential wind developments in a given area, well before any developers are involved in promoting individual sites for specific turbines. However, since little technical or site specific noise analysis will need to be done in order to allocate a site, there still remains opportunity for conflict to arise over perceived noise issues once a specific site for a wind farm project is progressed.

Finally, one important point should be borne in mind: wind turbines are often situated in rural areas, what the EU Noise Directive classes as 'quiet area in open country'.[‡‡] This means the effect of wind turbine noise is more likely to cause annoyance that is disproportionate to their impact on ambient sound levels.[22] Noise assessments must take into account the 'psycho-acoustical factors' that can affect whether the sound is pleasant or unpleasant, which is particularly germane to the type of landscape where wind farms are frequently sited.[63] Surveys of residents show that wind turbine noise levels and annoyance are more strongly linked in quiet areas.[20] Although wind turbines were far from the most prevalent cause of sleep disturbance in the Canadian study, there was a link between wind turbine noise of 35 dB(A) or more and residents self-reporting that wind turbines were the cause of their disturbed sleep.[17] It should be noted that the researchers found background night-time sound levels were lowest in areas where wind turbine noise exposure was highest (40–46 dBA), so it is plausible that once awake, residents were more aware of wind turbine noise.

In instances where annoyance or disturbance is caused by wind turbine noise, some of these may well be the result of shortcomings in planning guidelines. For some residents, the manner in which wind farm developments are carried out, with perceptions of secretive planning in the early stages and last-minute consultations once plans have already been laid, means that disillusioned residents who may be able to hear the wind turbines operating will experience the noise as annoying, even if levels are comfortably within guidelines. This should not be understated – annoyance caused by a sound that is deemed inappropriate or to represent an imposition is still intrusive to the sufferer.

The Institute of Acoustics take the position that:

> *'A significant aspect of the consultation should be whether [noise] surveys are required, and if they are, agreement on the number and position of background noise level measurement locations should be sought. Such agreement will benefit all parties, as background noise level measurements can be an area of considerable debate, and targeting resources at this early stage in the development process should provide dividends in the future by reducing the likelihood of protracted arguments and potentially the need for additional background noise level measurements'* (See ref.14, p.38).

Conclusion

Renewables are essential for the move toward low-carbon energy sources and public attitudes on the whole are strongly in favour of their implementation. However, there is a striking divergence between overall support and more local opposition to the installation of renewable technologies (see chapter 8, 'Public acceptance and community engagement'). An increasing number of installations will see an increasing number of challenges from concerned residents unless the causes of negative opinion are understood. In spite of continual improvements made to turbine design, there is a significant body of evidence showing that the characteristics of noise emissions from wind turbines can affect a small proportion of the communities that are exposed. Initially, complaints were typically met with assurances by wind farm developers that guidelines were in place and that the sited turbines complied (with a few

†† www.publications.parliament.uk/pa/cm201516/cmhansrd/cm150618/wmstext/150618m0001.htm (Accessed 19/05/16)

‡‡ EU Directive 2002/49/EC relating to the assessment and management of environmental noise, OJ, L189, 18.07.2002, p.14.

exceptions). However, the guidelines in place, set by the ETSU-R-97 report, are problematic, as they do not always take adequate account of the aerodynamic noise characteristic of wind turbines. More troubling is the application of noise limits in ETSU-R-97, which are quite unlike any other national guidelines and can result in a significant disparity between background noise levels and wind turbine noise. The issue is further complicated by the fact that background noise levels are affected by wind speed, which is also directly related to the operational noise level of the turbines themselves.

Accordingly, the issue of noise should be treated with due consideration, and guidelines must be strictly adhered to, or efforts made to revise them if necessary. Although some steps have been taken to ensure the practice of noise assessments for wind turbines is more rigorously and consistently applied, critics point out that the existing UK planning guidelines, enshrined by ETSU-R-97, are inadequate to safeguard residents' acoustical amenity. There is some justification for this when current planning regulations continue to refer to a working group report released in 1996; indeed, the original authors themselves stated that ETSU-R-97 should be updated in a timely manner as new evidence emerges and wind power technology advanced. Despite its shortcomings, the ETSU report clearly adheres to the principle that sound pressure levels, not distance, should determine the minimum setback from nearby dwellings:

> *The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described...all dictate that separation distances of 350–400 metres cannot be relied upon to give adequate protection to neighbours of wind farms' (*See ref.5, p.46).

There is arguably a need for overhauling the ETSU guidelines rather than attempting to reconcile its shortcomings by issuing usage guidance. Where ETSU-R-97 departs from the BS4142 standard – such as the use of metrics that may underestimate the noise impact of turbines relative to background levels, or applying a fixed minimum permitted noise level that is higher at night-time than daytime – it has created a situation where wind farms may be compliant but still cause unnecessary annoyance to some neighbouring dwellings.
It is important to note that the literature on the small but significant number of residents who are continually disturbed by perceived noise from wind farms reveals that self-reported annoyance or disturbance is frequently not directly related to the respondents' exposure to wind turbine noise. Visibility plays a significant part in exacerbating disturbance due to sound, with affected respondents frequently already unhappy that their local setting has been marred by the introduction of wind farms, and the overall perception of intrusive sound is intimately associated with the feeling that the visible structures have been forced on the landscape without any say from them.

Civic planning ought to reduce conflict and lead to more positive consent decisions. Alienated residents – those not involved in decision making, with no direct economic benefit, without a knowledge of how wind energy operates and suspicious of wind farms thrust upon them – will ultimately perceive any wind farm development negatively, regardless of public support in general.

What has worsened the situation is the reaction of many residents who are ambivalent to or outright oppose wind farms to assume harm where there is none. Controversies over wind turbine noise has given rise to various myths surrounding the nature of the sound from wind farms, in many cases setting negative expectations that are self-fulfilling. The 'nocebo effect' where sufferers continue to hear noise that is not detectable or not generated at all (i.e. activity has ceased) has been documented in similar instances of industrial noise. Dismissing complainants by resorting to tactics such as pointing to compliance with (possibly inadequate) guidelines is damaging to genuine cases where noise is a problem, and jeopardises future renewable developments. Accusations of nimbyism are unhelpful and irrelevant: it is up to the wind energy industry and its supporters to be honest about any noise concerns local residents might have, and to work with them to minimise these affects within the framework of the planning regulations (designed for exactly this purpose).

Human beings give meaning to sound. It is evident that residents who feel wind developments are forced upon their local setting will judge any subsequent noise accordingly. Trust in the developer and development process must be earned. It is cogent that clearly realised benefits for residents, such as direct financial benefit and a better understanding of how wind power contributes to a low-carbon economy, can also significantly mitigate this negative bias.

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