Carrick Windfarm

Hearing Statement: Noise

DPEA Reference: WIN-370-5

Date of document: 17 April 2023

Index

1. Introduction

1. A number of abbreviations are used throughout this document which are defined as they arise. In addition, a glossary of terms and abbreviations is provided at the end of the main text.

AUTHORS AND QUALIFICATIONS

2. This Hearing Statement has been jointly prepared by James Powlson BSc (Hons) MIOA and Michael Lotinga BSc (Hons) MSc CEng MIOA MASA on behalf of ScottishPower Renewables (SPR) (the Applicant).

3. Mr Powlson has been the lead author for this Hearing Statement, preparing the majority of Section 1 and all of Sections 2, 4, 5, 6, and 7. Mr Lotinga has authored Section 1 sub-section entitled: *Relevant Experience – Michael Lotinga* and all of Section 3 which covers low frequency noise, infrasound and amplitude modulation (AM).

4. Mr Powlson and Mr Lotinga will represent the Applicant at the Hearing Session on noise.

RELEVANT EXPERIENCE – JAMES POWLSON

5. I am a Technical Director of the Acoustics Team at WSP which sits within WSP's Earth and Environment business. I hold a first-class Batchelor of Science honours degree in Audio Technology, graduating from the School of Acoustics and Electronic Engineering at the University of Salford in 1999. I am a corporate member of the Institute of Acoustics (MIOA).

6. I specialise in environmental noise and vibration, and I have worked in this area for the last 20 years, which have been in continuous employment with WSP. I have completed environmental noise assessments for numerous large scale onshore wind farm developments in the UK and internationally and have been lead environmental noise consultant for many projects in Scotland.

7. I am the Project Director for the acoustic consultancy services provided to the Applicant for the proposed Carrick Windfarm development, and I have provided expert advice on environmental noise throughout the project, from concept and scheme design stages to submission of the application for planning consent to the Scottish Government Energy Consents Unit. I authored Chapter 10: *Noise* of the *Carrick Windfarm Scoping Report* dated May 2020 [CD002.188] and Chapter 9: *Noise* of the *Carrick Windfarm Environmental Impact Assessment Report* dated December 2021 [CD002.011] which was submitted as part of that application for consent.

8. The evidence I have authored within this Hearing Statement has been prepared by me in accordance with the guidance of my professional institute and any opinions expressed are my true and professional view.

RELEVANT EXPERIENCE – MICHAEL LOTINGA

9. I am an Associate Engineer in the Acoustics team at WSP, in which I have worked since 2015. Prior to this I was a Noise and Vibration Engineer in the Research Design and Development department at Dyson. I have worked in acoustics, noise and vibration engineering for over 15 years, during which I have provided technical acoustics advice for developers and local authorities on several wind energy developments, both planned and operational. I have led research studies into human responses to wind turbine noise on behalf of the UK government, and I was the lead researcher and author of the recently published Review of Noise Guidance for Onshore Wind Turbines commissioned by the former Department for Business, Energy and Industrial Strategy [CD012.015] (the WSP BEIS Report). I have also written and presented

several papers on the subject of human response to wind turbine noise and other acoustics topics at international scientific conferences.

10. I am a Chartered Engineer, a Member of the Institute of Acoustics, and a Member of the Acoustical Society of America. I hold a Master of Science degree in Environmental Acoustics from the University of Salford (2014), a Diploma in Acoustics and Noise Control from the Institute of Acoustics (2008), and a Bachelor of Science degree in Audio and Music Technology from Anglia Ruskin University (2005).

11. The evidence I have authored within this Hearing Statement has been prepared by me in accordance with the guidance of my professional institutes and any opinions expressed are my true and professional view.

SCOPE OF HEARING STATEMENT

12. A Pre-Examination Meeting ("PEM") was held on 10 January 2023. A Note of the PEM was subsequently issued on 17 January 2023 [CD015.001]. Appendix C of that PEM Note detailed how the Reporters requested the submission of additional information from Save Straiton for Scotland (SSfS) on the extent of the noise evidence it planned to submit (PEM Note action 5b), and that the Council and applicants then provided a response to that submission (PEM Note action 5c).

13. In response to the 5b and 5c submissions, the Reporters confirmed their position that noise evidence will be heard at a Hearing Session for which an allowance of 2 days has been made. The Reporters subsequently confirmed by email[1] that the scope of the noise Hearing Session will be as follows:

14. "Operational turbine noise:

- *current guidance, advice and methodology which should be applied to the assessment of the operational noise of wind turbines;*
- *the role of topography, infra-sound, low frequency noise, amplitude modulation and SAM Scribe Full Spectrum recording equipment in the assessment of operational turbines noise;*
- *adequacy of the operational noise assessments of the three applications – including background noise measurements;*
- *extent of individual and cumulative operational noise effects of the proposed schemes (including with other applications subject to this inquiry and nearby wind farms);*
- *identification of properties most likely to be affected and to what degree the properties would be affected - including cumulatively; and*
- *the general terms of planning conditions that would be required in different scenarios - should consent be given to any combination of the proposals (cumulative noise limits/site specific noise limits)."*

15. The scope of this Hearing Statement is therefore operational turbine noise extending to consideration of the points listed above.

STATEMENT OF AGREED MATTERS

16. I have worked at length in arriving at a noise Statement of Agreed Matters (SoAM) [CD015.014] with my counterpart noise Expert Witnesses acting on behalf of the applicants of the Craiginmoddie Wind Farm (CMWF) (DPEA Reference: WIN-370-4) and the Knockcronal

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[1] *Email from Case Officer Morag I Smith dated 01 March 2023 14:33subject: [EXTERNAL] WIN-370-4, 5 & 6 conjoined wind farm hearing*

Wind Farm (KWF) (DPEA Reference: WIN-370-6), as also being considered at the conjoined Inquiry.

17. The SoAM confirms that the conclusions of the noise assessments undertaken for the three proposed developments [CDs 002.011, 001.008 & 012.024 and 003-193] are consistent, identifying that all three could be consented with resulting cumulative operational noise levels remaining compliant with the total ETSU-R-97 [CD012.001] noise limits.

18. Paragraphs 5.1 and 5.2 of the SoAM [CD015.014] confirms the total ETSU-R-97 noise level limits that have been adopted:

> *"5.1 In accordance with ETSU-R-97 and the IOA GPG, total ETSU R 97 noise limits have been set using a threshold of 5 dB above the prevailing background noise levels, subject to the following fixed minimum thresholds, which are applied when the background noise levels are low:*
>
> - *38 dB during the day*
> - *43 dB at night*
>
> *5.2 ETSU-R-97 also allows adoption of a 45 dB fixed minimum threshold for both day and night when the occupants of a property are financially involved. Within this SoAM this option has not been adopted for any of the considered NALs."*

19. A higher fixed minimum threshold during the daytime period, up to 40dB(A), would be allowable under ETSU-R-97 guidance. This is discussed further in Paragraph 42, 264-269 and 349 of the CWF EIAR Chapter 9: Noise [CD002.011], and so the adopted daytime value of 38dB(A) can be considered duly conservative.

20. The SoAM confirms how each of the proposed developments can be operated within individual Site Specific Noise Limits (SSNLs), and how those limits could be incorporated into a consent condition for each development, requiring that they are complied with.

21. The SSNLs presented in the SoAM are set such that cumulative noise from the three proposed developments in combination with noise from consented/operational wind farms, will, cumulatively, remain compliant with the total ETSU-R-97 noise limits.

22. The SoAM was prepared drawing upon the baseline survey data and predicted operational noise level data presented within the noise assessments prepared for each of the three proposed developments [CDs 002.011, 012.024 and 003.193]. A precautionary approach was adopted selecting the lowest baseline survey data and the highest predicted noise levels where choices could be made between the data presented in the three noise assessments.

23. The SoAM presents a comprehensive position, so this Hearing Statement cross-references to it throughout.

24. During the work undertaken in preparation of the SoAM the need for some errata to Chapter 9 of the EIAR [CD002.011] were identified. These are presented in Annex A of this Hearing Statement. None of the errata have any bearing upon the conclusions previously drawn within the EIAR, or the content of the SoAM.

2. Applicable Assessment Methodology

Planning Policy and Guidance

NATIONAL POLICY AND GUIDANCE

25. The Scottish Government Online Planning Advice for Renewable Energy Technologies: *Onshore Wind Turbines* [CD012.014] references the use of ETSU-R-97 [CD012.001] stating that it should be applied by applicants, consultees and planning authorities to assess noise from wind farms:

> *"The report, 'The Assessment and Rating of Noise from Wind Farms' (Final Report, Sept 1996, DTI), (ETSU-R-97) describes a framework for the measurement of wind farm noise,* ***which should be followed by applicants and consultees, and used by planning authorities to assess and rate noise from wind energy developments, until such time as an update is available****.* [our emphasis]"

26. It proceeds to also reference the Institute of Acoustics': A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise (IOA GPG) [CD012.002] stating:

> *"The Institute of Acoustics (IOA) has since published a 'Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise'. The document provides significant support on technical issues to all users of the ETSU-R-97 method for rating and assessing wind turbine noise and* ***should be used by all IOA members and those undertaking assessments to ETSU-R-97. The Scottish Government accepts that the guide represents current industry good practice.****"* [our emphasis]

27. The IOA also produced a series of Supplementary Guidance Notes (SGNs) [CD012.022] which expand upon many aspects of the Good Practice Guide, and which are referenced in South Ayrshire Council (SAC) local planning policy guidance (see below). The SGNs are generally considered to form part of the IOA GPG so they should also be used in assessments.

28. Planning Advice Note 1/2011: *Planning and noise* (PAN 1/2011) [CD012.003] and the Technical Advice Note (TAN): *Assessment of noise* [CD012.004], also recognises the application of ETSU-R-97. Paragraph 29 of PAN 1/2011 states:

> *"Web based planning advice on renewable technologies for Onshore wind turbines provides advice on 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97) published by the former Department of Trade and Industry [DTI]."*

29. In the TAN to PAN 1/2011, at Appendix 1: *Legislative background, technical standards and codes of practice*, the following is stated:

> *"Advice on Onshore Wind Turbine* [sic] *provides advice based on 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97) published by the former Department of Trade and Industry [DTI]."*

30. The TAN to PAN 1/2011 goes on to confirm that ETSU-R-97:

> *"…provides a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers. ETSU-R-97 presents relevant guidance on good practice and lists a series of recommendations"*

31. It goes on to summarise the ETSU-R-97 assessment methodology including reference to the noise modelling parameters that were detailed in the Institute of Acoustics (IOA) Bulletin

article, Vol 34 No 2, March/April 2009[2]. The IOA Bulletin article includes guidance that was incorporated into the subsequently published IOA GPG [CD012.002].

32. In addition to the above planning advice, the recently published Onshore Wind Policy Statement (OnWPS) (December 2022) [CD005.016] lays out, in policy, the requirement for wind farm developers to apply ETSU-R-97. It also recognises the IOA GPG as a useful tool which developers can use in conjunction with ETSU-R-97. Section 3.7 of the OnWPS is reproduced below:

> *"3.7. Noise*
>
> *3.7.1. 'The Assessment and Rating of Noise from Wind Farms' (Final Report, Sept 1996, DTI), (ETSU-R-97) provides the framework for the measurement of wind turbine noise, and* ***all applicants are required to follow the framework and use it to assess and rate noise from wind energy developments*** [our emphasis].
>
> *3.7.2. The Institute of Acoustics (IOA) Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise was published in May 2013 to support the use of ETSU-R- 97 when designing potential windfarm schemes, and the monitoring of noise levels from generating sites. The Scottish Government recognises this guide as a useful tool which developers can use in conjunction with ETSU-R-97.*
>
> *3.7.3. The Scottish Government is aware that the UK Government has been considering the extent to which ESTU-R-97 may require updating to ensure it is aligned with the potential effects from more modern turbines. The Scottish Government supports this work and we anticipate the results of a short-term review project in due course.*
>
> ***3.7.4. Until such time as new guidance is produced, ETSU-R-97 should continue to be followed by applicants and used to assess and rate noise from wind energy developments****."* [our emphasis]

33. The above is confirmed at Paragraph 6 of the SSfS Scope of Evidence (SoE) [CD016.032].

LOCAL POLICY AND GUIDANCE

34. Section 9.2.1.2 of the CWF EIAR [CD002.011], details the local planning policy in force at the date of application submission, that being the SAC Local Development Plan (LDP) adopted in September 2014 [CD007.003]. The two key noise policies were:

> *"LDP policy: air, noise and light pollution*
>
> *We will not allow development which would expose significant numbers of people to unacceptable levels of air, noise or light pollution."*

And

> *"LDP policy: wind energy*
>
> *We will support proposals if: ...*
>
> *c. they do not have any other significant detrimental effect on the amenity of nearby residents, including from noise and shadow flicker; ..."*

35. Beneath the LDP wind energy policy it is stated that SAC will:

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[2] *Leventhall, Bullmore, Jiggins, Hayes, McKenzie, Bowdler and Davis, 2009: Prediction and assessment of wind turbine noise. Agreement about relevant factors for noise assessment from wind energy projects. IoA Bulletin Article Vol 34 No. 2 March/April 2009.*

> *"produce supplementary guidance on wind farms, which will... provide more detail on how the above-mentioned criteria will be applied in assessing all proposals for wind farms and turbines."*

36. Guidance on the assessment methods to be applied was then published in the SAC Supplementary Guidance: *Wind Energy* (SGWE) adopted in December 2015 [CD007.004], as considered further below,

37. The LDP was replaced by the Local Development Plan 2 (LDP2) when it was adopted in August 2022 [CD007.001] (after the CWF submission for planning consent was made). The LDP2 includes two similar policies:

> *"LDP policy: air, noise and light pollution*
>
> *We will not allow development which would expose people to unacceptable levels of air, noise or light pollution.*
>
> *Note: In determining planning applications for development that might generate pollution, we'll take the advice of the Council's Environmental Health Service, as local pollution regulator, as to whether the development would be likely to generate unacceptable levels of pollution. The Council may seek additional relevant impact assessments to demonstrate impacts on, or from proposed development on air, noise or light pollution."*
>
> and
>
> *"LDP policy: wind energy*
>
> *We will support proposals for wind energy development (including repowering or extensions) comprising one or more wind turbine greater than 15 metres to blade tip. Proposals for wind farms on sites that are not within Group 1 or Group 2 areas, as described in Scottish Planning Policy Table 1, are likely to be acceptable subject to detailed consideration against the criteria set out below.*
>
> *All proposals will be assessed against the following criteria: ...*
>
> *e. They would have no other unacceptably detrimental effect upon the amenity of nearby residents, including from noise and shadow flicker"*

38. Guidance on the assessment methods to be applied is presented in SGWE [CD007.004], and the Environmental Health Wind Turbine Development Submission Guidance Note: *Wind turbine development: Submission guidance note on the information required for an assessment of the noise impact of proposed wind turbine developments to be undertaken in connection with a planning application* (EHSGN) [CD012.016]. The SGWE states:

> *"Developers should refer to: ETSU-R-97, the IOA Good Practice Guide to the Application of ETSU (May 2013) and the IOA Supplementary Guidance Notes that accompany these documents."*

39. and goes on to reference the EHSGN, which states:

> *"All planning applications for wind turbine development must be accompanied by a site specific noise impact assessment. It is expected that the noise impact assessment will be undertaken in accordance with ETSU-R-97, the IOA Good Practice Guide to the Application of ETSU (May 2013) and the IOA Supplementary Guidance Notes that accompany these documents."*.

THE WSP BEIS REPORT [CD012.015]

40. SSfS point out, at paragraph 6 of their Scope of Evidence [CD016.032], that the UK has been considering the extent to which ETSU-R-97 may require updating. This is true, although that review process is at a relatively early stage. WSP undertook the initial scoping review on behalf

of the UK Government Department for Business, Energy & Industrial Strategy (BEIS), and the lead author was Mr Lotinga, joint author of this Hearing Statement.

41. The review findings are presented in *A review of noise guidance for onshore wind turbines* (the WSP BEIS Report) which was published on 10 February 2023 [CD012.015]. The implications of the WSP BEIS Report in respect of the currently applicable wind turbine noise assessment methodology are considered in the SoAM at paragraphs 2.6 to 2.8:

> *"2.6 ...The review represents only an initial step in any process of updating existing guidance that may be progressed in the future. The review identifies areas of the guidance that warrant consideration for updating, but also provides recommendations for further evidence needed to support any future updates should they be progressed.*
>
> *2.7 The WSP BEIS report itself does not provide new guidance, nor does it form, or function as, a replacement for ETSU R 97 or supersede any parts of the current policy or guidance frameworks in place, in Scotland or elsewhere in the UK.*
>
> *2.8 At the time of writing, there has been no official response to the report from BEIS or any of the new UK Government departments which are being created to replace BEIS. In the event that a decision is made to follow up on the recommendations within the WSP BEIS report, it is unclear how new guidelines would account for the UK Governments Net Zero targets, nor is there any indication of timescales within which updated guidance would be produced."*

42. Both the OnWPS [CD005.016] and the *Online Planning Advice for Renewable Energy Technologies: Onshore Wind Turbines* [CD012.014] are also clear in respect of possible future updates to noise assessment guidance. The OnWPS states that:

> *"3.7.4.* ***Until such time as new guidance is produced, ETSU-R-97 should continue to be followed by applicants and used to assess and rate noise from wind energy developments.*** [our emphasis]"

43. whilst the Online Planning Advice for Renewable Energy Technologies: *Onshore Wind Turbines* states that ETSU-R-97 should be followed by applicants and planning authorities:

> "... ***until such time as an update is available***. [our emphasis]"

44. In conclusion it is agreed in the SoAM that:

> *"2.10 ...the relevant assessment methodology remains that set out in ETSU-R-97, with guidance on the application of ETSU-R-97 set out in the IOA GPG and related SGN's."*

45. Paragraph 2.11 of the SoAM goes on to confirm that:

> *" 2.11 The assessments produced to consider operational noise from all three proposed developments, and the approach used to determine suitable noise limits as discussed in this SoAM, followed the guidance set out in ETSU-R-97 and the IOA GPG.* ***We agree that the methodologies defined within these documents remain relevant and valid for the purposes of assessing these proposed developments.****"*

Compliance with Policy and Guidance

46. It is clear that the applicable assessment methodology, and that which is required to be applied to ensure compliance with national policy and local authority guidance, is ETSU-R-97 and the IOA GPG (including the Supplementary Guidance Notes).

47. This is the approach that was laid out in Chapter 10: *Noise* of the CWF Scoping Report [CD002.0188], and then followed in the noise assessment reported in Chapter 9: *Noise* of the CWF EIAR [CD002.011], and also followed in the SoAM [CD015.014]. The adopted assessment approach is therefore compliant with the requirements of both national and local policy and guidance.

48. The completed assessment was subject to technical review by SAC's appointed independent noise consultant (ACCON UK). Its review document was entitled: *Carrick Wind Farm*, reference 22/00094/DEEM dated 23 March 2022 [CD012.041] and is referred to hereafter as the 'ACCON Review'. It states that the review was undertaken to:

> *"determine whether the noise assessments have been carried out appropriately and to advise on the acceptability or otherwise of the proposals with respect to noise."*

49. It concludes at paragraph 33 that:

> *"The methodologies used in the noise chapter have followed ETSU-R-97 and the IOA Good Practice Guidance for wind turbines"*

50. and at paragraph 37 that:

> "**Subject to imposing noise limits and controls as discussed above, there would be no over-riding reason for refusal in respect of noise.** [Their emphasis]"

51. Acceptance that the assessment followed ETSU-R-97 and the IOA GPG has been confirmed by SAC. SSfS include the following confirmation at paragraph 4 of their SoE [CD016.032]:

> *"**ACCON has advised that the methodologies used in the noise chapter represent good practice and are in line with ETSU-R-97 (operational noise) and the Institute of Acoustics (IOA) Good Practice Guidance for wind turbines.**"* [our emphasis]

52. The SAC Regulatory Panel Report dated 24 June 2022 [CD002.189] further confirms ACCON UK's technical review findings, and that they are accepted by SAC. Paragraph 9.6.5 states:

> *"9.6.5 The operational noise assessment has been reviewed on behalf of the Council by ACCON UK Ltd, who are an environmental consultancy with specialisms in energy and wind farm developments. ACCON are content that the methodologies used for the baseline noise survey and assessing potential effects were appropriate."*

53. In brief, the completed noise assessment has been undertaken in full compliance with the applicable noise assessment method, ETSU-R-97 and the IOA GPG, as referenced for use in both national and local planning policy and advice. The completed assessment has been reviewed by SAC's appointed independent noise consultant who found that the adopted assessment approach was correct and appropriate, and that is accepted by SAC.

Noise Level Prediction Method & Topography

54. The SoAM [CD015.014] confirms at paragraph 6.1 that the noise level predictions undertaken for all three noise assessments (CWF, CMWF and KWF) were:

> *"...completed using the prediction methodology defined in the IOA GPG."*

55. In accordance with the IOA GPG, the applicable wind turbine noise prediction method is that detailed ISO 9613: *Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation* [CD012.005], incorporating the additional propagation recommendations that the IOA GPG makes in respect of specific topographic considerations.

56. Further details on the applied prediction method can be found in the CWF EIAR [CD002.011] at Section 9.6.5.2 and Appendix 9-2: *Noise modelling prediction*, including confirmation of the prediction parameter settings applied, which were in accordance with the IOA GPG.

57. One of the specific topographic considerations required by the IOA GPG is in respect of propagation across a valley (concave ground profiles, or where the ground falls away significantly, between the turbine and the receiver location). Where this is the case, an additional +3dB correction is applied to prediction results. The second is concerned with screening attenuations. The ISO barrier attenuation value is limited to be no more than a 2dB reduction and is only applied when there is full screening afforded to the turbine tip (e.g., as a result of the ground profile / topography). These corrections were applied, as required by the IOA GPG, in the noise level predictions undertaken and reported in all three noise assessments (CWF, CMWF and KWF).

58. The adopted noise level prediction method is for the calculation of sound pressure levels at a 'downwind' location and the research findings presented in *Development of a windfarm noise prediction model* (Bass et al 1998) [CD012.040] identified that this model tends to over-estimate windfarm noise levels. It is standard and current best practice (as defined in the IOA GPG) to apply this approach for proposed windfarms. In practice, however, lower noise levels to those predicted, can be expected, in particular under upwind or crosswind conditions.

59. The IOA GPG confirms at paragraph 4.4.1 that:

> *"4.4.1 When considering cumulative noise impacts, the effects of propagation in different wind directions can be considered. Any such direction attenuation factors, if used, should be clearly stated in any assessment."*

60. Further details are given in Annex B of this hearing statement, including example directivity correction values that can applied in accordance with the IOA GPG.

61. No such directivity corrections have been applied in the completed noise assessments or are therefore accounted for in the level data presented in the SoAM [CD015.014]. The predicted noise levels can therefore be considered to be pessimistic, giving rise to a worst-case assessment.

3. Infrasound, Low Frequency Noise and Amplitude Modulation

Infrasound and Low Frequency Noise

62. This section addresses the issues raised in the SSfS Scope of Evidence (SoE) [CD016.032] regarding infrasound and low frequency noise, within the context of the hearing scope defined by the Reporters (*"the role of topography, infra-sound, low frequency noise, amplitude modulation and SAM Scribe Full Spectrum recording equipment in the assessment of operational turbines noise"*).

63. I (Michael Lotinga) have reviewed the SSfS SoE [CD016.032] and have drawn out the key arguments therein and in any supporting evidence presented. By my reading, the arguments and the logic advanced in the SSfS SoE regarding infrasound and low frequency noise can be summarised as follows:

1. There are adverse effects on human health from wind turbine infrasound, even when it is below established sensation thresholds (SSfS SoE point 19 and Appendix 1).
2. The potential for adverse impact of infrasound or low frequency noise is greater than considered during the development of the guidance, because the current guidelines (i.e., ETSU-R-97 and the IOA GPG) are based on a frequency-weighted sound level index, which insufficiently considers the impact of sound energy in the low frequency end of the spectrum (SSfS SoE point 18).
3. The applicable guidance framework does not address the potential for adverse impact of infrasound or low frequency noise on human health, and as such, the completed noise assessment work does not fully address the potential environmental impact, or address relevant planning policies (SSfS SoE points 1, 5, 7-8, and 12).

64. I address these interrelated arguments below. The key points I make in response can be summarised as follows:

- The evidence provided in the SSfS SoE Appendix 1 is, by my reading, not scientifically rigorous, and appears to be subject to a high risk of bias; as such I consider it to be unreliable. It does not provide any robust evidence in support of the claim that wind turbine infrasound experienced at levels below sensation thresholds adversely affects human health.
- There remains no compelling, scientific evidence to support the claim that wind turbine infrasound at the exposure levels typical for wind farm neighbours is associated with any adverse health outcomes. Moreover, the weight of scientific evidence supports the opposite conclusion.
- The current guidance framework is based on frequency-weighted levels, which characterise the non-linear response of the human hearing system. There are no current regulations or guidelines in the world requiring assessment of unweighted wind turbine sound levels, nor are there any criteria or exposure-response relationships in the scientific literature that would support the development of an assessment of unweighted sound levels. Moreover, there is no compelling evidence suggesting this would be necessary to provide suitable controls for wind turbine noise. On the other hand, there is evidence supporting the use of frequency-weighted levels to assess and control wind turbine noise.
- With respect to infrasound and low frequency noise, the noise assessment presented in the CWF EIAR [CD002.011] was undertaken in accordance with the current guidance. Based on the current scientific evidence, no adverse effects are anticipated due to infrasound or low frequency noise beyond the scope of the EIAR noise assessment.

ANALYSIS OF EVIDENCE IN SSFS SOE APPENDIX 1 MONOGRAPH

The evidence provided in the SSfS SoE Appendix 1 is not rigorous, is subject to a high risk of bias, and is unreliable. It does not provide any robust evidence in support of the claim that infrasound at levels below sensation thresholds adversely affects human health.

65. The thrust of argument 1 is advanced in Appendix 1 of the SSfS SoE [CD016.032], which comprises a monograph co-authored by one of the SSfS SoE signatories. The monograph documents field research, which the authors contend provides evidence of a potentially causal link between detectable wind turbine infrasound identified by the field measurement analysis, and symptoms of ill-health reported by three householders living in the general vicinity of wind farms, at one site in Portugal, and two in Scotland.

66. Of the three households, only one (situated in Portugal) was able to provide records of their symptoms in a manner that allowed the authors to directly compare the periods the residents recorded as feeling ill with simultaneous periods of (infra)sound measurements. The authors report that, of 18 occasions when an occupant of this household recorded feeling symptoms of ill-health (disturbed sleep), all coincided with recordings that the authors analysed as showing detectable wind turbine infrasound, considered likely to be emanating from the wind farm. Conversely, the authors report that of 18 occasions when the occupants reported no symptoms, the sound recording analysis indicated that there was no detectable infrasound observed in the measurements. Only a very limited sample of the data supporting this apparent finding is presented in the monograph, and, as I will detail below, there is no reported analysis, investigation or consideration of any other factors that may have influenced or been able to explain the apparent connections, beyond the presence of detectable infrasound.

67. The most obvious and easily investigated confounding factor would be the potential for audibility of sound inside the normal ‘audio’ range, commonly considered to be between 20 Hz and 20 kHz. If audible, this would naturally alert the household occupants to the wind turbine operation. Furthermore, if the occupants had a negative emotional relationship with the wind farm (for example, if they felt resentment towards the presence of the wind farm), the audibility of wind farm sound could exaggerate their response beyond what might be otherwise expected, and may elevate any existing feelings of annoyance, with potential for consequential effects such as difficulty in sleeping. I briefly discuss further below the complex connections between sound perception (i.e., sensory detection) and the wide range of personal and contextual factors that can influence noise responses (i.e., psychological, emotional, and physiological reactions).

68. As an example of the kind of analysis that might be used to investigate this, I have compared the data shown in the SSfS SoE Appendix 1 figure 5B (depicting the frequency spectrum inside the occupant’s bedroom at the dwelling in Portugal, during an ‘episode’ in which the occupant reported ill-health, in this case disturbed sleep) and figure 6B (an equivalent measurement made when the occupant reported no such symptoms). I have overlaid these two spectra in Figure 1, such that the axis scaling is aligned – the latter spectrum, which represents what is commonly known as the ‘residual sound’, i.e., the sound remaining present in the absence of a sound source of interest (here, wind turbines), has been recoloured in green, for ease of comparison. I have also overlaid another set of data, which plots ‘hearing thresholds’ obtained from laboratory testing of the lowest levels of sound perceived by adults with ‘normal’ hearing ability[3,4,5,6]. Naturally, there is a range of ability, which is represented by the curves plotted: the solid blue line is the 50th percentile (i.e., the median, also equal to the mean in a normally distributed sample), while the dotted blue lines are the 5th and 95th percentiles; between these lie 90% of the expected distribution of threshold values[7].

69. Sounds with a level above these curves would be expected to be audible and vice versa. Inspection of this figure shows that, during the period when the wind turbine sound signature is evident inside the bedroom, an increase in sound energy is apparent in the audio frequency range between 20 Hz and approximately 500 Hz, of which the range 160-500 Hz (indicated with a yellow dashed box) is above the 50th and even the 95th percentiles of normal hearing thresholds (i.e., almost everybody would be able to hear these sounds). This range includes

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[3] *ISO 226:2003. Acoustics — Normal equal-loudness-level contours. International Organization for Standardization. [URL]*

[4] *Kurakata, K, Mizunami, T & Matsushita, K, 2005. Percentiles of normal hearing-threshold distribution under free-field listening conditions in numerical form.* Acoustical Science and Technology, *26 (5), 447-449. [URL]*

[5] *Kurakata, K & Mizunami, T, 2008. The statistical distribution of normal hearing thresholds for low-frequency tones.* Journal of Low Frequency Noise, Vibration and Active Control, *27 (2), 97-104. [URL]*

[6] *The hearing threshold curves shown here were derived using pure-tone stimuli in free-field conditions. It has been shown that more complex sounds (such as multiple tones, or broadband or complex sounds) elicit lower thresholds of detection – for discussion and further literature references, see: Lotinga, MJB, Lewis, T & Taylor, T, 2019. Music venue noise: A development planning case-study examining the application of the 'Agent Of Change' principle, a novel legal mechanism, and noise control design issues. Inter-noise 2019, 16-19 June, Madrid, Spain. International-INCE. [URL]. In the context of the points being made here, this indicates that the portion of the audible range of sound in the audio frequencies is likely to be somewhat larger than indicated, i.e., the sound would be more easily heard.*

[7] *The original threshold curves as defined in 1/3-octave bands have been adjusted to compensate for the difference in frequency resolution compared with the 1/36-octave resolution of the narrowband spectral measurements reported in the SoE Appendix 1. See the Glossary of Terms & Abbreviations section for more information.*

frequencies that would normally be considered as ‘mid-frequency’, and well above the commonly defined infrasound (<20 Hz) and low frequency sound (<250 Hz) ranges.

70. The change in sound energy observed is of the order of around 5-10 dB, which in my experience is a level change that would be expected to be clearly detected by most listeners – in other words, the data indicates that the operation of the turbines would have been expected to be audible to the occupants inside the bedroom. In that case, the physiological symptoms reported by the occupants could have been attributable to their psychological response to normally audible sound. It would also be plausible that an individual dislike of the sound, which could have emotional connotations for the occupants, may have exacerbated the responses. In my view, these possibilities, which apparently remain un-investigated, fundamentally undermine the robustness of the conclusions reached by the investigators, as set out in their introductory and concluding remarks:

> *“The highest peaks of the wind turbine acoustic signature…occurred within the 0.5–5 Hz window which is classically defined as below the human hearing threshold; and yet these ‘inaudible’ phenomena appear to trigger severe biological reactions.*
>
> [The approach] *to the measurement and analysis of infrasound…can reveal acoustical features in the infrasonic range that may indicate a causal relationship with self-reported medical symptoms. This possibility is usually considered non-existent since the infrasonic range is generally viewed as inaudible, and thus innocuous, to humans. The suggestion therefore arises that current noise protection procedures are insufficient to protect public and occupational health.”*

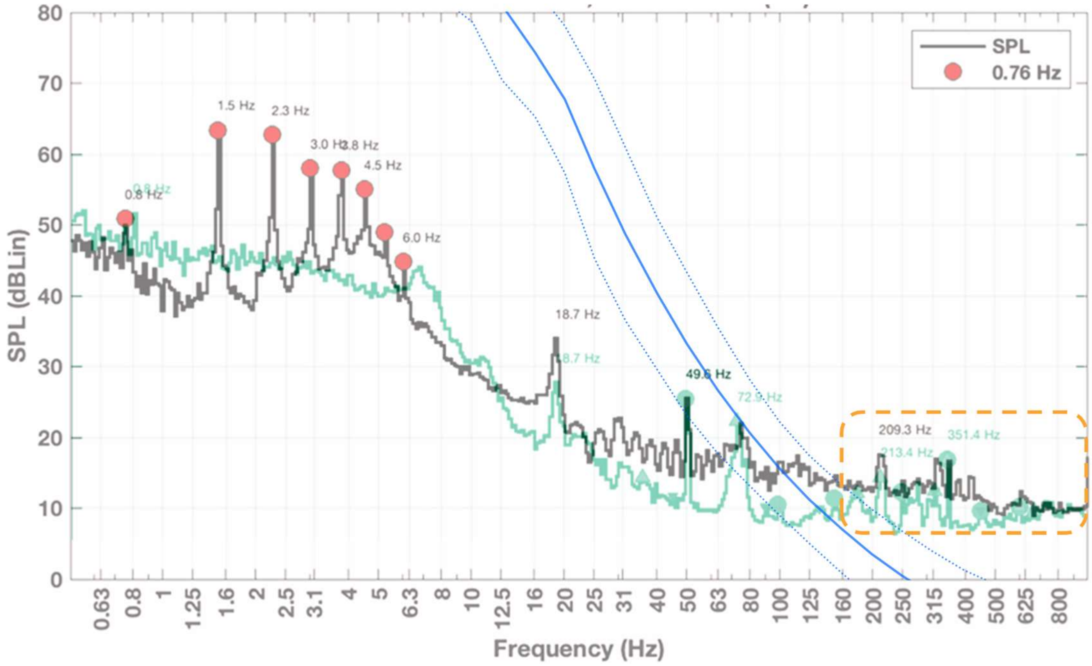

Figure 1: Reanalysis of the data shown in SSfS SoE Appendix 1 figure 5B and figure 6B
Black solid line represents measured sound levels inside master bedroom during wind turbine operation; green solid line represents an equivalent measurement in the absence of turbine operation; blue lines show normal adult pure-tone hearing thresholds, solid line is the median, dotted lines indicate the 5th and 95th percentiles – all levels are depicted at equivalent 1/36 octave resolution

71. The simple analysis I have outlined shows that a cursory inspection of the evidence presented by the SSfS SoE Appendix 1 authors suggests the potential for alternative explanations for the reported observations.

72. To be clear, my intention with the point made here is not to assert that audible sound in the audio range definitely explains the occupant's symptom-reporting. Rather, I am demonstrating that there would be other, quite plausible, and easily examined factors that might have influenced or produced the results, yet no other potentially confounding factors appear to have been systematically investigated or considered by the SSfS SoE Appendix 1 authors in their investigation. In my view, the absence of such scientific rigour suggests that the results of the investigation are unreliable, and carry risks of bias, which do not appear to have been identified or considered by the investigators or by the monograph reviewer/s. The outcome of the study appears to me to have been preconceived, and no attempt has been made to test the strength of the hypothesis that the symptom-reporting was a direct result of imperceptible infrasound exposure against other possible explanations or influences.

73. As noted above, as well as acoustic factors (sound levels and characteristics) there is a multiplicity of other factors that have been shown to affect the responses that people attribute to noise, and this is as true for wind turbines as it is for any source of environmental sound. In some cases, it has been shown that these 'personal and contextual' factors can have a far greater influence on 'noise responses' than the level or character of the sound itself. We examined evidence on such factors affecting noise responses in our recent review of onshore wind turbine noise assessment guidance on behalf of the UK government (the WSP BEIS Report [CD012.015]), and summarised these as follows:

> *"The evidence indicates that noise annoyance can be aggravated by sound characteristics, including AM* [amplitude modulation] ..., *and can be strongly influenced by various personal and contextual factors, including (e.g.,*[8,9,10,11]*):*
>
> - *visual impacts of turbines (associated with increased annoyance)*
> - *individual attitudes to wind turbines or wind energy, and how these can be influenced by messaging (negative attitudes associated with increased annoyance) individual sensitivity to noise (heightened sensitivity associated with increased annoyance)*
> - *economic benefits or financial involvement in wind energy developments (benefits or involvement associated with reduced annoyance)*
> - *the character of the area and the acoustic environment in the absence of wind turbine sound (some evidence indicates greater annoyance in quieter, rural environments)*
> - *long-term duration of exposure (some evidence suggests possible sensitisation to wind turbine sound, i.e., increasing duration associated with increased annoyance)*
> - *trust in planning authorities, community involvement, and the perception of fairness in the wind farm development planning process (perception of unfairness, lack of trust and lack of community involvement associated with increased annoyance)"*

74. Typically, when undertaking epidemiological field research, scientists go to great lengths to test, identify and control such factors, so that their potential influence on the results of the research can be carefully investigated and quantified. There is no indication that any of these factors have been considered by the investigators when analysing the measurements and observations

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[8] *Onakpoya, IJ, O'Sullivan, J, Thompson, MJ & Heneghan, CJ, 2015. The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies.* Environment International, *82, 1-9* [URL]

[9] *van Kamp, I & van den Berg, F, 2018. Health effects related to wind turbine sound, including low-frequency sound and infrasound.* Acoustics Australia, *46, 31-57* [URL]

[10] *Freiberg, A, Schefter, C, Girbig, M, Murta, VC & Seidler, A, 2019. Health effects of wind turbines on humans in residential settings: results of a scoping review.* Environmental Research, *169, 446-463* [URL]

[11] *van Kamp, I, & van den Berg, F, 2021. Health effects related to wind turbine sound: An update.* International Journal of Environmental Research and Public Health, *18 (17), 9133.* [URL]

reported in the SSfS SoE Appendix 1; the only potentially explanatory factor considered in the study appears to have been the exposure to imperceptible levels of infrasound.

75. Our review for BEIS also concluded that "evidence on sleep disturbance associated with wind turbine sound exposure is inconsistent, with some studies indicating an effect and others not. In many cases, the analysis shows that noise annoyance is a stronger predictor of subjective sleep disturbance than levels of wind turbine sound exposure". This is also relevant to the concerns raised above, since it provides additional potential explanation for the results observed in the SSfS SoE Appendix 1: any of the wide range of factors that could contribute to annoyance felt by the householders towards the presence of the wind farm could also contribute to adverse effects on their sleep quality, irrespective of the presence or absence of infrasound at any level.

76. A further observation to be made from Figure 1 is that, as is acknowledged by the SSfS SoE Appendix 1 authors, the levels in the infrasonic range, and most of the low frequency range, are well below the thresholds of audibility, despite being measurable. For example, below 80 Hz, the sound levels during wind turbine operation do not exceed the median threshold curve, and below 20 Hz, the difference increases to more than 30 dB, a margin that increases so steeply that the margin beneath the 5th percentile hearing threshold is more than 50 dB by 10 Hz, and more at even lower frequencies. In other words, the sound level at 10 Hz would need to be increased by at least 50 dB to be perceived by even the 5% of adults with the most sensitive hearing. These are very large margins in terms of sound pressure levels relative to hearing thresholds, which means there is no realistic chance of audibility of the sound in this frequency range. Furthermore, thresholds for sensations of infrasound that do not originate in the hearing system (i.e., tactile vibrations and bodily resonances) are considerably higher still than those for audibility[12]. In other words, the human hearing system is more sensitive to infrasound than other human sensory mechanisms that could potentially be stimulated by infrasound, such that (for those with normal hearing) audibility would be expected to occur at lower sound pressure levels than the tactile sense. This means that there is also no realistic chance that another form of detectable infrasonic bodily excitation could be taking place.

77. It is well known that, in relatively quiet ambient sound environments, sources of sound and infrasound, including wind turbines, as well as other sources, can be detected by sensitive sound or vibration measurement instruments at relatively long distances. However, the capability of sensitive instruments to be able to detect sonic energy does not mean that the sound has any adverse effect on humans at similar ranges, and as discussed above, any connection between inaudible infrasound and adverse health outcomes has not been scientifically demonstrated, despite several investigative, controlled experiments aimed at identifying any possible link (which I discuss further below).

78. Other fundamental methodological issues with the study indicating risks of bias in the results include the following:

- There is no statistical analysis of the measured exposure or response data presented
- The samples of participants involved at each location comprised only one household
- There were no control groups used (i.e., an equivalent set of participant samples in an area not in the vicinity of a wind farm but otherwise exposed to a similar environment)

79. The SSfS SoE Appendix 1 authors also suggest that the use of the analysis tools they employ in researching wind turbine infrasound represents a 'new methodology' that uses a 'different

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[12] *Yamada, S, Ikuji, M, Fujikata, S, Watanabe, T & Kosaka, T, 1983. Body sensation of low frequency noise of ordinary persons and profoundly deaf persons.* Journal of Low Frequency Noise, Vibration and Active Control, *2 (3), 32-36. [URL]*

approach' (I have provided a brief technical explanation of the techniques referred to in the Glossary of Terms & Abbreviations section below). However, in my experience, the application of these techniques is not novel – on the contrary, they are commonplace, routine and well-known tools, which are nowadays often deployed in situations when particular sound characteristics are reported as contributing to disturbances. These kinds of techniques have no obvious application in the context of development planning, but are frequently used to investigate existing noise complaints, or otherwise in research contexts.

80. In relation to the measurement approach the SSfS SoE Appendix 1 authors adopt, they assert that "most, if not all papers on infrasound are conducted with a 1/3-octave resolution, which immediately precludes any data comparison with that presented here." This inaccurate statement indicates that the authors have not reviewed, or are unaware of, the body of previous research into wind turbine infrasound using the same and similar sorts of tools (e.g.,[13,14,15,16,17,18]), which dates from the earliest published research in wind turbine acoustics (in the 1980-90s) until the present day. This evident lack of consideration of existing, relevant, scientific research, readily available for comparison with their results, further undermines my confidence in the reliability of the monograph presented in SSfS SoE Appendix 1.

EVIDENCE FROM OUR REVIEW FOR UK GOVERNMENT

There remains no compelling, scientific evidence to support the claim that wind turbine infrasound at the exposure levels typical for wind farm neighbours is associated with any adverse health outcomes.

81. Several studies have been undertaken in carefully controlled conditions to investigate the potential for adverse effects of exposure to wind turbine infrasound. During the recently-published review we undertook for the UK government (the WSP BEIS Report [CD012.015]), we considered the findings of peer-reviewed articles documenting the results of these studies. On the basis of our review, we found that:

> *"Several studies have investigated the claimed links between adverse health symptoms and infrasound emissions from wind turbines. Although some experimental studies have linked infrasonic signals with activation of physiological sensory processing[19,20], these have tended to be based on signals that are not representative of wind turbine infrasound. There remains no compelling evidence of adverse health effects associated with wind turbine infrasound exposure at sound frequencies and levels expected to be present at noise-sensitive receptor locations in the vicinity of wind farms[21].*
>
> *While biologically plausible pathways for infrasound activation of the auditory or vestibular systems cannot yet be definitively ruled out, the infrasound emissions from wind turbines at ranges relevant to neighbouring dwellings are typically too low to expect any adverse effects, even for people with heightened sensitivity due to medical conditions[22]. Any observed sensory activation has not been reliably linked with any physiological or psychological effects on individuals and has typically been observed during exposures higher than expected for wind turbine infrasound incident at dwellings.*

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[13] *Hubbard, HH & Shepherd, KP, 1990. Wind turbine acoustics. NASA Technical paper 3057. National Aeronautics and Space Administration. [URL]*

[14] *Hansen, C, Zajamšek, B & Hansen, K, 2016. Infrasound and low-frequency noise from wind turbines.* Proceedings of the 3rd Symposium on Fluid-Structure-Sound Interactions and Control, *5-9 July, 2015, Perth, Australia. [URL]*

[15] *Zajamšek, B, Hansen, KL, Doolan, CJ & Hansen, CH, 2016. Characterisation of wind farm infrasound and low-frequency noise.* Journal of Sound and Vibration, *370 (2016), 176-190. [URL]*

[16] *Blumendeller, E, Kimmig, I, Huber, G, Rettler, P & Cheng, PW, 2020. Investigations on low frequency noises of on-shore wind turbines.* Acoustics, *2 (2), 343-365. [URL]*

[17] *D'Amico, S, Van Renterghem, T & Botteldooren, D, 2022. Influence of atmospheric conditions on measured infrasound from wind turbines.* Journal of Wind Engineering & Industrial Aerodynamics, *225 (2022), 105021. [URL]*

[18] *Nguyen, PD, Hansen, KL, Lechat, B, Hansen, C, Catcheside, P & Zajamsek, B, 2022. Audibility of wind farm infrasound and amplitude modulated tonal noise at long-range locations.* Applied Acoustics, *201 (2022), 109106. [URL]*

[19] *Salt, AN & Hullar, TE, 2010. Responses of the ear to low frequency sounds, infrasound and wind turbines.* Hearing Research, *268 (1-2), 12-21. [URL]*

[20] *Weichenberger, M, Bauer, M, Kühler, R, Hensel, J, Forlim, CG, Ihlenfeld, A, Ittermann, B, Gallinat, J, Koch, C & Kühn, S, 2017. Altered cortical and subcortical connectivity due to infrasound administered near the hearing threshold- Evidence from fMRI.* PLoS ONE, *12, e0174420. [URL]*

[21] *van Kamp, I, & van den Berg, F, 2021. Health effects related to wind turbine sound: An update.* International Journal of Environmental Research and Public Health, *18 (17), 9133. [URL]*

[22] *Harrison, RV, 2014. On the biological plausibility of Wind Turbine Syndrome.* International Journal of Environmental Health Research, *25 (5), 463-468. [URL]*

> *Moreover, similar levels of exposure as are typical for wind turbine infrasound at dwellings can be expected from other common environmental sources of infrasound*[23]*, which tend not to be associated with the wide range of specific and non-specific symptoms that have been claimed to be attributable to wind turbine infrasound*[24].
>
> *It has been demonstrated in controlled experiments*[25,26,27,28]*, including the involvement of participants self-reporting to be sensitive to wind turbine infrasound, that exposure to infrasound at levels representative of wind turbine immissions at dwellings is not associated with physiological or psychological health effects, whereas the expectation of effects from being exposed to wind turbine infrasound, and positive or negative messages influencing that expectation, can affect health symptom reporting*[29].
>
> *Overall, the findings from the existing evidence base indicate that infrasound from wind turbines at typical exposure levels has no direct adverse effects on physical or mental health and reported symptoms of ill-health are more likely to be psychogenic in origin.*
>
> *It is expected that further evidence from ongoing studies into wind turbine infrasound effects will emerge soon, in particular from the NHMRC* [National Health and Medical Research Council] *studies in Australia. However, based on the existing scientific evidence, it does appear probable that the above findings will not be contradicted by newer evidence."*

82. Further research articles concerning direct investigations of the human perception, responses, or health outcomes in relation to wind turbine infrasound or low frequency sound have been published since our review for BEIS, which continue to provide evidence consistent with our conclusions as set out above[30,31,32,33].

83. One of these latest studies, Marshall et al (2023)[33] [CD012.039], is especially notable, as it presents the *"further evidence…from the NHMRC studies in Australia"* that we referred to in the above-quoted section from the WSP BEIS Report [CD012.015], This study comprised a double-blinded randomised crossover trial involving 37 participants, and may be considered to be the most comprehensive controlled investigation of human responses to wind turbine infrasound exposure to date.

84. The participants were exposed to three types of sound in separate, 3-day long laboratory exposures in a controlled testing environment comprising an ensuite bedroom. During each 72-hour exposure, the participants were exposed to either a wind turbine infrasound stimulus, a 'sham' stimulus (i.e., pretence of infrasound), or a control sound comprising a mix of road traffic and aircraft. The wind turbine infrasound was carefully tailored to match as closely as possible

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[23] *van Kamp, I & van den Berg, F, 2018. Health effects related to wind turbine sound, including low-frequency sound and infrasound.* Acoustics Australia, *46, 31-57 [URL]*

[24] *Chapman, S & Simonetti, T, 2012. Is there anything not caused by wind farms? [URL]*

[25] *Tonin, R, Brett, J & Colagiuri, B, 2016. The effect of infrasound and negative expectations to adverse pathological symptoms from wind farms.* Journal of Low Frequency Noise, Vibration and Active Control, *35 (1), 77-90. [URL]*

[26] *Nelson, P, Bryne, A, Waggenspack, M, Lueker, M, Feist, C, Herb, B & Marr, J, 2019. Testing the human response to wind turbine emissions. Wind Turbine Noise 2019, 12-14 June, Lisbon. INCE-Europe.*

[27] *Maijala, PP, Kurki, I, Vainio, L, Pakarinen, S, Kuuramo, C, Lukander, K, Virkkala, J, Tiippana, K, Stickler, EA & Sainio, M, 2021. Annoyance, perception, and physiological effects of wind turbine infrasound.* Journal of the Acoustical Society of America, *149 (4), 2238-2248. [URL]*

[28] *Krahé, D, Alaimo Di Loro, A, Müller, U, Elmenhorst, E, De Gioannis, R, Schmitt, S, Belke, C, Benz, S, Großarth, S, Schreckenberg, D, Eulitz, C, Wiercinski, B & Möhler, U, 2020. Lärmwirkungen von Infraschallimmissionen (Noise Effects from Infrasound Immissions, in German, with abstract in English). [URL]*

[29] *Crichton, F, Dodd, G, Schmid, G, Gamble, G & Petrie, KJ, 2014. Can expectations produce symptoms from infrasound associated with wind turbines?* Health Psychology, *33 (4), 360-364. [URL]*

[30] *van den Berg, 2022. Comments on the Article "Negative Effect of High-level Infrasound on Human Myocardial Contractility: in Vitro Controlled Experiment" by Chaban R. et al. (Noise Health 2021;23:57-66).* Noise & Health, *24 (112), 28-29. [URL]*

[31] *Nguyen, PD, Hansen, KL, Lechat, B, Hansen, C, Catcheside, P, Zajamsek, B, 2022. Audibility of wind farm infrasound and amplitude modulated tonal noise at long-range locations.* Applied Acoustics, *201 (2022), 109106. [URL]*

[32] *Małecki, P, Pawlaczyk-Łuszczyńska, M, Wszołek, T, Preis, A, Kłaczyński, M, Dudarewicz, A, Pawlik, P, Stępień, B & Mleczko, D, 2023. Does stochastic and modulated wind turbine infrasound affect human mental performance compared to steady signals without modulation? Results of a pilot study.* International Journal of Environmental Research and Public Health, *20 (3), 2223. [URL]*

[33] *Marshall, NS, Cho, G, Toelle, BG, Tonin, R, Bartlett, DJ, D'Rozario , AL, Evans, CA, Cowie, CT, Janev, O, Whitfield, CR, Glozier, N, Walker, BE, Killick, R, Welgampola, MS, Phillips, CL, Marks, GB & Grunstein, RR, 2023. The health effects of 72 hours of simulated wind turbine infrasound: A double-blind randomized crossover study in noise-sensitive, healthy adults.* Environmental Health Perspectives, *131 (3), CID: 037012. [URL]*

audio recordings of wind turbine infrasound made in the vicinity of residential properties at real wind farms. The authors note that the wind turbine infrasound stimulus was "*measurable but inaudible to all participants…*[and] *is higher than what has been recorded both inside and outside a dwelling where people have previously reported* [adverse health symptoms attributed to wind turbine infrasound] *from exposure experienced at 335 m…from a wind turbine*". They also report a "*high level of confidence that an appropriate infrasound exposure was generated in the study*".

85. A wide range of response types was measured in the study, the most important of which (to the study objectives) was objective measurements of sleep quality and structure, using polysomnography (PSG). PSG involves attaching electrodes to participants and directly measuring electrical brain activity during sleep and is widely regarded as the most accurate objective method currently available for investigating sleep quality. Further tests and measurements were made, to examine the occurrence of other health symptoms that have been reported and attributed to wind turbine infrasound, including cognitive impairment, stress, abnormal heart activity, depression and anxiety, which were examined via neurocognitive exercises, subjective questionnaire, blood pressure measurements, urine and blood samples.

86. The measurement data from the trial were analysed using a range of statistical tests. The study conclusions were summarised as follows:

> "*Our study found no evidence that 72 h of exposure to a sound level of ∼90 dB pk re 20 μPa of simulated wind turbine infrasound in double-blind conditions perturbed any physiological or psychological variable. None of the 36*[34] *people exposed to infrasound developed what could be described as WTS* ['wind turbine syndrome'[35]]. *Our study is unique because it measured the effects of infrasound alone on sleep. This study suggests that the infrasound component of WTN is unlikely to be a cause of ill-health or sleep disruption, although this observation should be independently replicated.*"

87. These findings, viewed alongside the existing body of scientific research into wind turbine infrasound, provide further, robust evidence supporting the position that wind turbine infrasound at exposure levels expected at neighbouring residents does not cause or contribute to any adverse health symptoms. Rather, (as noted in the WSP BEIS report [CD012.015]) the scientific evidence continues to indicate that reports of health symptoms are more likely to be psychogenic in origin than associated with infrasound exposure. This conclusion may, understandably, be somewhat unpalatable to some of those who believe that wind turbine infrasound causes them to feel ill, but there is no convincing scientific case supporting the alternative conclusion.

The current guidance framework is based on frequency-weighted levels, which characterise the non-linear response of the human hearing system. There are no current regulations or guidelines in the world requiring assessment of unweighted wind turbine sound levels, nor are there any criteria or exposure-response relationships in the scientific literature that would support the development of an assessment of unweighted sound levels. Moreover, there is no compelling evidence suggesting this would be necessary to provide suitable controls for wind turbine noise. On the other hand, there is evidence supporting the use of frequency-weighted levels to assess and control wind turbine noise.

88. The idea that increases in turbine size have led to a significant, systematic increase in low frequency sound emissions, or a shift in the spectrum of turbines towards lower frequency-skewed sound emissions is, in my experience, frequently presented as scientific fact. We examined evidence for and against this claim in relation to wind turbines during preparation of

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[34] *Although 37 participants took part in the study, 1 of the participants did not receive the infrasound exposure.*

[35] *'Wind turbine syndrome' is a term some people give to the wide range of specific and non-specific physiological and psychological symptoms of ill-health that have been claimed to be attributable to wind turbines.*

the WSP BEIS Report [CD012.015]. We found that, when this has been systematically investigated, different investigators arrived at differing conclusions, even when examining similar sets of data. From our report:

> *"Research evidence on the general low frequency character of the sound emissions from larger, more powerful turbines is conflicting. A study undertaken for the Danish government produced differing interpretations of the measurement data by two of the project partners: one concluded[36] that increasing turbine size and power ratings was not associated with a systematic increase in the proportion of low frequency sound emissions; another analysed the same dataset and reached the opposite conclusion[37]. Further analysis was later undertaken on an expanded dataset, which again concluded that the notion that larger turbines systematically emit a greater proportion of low frequency sound energy compared with smaller turbines is not supported by the available evidence[38,39]."*

89. My point here is not to completely discount the possibility that larger turbines *may* emit greater lower frequency sound energy than smaller turbines, but to highlight that this notion is not proven knowledge, but rather, is an open matter of scientific debate.

90. Aside from the sound emission character of turbines there is also the matter of frequency weighting in the sound level assessment index. Simplistically-speaking, the applied A-weighting curve reduces the emphasis of the low frequency range to enable a single-number value to approximately represent the wide frequency response of the human hearing system. The provenance of the curve lies in extensive, controlled laboratory measurements of human hearing, which produced what are known as 'equal loudness contours'. These, as shown in Figure 2, represent the decibel values at each frequency considered to be subjectively equal in loudness to a human listener (as quantified using a loudness rating of 'phons'). The strong non-linearity of these curves demonstrates the decreasing sensitivity of the hearing system at low (and high) frequencies, and its concentration of sensitivity in frequencies around the 1 kHz – 5 kHz range, which is important for human evolutionary reasons concerning threat detection and speech intelligibility. For example, a 20 Hz tone at a sound pressure level of 105 dB is judged to have the same subjective loudness as a 200 Hz tone at 62 dB or a 2000 Hz tone at 50 dB. In other words, far more sound energy is needed to elicit the same subjective perception at a lower frequency than at a higher frequency.

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[36] *Madsen, KD & Pedersen, TH, 2010. EFP-06 project: Low frequency noise from large wind turbines. Final report. AV 1272/10. Danish Energy Authority.*

[37] *Møller, H & Pedersen, CS, 2011. Low-frequency noise from large wind turbines.* Journal of the Acoustical Society of America, *129 (6), 3727-3744. [URL]*

[38] *Søndergaard, B, 2014. Noise and low frequency noise from wind turbines. Inter-noise 2014, 16-19 November, Melbourne. I-INCE [URL]*

[39] *Søndergaard, B, 2015. Low frequency noise from wind turbines: do the Danish regulations have any impact? An analysis of noise measurements.* International Journal of Aeroacoustics, *14 (5-6), 909-915. [URL]*

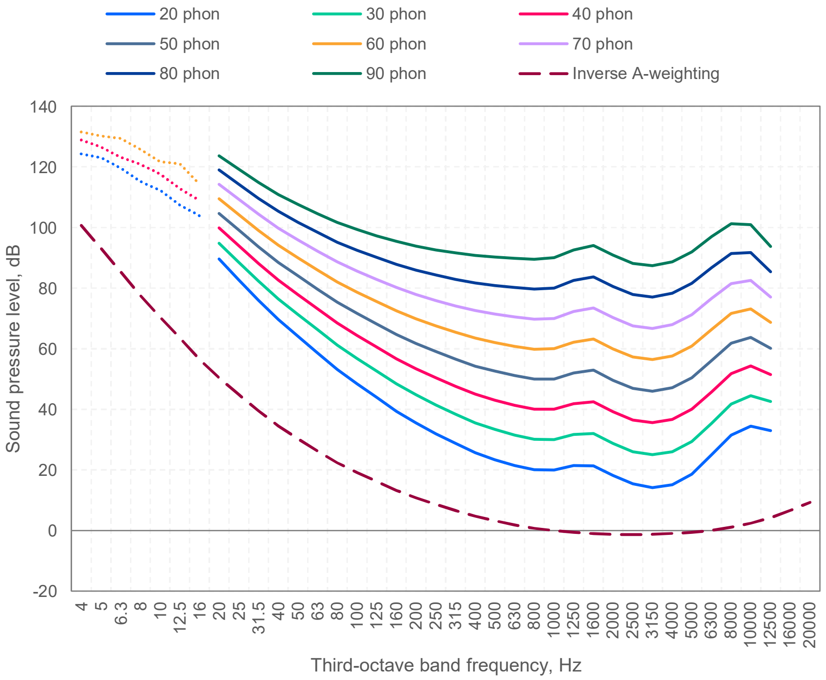

Figure 2: Equal loudness contours; solid lines: 20 Hz–12.5 kHz from ISO 226:2003[40]; dotted lines: 4-16 Hz experimental results from Rajala et al (2022)[41]; dashed line: inverse A-weighting from BS EN (IEC) 61672-1:2013[42]

91. What is also shown in Figure 2 is that the A-weighting curve (dashed line, shown here inverted for consistency of comparison) approximates the frequency-dependent response of the hearing system over a wide range of frequencies. When A-weighting is applied to a sound spectrum, the levels of sound shown in the lower frequencies are reduced, because this is what happens naturally in the human hearing system – the ear acts as a filter, in which much of the low frequency energy incident at the outer ear is attenuated. The weighted spectral levels are then combined to yield a single value that is intended to represent a form of 'overall loudness', as perceived by a typical human with normal hearing.

92. Alternative, more complex approaches to obtaining a single value representing perceived loudness do exist. These are more computationally intensive and require greater amounts of sound data as inputs. Yet it has been shown in a controlled laboratory study that the far simpler approach of A-weighting sound levels has at least as good a correlation with subjective ratings of the loudness perception of wind turbine sound (and many other types of environmental sound) as these dedicated 'loudness metrics'[43]. In other words, the A-weighting curve represents a remarkably effective and efficient approach to approximating subjective loudness, which is supported by evidence.

93. In relation to low frequency sound and noise limits, the WSP BEIS Report also noted the following:

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[40] *ISO 226:2003. Acoustics — Normal equal-loudness-level contours. International Organization for Standardization. [URL]*

[41] *Rajala, V, Hakala, J, Alakoivu, R, Koskela, V & Hongisto, V, 2022. Hearing threshold, loudness, and annoyance of infrasonic versus non-infrasonic frequencies.* Applied Acoustics, *198 (2022), 108981. [URL]*

[42] *BS EN 61672-1:2013. Electroacoustics — Sound level meters. Part 1: Specifications. British Standards Institution. [URL]*

[43] *Yokoyama, S, Sakamoto, S, Tsujimura, S, Kobayashi, T & Tachibana, H, 2015. Loudness experiment on general environmental noises considering low-frequency components down to infrasound.* Acoustical Science and Technology, *36 (1), 24-30. [URL]*

> *"Studies have highlighted that wind turbines emit a greater proportion of low frequency sound than is associated with some other common sources of environmental sound (such as road traffic[44]). However, it has also been noted that the typical spectrum of wind turbine sound does not have the expected features to indicate it would be associated with specific low frequency noise issues[45] (which is consistent with experiments undertaken as part of the Japan study[46]). Previous evidence reviews have concluded that there are unlikely to be specific adverse effects or health outcomes associated with wind turbine low frequency sound exposure beyond annoyance[47,48]. Furthermore, a comparison of noise annoyance exposure-response functions from various studies concluded that low frequency sound is unlikely to be a primary factor in responses[49]. This conclusion was based on the observed fit of the modelled relationships (which were developed from an assumed loudness function that would not provide a good fit if low frequency components had a strong influence on the observed responses).*
>
> …
>
> *The wind turbine sound regulation in Denmark includes a specific limit for A-weighted indoor low frequency sound levels in the range 10-160 Hz, which is 25 dB $L_{Aeq(10\text{-}160Hz)}$ during the day and 20 dB $L_{Aeq(10\text{-}160Hz)}$ at night.*
>
> *A review undertaken for the Australian government concluded that there is insufficient evidence on the effects of low frequency sound and infrasound…to recommend any limits[50].*
>
> *Another review showed that C-weighted wind turbine sound levels are unlikely to exceed criteria for low frequency noise disturbance while A-weighted levels are below ~48 dB L_{Aeq} and concluded that no specific low frequency limits are necessary to control wind turbine sound beyond limits on A-weighted levels[51] (which have been shown in controlled experiments to provide a reliable estimator for the perceived loudness of wind turbine sound[52]).*
>
> …
>
> *Reviews of the* [potential] *effects of exposure to low frequency sound from wind turbines currently suggest these are limited to annoyance, at typical exposure levels. It was found in a previous UK study of reported 'low frequency noise' issues associated with wind turbines, that disturbances reported were more likely to be due to audible AM* [amplitude modulation] *rather than low frequency sound[53]. Moreover, the evidence currently suggests that, due to the inherent characteristics of wind turbine sound, suitable controls on A-weighted sound levels are expected to also provide sufficient control for the potential impact of low frequency noise."*

94. The potential connection mentioned above between the perception of AM and reports of low frequency noise impacts is discussed further below.

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[44] *Alamir, MA, Hansen, KL & Catcheside, P, 2021. Penalties applied to wind farm noise: Current allowable limits, influencing factors, and their development.* Journal of Cleaner Production, *295 (2021). [URL]*

[45] *Hessler, G, Leventhall, G, Schomer, P, & Walker, B, 2017. Health effects from wind turbine low frequency noise & infrasound: Do wind turbines make people sick? That is the issue.* Sound and Vibration, *51 (1), 34-44. [URL]*

[46] *Yokoyama, S, Sakamoto, S & Tachibana, H, 2014. Perception of low frequency components in wind turbine noise.* Noise Control Engineering Journal, *62 (5), 295-305. [URL]*

[47] *van Kamp, I, & van den Berg, F, 2021. Health effects related to wind turbine sound: An update.* International Journal of Environmental Research and Public Health, *18 (17), 9133. [URL]*

[48] *van Kamp, I & van den Berg, F, 2018. Health effects related to wind turbine sound, including low-frequency sound and infrasound.* Acoustics Australia, *46, 31-57 [URL]*

[49] *Michaud, DS, Keith, SE, Feder, K, Voicescu, SA, Marro, L, Than, J, Guay, M, Bower, T, Denning, A, Lavigne, E, Whelan, C, Janssen, SA, Leroux, T & van den Berg, F, 2016. Personal and situational variables associated with wind turbine noise annoyance.* Journal of the Acoustical Society of America, *139 (3), 1455-1466. [URL]*

[50] *Davy, JL, Burgemeister, K, Hillman, D & Carlile, S, 2020. A review of the potential impacts of wind turbine noise in the Australian context.* Acoustics Australia, *48 (2), 181-197. [URL]*

[51] *Hessler, G, Leventhall, G, Schomer, P, & Walker, B, 2017. Health effects from wind turbine low frequency noise & infrasound: Do wind turbines make people sick? That is the issue.* Sound and Vibration, *51 (1), 34-44. [URL]*

[52] *Yokoyama, S, Sakamoto, S, Tsujimura, S, Kobayashi, T & Tachibana, H, 2015. Loudness experiment on general environmental noises considering low-frequency components down to infrasound.* Acoustical Science and Technology, *36 (1), 24-30. [URL]*

[53] *Hayes McKenzie Partnership, 2006.* The measurement of low frequency noise at three UK wind farms. *Contract no. W/45/00656/00/00 URN no. 06/1412. Department of Trade & Industry. [URL]*

SUMMARY

The EIA methodology was undertaken in accordance with the current guidance. Based on the current scientific evidence, no adverse effects are anticipated due to infrasound or low frequency noise beyond the scope of the EIAR noise assessment.

95. The current guidance is based on assessing and controlling exposure to A-weighted sound levels with the intention of providing reasonable protection for 'outdoor amenity' (noise annoyance) and indoor sleep quality. The evidence I have outlined above and detailed in the WSP BEIS Report [CD012.015] indicates that this general approach remains credible, and there is currently no strong case for specific, technical assessments of risks from infrasound or low frequency noise on human health above and beyond what is addressed in the guidance.

96. Similarly, no concerns have been raised by the SAC's independent acoustic consultant ACCON UK [CD002.189] regarding risks of infrasound or low frequency noise impacts that are unaddressed in the CWF EIAR [CD002.011].

97. The evidence presented in the SSfS SoE Appendix 1 [CD016.032] purporting to demonstrate that imperceptible infrasound is associated with adverse effects on human health is, by my reading, technically flawed, likely to be biased, and conflicts with the weight of recent scientific evidence on wind turbine infrasound identified in the literature.

Amplitude Modulation

98. The SSfS SoE [CD016.032] only briefly addresses AM, noting that further evidence will be presented at the Hearing. The SoE advises that the scoping out of AM from the EIAR assessment will be challenged in the further evidence to be presented but does not specify what grounds will be relied on. Accordingly, this section provides a brief overview of the state of understanding of wind turbine AM as found in the scientific evidence, the existing guidance, and how this relates to development planning processes.

99. Amplitude modulation in wind turbine sound is a regular variation in the sound level that is associated with the blade rotation. This characteristic is illustrated in Figure 3, which shows a short period of measured wind turbine sound levels exhibiting AM, as an example. The plot in Figure 3 also illustrates that there are two aspects of AM to consider: the 'modulation depth', which is the range between the 'peaks' and 'valleys' in the sound level, and the 'modulation frequency', which is the number of peaks in a given time period.

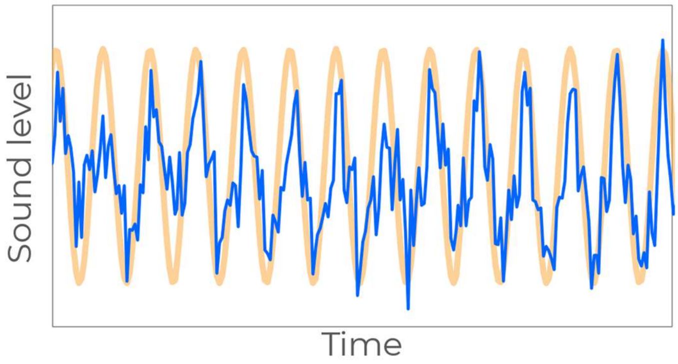

Figure 3: Example of amplitude modulation in wind turbine sound
Blue line indicates measured A-weighted sound levels exhibiting periodic AM, which is emphasised for visualisation purposes by the underlying yellow line

100. There are two distinct forms of wind turbine AM that are associated with different causal mechanisms and contributing factors.

101. The best-understood form is the AM that is commonly described as ‘blade swish’, which typically is only prominent at close ranges to turbines. This AM has a higher frequency character, as indicated by its common description.

102. The second form of AM encompasses a wide range of potential sound characters with greater emphasis in lower frequencies (for example, common descriptions include ‘whoomph’, ‘whoosh’ or ‘lash’), and can be more prominent at longer ranges. This form is less well understood compared with ‘blade swish’, but has been investigated, leading to the proposition of several potential contributing factors, any of which could potentially be involved to greater or lesser degrees in its occurrence. One important potential factor is that of blade ‘stall’, which results in exaggerated turbulence at the blades. This is particularly notable because stall is associated with the positioning of the turbine blade angle in relation to the incoming wind, which is, to an extent, under the control of the operator. In other words, one option for mitigating the risk of this form of AM occurring is available to operators within standard turbine control systems.

103. As noted above, a UK government-commissioned study published in 2006[54] found that reported disturbances due to ‘low frequency noise’ from wind turbines at three UK sites were more likely to be connected with the AM that was recorded as being audible during the night at the households involved.

104. A further government-funded study was published in 2007, which examined the prevalence of AM-related complaints from wind farms, based on a questionnaire survey of local authorities[55]. The study concluded that the number of people affected, in comparison with other sources of environmental sound, was probably too small to justify further publicly funded research. The conclusions concerning the actual number of complaints reported by the survey respondents that could be considered to be AM-related was subsequently challenged in a reanalysis of the survey data, which argued that the proportion of respondents identifying likely AM as a factor in complaints was greater than had been highlighted in the original study[56,57].

105. A wide-ranging study of AM, commissioned by RenewableUK, was published in 2013, which included investigations into possible causes for AM, methods of quantifying AM, turbine operational influences on AM, and subjective responses to AM exposure[58]. Among other things, the study proposed a ‘penalty scheme’ for AM, to be considered for inclusion in planning conditions, which echoed existing schemes in place to control other sound characteristics, such as tonality.

106. The current Scottish Government online planning guidance, *Onshore wind turbines* [CD012.014], was published in 2014. This noted the findings of the 2007 study in relation to AM prevalence[55], but no further guidance on AM was provided.

107. In 2016, we completed a UK government-commissioned study that reviewed evidence on human response to AM in wind turbine sound[59]. Key conclusions from our study included the following:

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[54] *Hayes McKenzie Partnership, 2006.* The measurement of low frequency noise at three UK wind farms. *Contract no. W/45/00656/00/00 URN no. 06/1412. Department of Trade & Industry.* [URL]

[55] *Moorhouse, A, Hayes, M, von Hünerbein, S, Piper, B & Adams, M, 2007. Research into aerodynamic modulation of wind turbine noise: final report.* [URL]

[56] *van den Berg, F, 2009. Why is wind turbine noise noisier than other noise? Euronoise 2009, 26-28 October, Edinburgh. Institute of Acoustics.*

[57] *van den Berg, F, 2011. In: Effects of sound on people. Bowdler, D & Leventhall, G (eds),* Wind turbine noise *(chapter 6). Multi-Science Publishing.*

[58] *RenewableUK, 2013.* Wind turbine amplitude modulation: research to improve understanding as to its cause and effect. [URL]

[59] *WSP | Parsons Brinckerhoff, 2016.* Wind turbine AM review: Phase 2 report. *3514482A Issue 3. Department for Business, Energy & Industrial Strategy.* [URL]

- Audible AM increases annoyance responses to wind turbine sound.
- AM is more likely to occur or be audible at night-time.
- A penalty scheme control for AM could be applied at development planning stages to address the risk of AM impacts, similarly to those applied for tonality.

108. The form of penalty scheme recommended took the same general form as that recommended in the 2013 RenewableUK study (as supported by available evidence from laboratory tests), but applied using a different metric for measuring AM, which had been developed by the IOA and presented in a report also published in 2016[60].

109. Following this, a proposed example planning condition for AM control implementing the recommended penalty scheme was developed by a group of consultant practitioners, which included some members of the ETSU-R-97 Noise Working Group[61]. It was noted that the proposals "*represent the broad consensus view…, following a period of discussion, compromise and agreement. This approach is proposed based on the current state of understanding but may be subject to modification in light of new research and further robust information*". This approach has subsequently formed the basis for proposed AM planning conditions attached to wind turbine development applications, however it has not yet been universally recognised or incorporated into official good practice guidance. It is important to note that a legal expert review of the proposal for adherence to the 'six tests'[62] was not sought, and, at the time of preparing this statement, I'm unaware of any planning decisions or court judgements that have tested this.

110. In the study documented in the WSP BEIS Report, we considered recent evidence and stakeholder views on AM, on the basis of which we recommended that further, officially-recognised AM guidance should be developed, with the aforementioned approach used as a starting point.

111. Our key findings on AM also included the following:

- The current guidance does not fully address the potential impact of AM in wind turbine sound.
- Reliable predictions of AM in the context of development planning and noise assessment guidance are unlikely to be practically feasible in the near future.
- Research on the effects of AM demonstrate that its audibility increases adverse impact, but the effect is secondary compared with the overall sound level. This indicates that a character penalty is a suitable control approach, and proposed penalty schemes are evident in the literature.
- A study should be undertaken to confirm the most effective approach. The practical application of the scheme in terms of compliance measurements would also require careful consideration and guidance.
- Responses to the stakeholder engagement indicate that turbine suppliers are aware of the importance of ensuring that operational mitigation for AM is available on modern turbines.

112. While we have recommended that further officially-recognised technical guidance on AM be developed, including a control for use at development planning stages, this recommendation has yet to be fulfilled.

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[60] *IOA Noise Working Group (Wind Turbine Noise) Amplitude Modulation Working Group, 2016.* Final report: A method for rating amplitude modulation in wind turbine noise. *[URL]*

[61] *McKenzie, A, Cand, M, Bowdler, D, Jiggins, M, Irvine, G, Reid, M, Perkins, R, Lotinga, M, Hayes, M & Bullmore, A, 2017. A planning condition for wind turbines.* Acoustics Bulletin*, 42 (6), 56-60. [URL]*

[62] *Scottish Government, 1998. Planning Circular 4/1998: The use of conditions in planning permissions. [URL]*

113. A recent, large-scale observational study investigating wind turbine noise and AM was commissioned by the German government, the full results of which were published in 2022[63]. The study involved over 400 participants situated around 5 geographical study areas within 3 km of wind turbines. It was found that the sound characteristics with the strongest correlations with reported noise annoyance were descriptions that would be associated with AM (such as 'whooshing'). The report did not provide any specific recommendations for AM assessment criteria or technical guidance that could be related to development planning.

114. SAC's consultant technical advisor ACCON has not raised any concern with the CWF EIAR noise assessment [CD002.011] in terms of the scoping out of a technical evaluation of AM but has recommended for a planning condition addressing AM to be imposed. It remains unclear at present whether a planning condition for control of AM could be prepared that ensures the Scottish Government criteria for planning conditions would be met[62].

115. In lieu of further, official technical guidance, the wording of a proposed condition addressing AM as received from SAC is under review.

4. Adequacy of the Noise Assessments and Background Noise Measurements

Baseline Noise Survey

APPROACH

116. To inform the CWF noise assessment [CD002.011], a detailed and extensive baseline noise survey was undertaken in accordance with the requirements of ETSU-R-97 and the IOA GPG.

117. Full details of the baseline noise survey are presented in Section 9.5.3 of the CWF EIAR [CD002.011] and the associated Appendix 9.4 [CD002.140].

118. Table 1 below presents a check list of specific survey recommendations / requirements that are detailed in the IOA GPG, as well as confirmation of how they were complied with for the completed survey.

Baseline Survey Requirement / Recommendation	IoA GPG Reference	Survey Detail	Compliance?
Noise from existing wind farms to be excluded from baseline survey data.	Summary Box 3 of the IOA GPG	Measurement data obtained at Location C (Genoch Cottage) and Location F (Doughty Farm), which are those closest to existing wind farms, was subject to directional analysis and	Met

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[63] *Schmitter, S, Alaimo Di Loro, A, Hemmer, D, Schreckenberg, D, Großarth, S, Pörschmann, C & Kühner, T, 2022. Noise effects of the use of land-based wind energy. Project Number 3717 43 110 0 Report No. FB000656/ENG (Final report). Umweltbundesamt. [URL]*

Baseline Survey Requirement / Recommendation	IoA GPG Reference	Survey Detail	Compliance?
		found not to include significant contribution from existing wind farms. ACCON Review paragraph 8: "*Directional filtering has also been undertaken to inform whether the noise data has been affected by currently operational wind farms. The analysis has confirmed that wind direction had negligible influence on the measured noise data and that Table 9.28 can be relied upon as representative of acoustic conditions without the presence of wind turbine noise.*	
Measurement Locations to be in the vicinity of noise sensitive receptors (principally houses), and selected to allow characterisation of the noise environment at the property or group of properties to which it is being applied	Paragraph 2.2.4 and Summary Boxes 4 and 8 of the IOA GPG	All measurements undertaken at residential dwellings. Care taken to ensure representative equipment installation locations. Adopted measurement locations selected as representative of property groups where applicable. ACCON Scoping Response [CD002.108]: "*The proposed measurement locations appear to provide suitable coverage for the nearest noise sensitive properties surrounding the proposed development. Based on my review of available information, the monitoring locations generally seem to have been selected such that they will provide suitable proxies for nearby properties*"	Met
Engagement with Local Planning Authority	Summary Box 5 of the IOA GPG	The scope and approach to the baseline noise survey was agreed with SACs specialist noise advisors (ACCON UK) prior to commencement of the baseline noise survey. [CD002.108]	Met
Surveys can be carried out at any time of year provided that seasonal effects leading to raised noise levels can be excluded	Summary Box 6 of the IOA GPG	The survey was carried out in August / September to avoid periods of increased watercourse noise. Periods of significant rainfall were removed during data analysis. ACCON Review paragraph 8: "*The noise measurement data has been subject to filtering based on rainfall and anomalous noise events.*"	Met
Measurement Equipment: Class 1 specification equipment to be used.	Summary Box 7 of the IOA GPG	Class 1 specification noise measurement equipment was deployed.	Met

Baseline Survey Requirement / Recommendation	IoA GPG Reference	Survey Detail	Compliance?
		CWF EIAR Chapter 9 paragraph 196: *“The noise survey was undertaken using BS EN 61672-1-2013 Class 1 specification sound pressure level measurement equipment…”*	
Use of enhanced or double skin windscreens	Summary Box 7 of the IOA GPG	Enhanced or double skin windscreens deployed at all measurement locations. CWF EIAR Chapter 9 paragraphs 198 and 200: “*Each of the 01dB measurement systems were fitted with a standard factory fit windshield, as well as a secondary windshield system which comprised a cylinder of 20mm thick 45ppi reticulated foam*”. *“Each of the Rion measurement systems were installed with their standard outdoor WS-15 windshields, which are of substantial dimensions (reticulated foam with approx. 200mm diameter)”* ”	Met
Survey data synchronised with site specific meteorological data	Summary Box 9 of the IOA GPG	Simultaneous on-site meteorological measurements undertaken over the full duration of the baseline noise survey. CWF EIAR Chapter 9 paragraph 205 *“For the duration of this baseline noise survey, simultaneous 10-minute meteorological measurements were undertaken on the Site of the Proposed Development.”* ACCON Review paragraph 7: *“Wind speeds have been measured on-site at heights of 50.4 m and 81 m. The measurements have been used to determine the site-specific wind shear profile, and to calculate the hub height wind speed at 125 m. The hub height wind speed has then been adjusted to a 10 m standardised height using the wind shear profile.”*	Met
Synchronisation with rain measurement data	Summary Box 10 of the IOA GPG	On-site meteorological measurements included rain fall data for the duration of the survey.	Met

Baseline Survey Requirement / Recommendation	IoA GPG Reference	Survey Detail	Compliance?
		CWF EIAR Chapter 9 paragraph 205 *"The obtained measurement data included rainfall, average wind speed and wind direction."*	
Noise and meteorological data synchronisation	Summary Box 11 of the IOA GPG	The time clocks of the deployed noise measurement systems were synchronised with the time clock of the meteorological measurement system (or the difference in time clocks was logged and measurement data subsequently adjusted). Time drifts were logged and were within the tolerances allowed by the IOA GPG. CWF EIAR Chapter 9 paragraph 202 *"The system time clocks were then checked at the end of the survey, to ensure that none had exhibited a significant drift in accordance with the IoA GPG"*	Met
Survey Duration	Summary Box 12 of the IOA GPG	Survey durations were between 23 and 36 days, depending upon Location, which are significantly longer than the 2-week period that the IOA GPG references. Survey durations were sufficient to ensure good resulting wind speed / background noise level trend lines were established and the numbers of obtained data points per wind speed bin were in excess of the IOA GPG requirements. ACCON Review paragraph 6: The survey duration varies between *"23 and 36 days at each receptor. The duration of the noise surveys is appropriate and in-line with assessment guidance."*	Met

Table 1 Summary of Survey Compliance

BASELINE DATA

119. Paragraph 192 of Chapter 9 the CFW EIAR [CD002.011] confirms that the following Measurement Locations were adopted during the CWF baseline noise survey:

- Location A: Blair Farm
- Location B: Glenalla
- Location C: Genoch Cottage
- Location D: Tairlaw Toll
- Location E: White Row

- Location F: Doughty Farm

120. The results of the baseline noise survey are presented in Graphs 9.5.1 to 9.5.12 in Appendix 9.5: *Baseline noise conditions*, and Table 9.28 of Chapter 9 of the CFW EIAR [CD002.011].

121. SACs technical noise advisors (ACCON UK), confirm acceptance of the baseline noise survey and results stating the following at paragraph 10 of the ACCON Review [CD012.041]:

> *"10. The approach to the Carrick baseline noise survey, wind shear calculations and data filtering is in-line with IOA GPG and ACCON agree that the data presented in Table 9.28 is representative of existing baseline noise conditions at the measurement locations."*

122. Of the above Locations, B, C and D were also adopted as measurement locations during the KWF baseline noise survey [CD012.012]. Graphs 9.5.19 to 9.5.24 of Appendix 9.5 [CD002.141] of the CWF EIAR [CD002.011] compare the results of these two surveys for these locations (B, C and D), showing the CWF results to be lower and therefore more stringent. The CWF baseline noise survey results were therefore adopted for those locations, representing a worst case. The same approach was adopted in the KWF EIAR [CD003.193] and the SoAM [CD015.014]. Paragraph 4.1 of the SoAM confirms that the baseline data chosen were the:

> *"…lowest of those previously presented in the separate noise assessments. For example, at Glenalla, which was subject to separate noise surveys for CWF and KWF, the survey data from CWF have been adopted, being the lowest and therefore the limiting case."*

123. The approach adopted therefore represents a worst case (i.e., it is precautionary).

124. The sound pressure level measurement equipment deployed during the survey comprised Class 1 specification systems. Concern is sometime raised regarding the noise floors of deployed equipment (i.e., how low the equipment can measure before noise inherent in the measurement system circuitry affects the measurement results).

125. The deployed measurement equipment had very low noise floors. Equipment noise floors have not had any significant effect on the assessment findings or conclusions drawn. This is considered further in Annex C.

Adequacy

126. As detailed in Section 3, the completed noise assessment work has been undertaken in accordance with the applicable assessment methodology ETSU-R-97 and the IOA GPG as required by both national and local planning policy and guidance. The adopted approach was agreed with SAC's specialist noise advisors through consultation at the Scoping Stage [CD002.108] and was then followed in the noise assessment as reported in the CWF EIAR [CD002.011]. The agreement of the approach extended to include the applicable assessment methodology (ETSU-R-97 and the IOA GPG), the approach to the baseline noise survey, noise level predictions and baseline data analysis, the total ETSU-R-97 noise levels limits to be applied, and the approach to cumulative noise assessment.

127. The consideration of potential cumulative noise impact is at the core of the completed noise assessment work. As required by ETSU-R-97, the assessment took due account of wind turbine noise impacts that could arise as a result of the three proposed developments (CWF, CMWF and KWF) as well as other consented / operational wind farms (DWF and HHWF) operating simultaneously.

128. The same considerations are encompassed within the detail presented in the SoAM [CD015.014]. The SoAM details how Site Specific Noise Limits (SSNLs) have been determined, for each of the three proposed developments (CWF, CMWF and KWF) accounting for the levels of noise that could be generated by the existing / consented wind farms. Compliance with their individual SSNLs will ensure that, when operated together with existing adjacent wind farms, the total operational wind turbine noise levels will remain compliant with the total ETSU-R-97 noise level limits.

129. Section 3 of this Hearing Statement confirms that the assessment of infrasound from wind turbines is not required, whilst the adopted assessment methodology is appropriate to duly account for any potential impact of low frequency noise from the proposed wind turbines.

130. In summary, the completed noise assessment work is fit for purpose, and this has been accepted by SAC in accordance with the findings of their technical noise advisors [CD012.041]. SAC have confirmed that subject to conditions governing operational noise limits, the operation of CWF, CMWF and KWF would not result in an unacceptable effect on any nearby noise sensitive receptors [CD016.031]. Further consideration to conditions is presented in Section 6 of this Hearing Statement.

5. Resulting Noise Effects

131. Section 9.4.4.4 of the CWF EIAR [CD002.011] provides full details of the adopted wind turbine noise assessment methodology.

132. The approach was in accordance with ETSU-R-97 and the IOA GPG, and in summary was to determine the remaining available noise level limits (after accounting for the levels that could potentially be generated by consented / operational wind farms (DSF and HHWF)) and to then compare predicted wind farm noise levels for two different scenarios against those remaining available limits. The two considered scenarios were:

1 CWF only (CWF in Isolation)

2 CWF + KWF + CMWF (Cumulative scenario)

133. The assessment was undertaken for a sample of receptors that are closest to the proposed development (CWF), and those which have the greatest potential to be subject to a cumulative noise impact.

134. For the second scenario, an example apportionment scheme is presented in Appendix 9-11 [CD002.147] of the CWF EIAR [CD002.011], to show how the remaining available noise level limits could be apportioned (split) into SSNL's for each individual proposed development. The assessment then shows how each development can comply with its SSNLs to ensure that the total ETSU-R-97 noise level limits would not be exceeded if all windfarms were operational simultaneously.

135. The same principle of approach is adopted within the SoAM, though the SoAM considers the cumulative scenario only, which is the limiting case. As such the SoAM first determines the SSNL's before any comparison with the predicted noise levels is made. Both approaches are consistent, showing how compliance with the SSNLs can be achieved ensuring that the total ETSU-R-97 noise level limits would not be exceeded if all windfarms were operational at the same time.

Carrick Windfarm in Isolation

136. The assessment results for the CWF operating in isolation are presented in Table 9.46 of the CWF EIAR [CD002.011] and the corresponding Graphs 9.10.1 to 9.10.6 of Appendix 9.10 [CD002.147].

137. Paragraphs 331 and 332 of the CWF EIAR [CD002.011] confirm that the noise levels from the CWF, when operating 'unconstrained', would be below the remaining available noise level limits. There are therefore no requirements for noise mitigation to be applied to CWF (such as the use of reduced noise turbine operating modes as part of a turbine noise management scheme).

138. The total ETSU-R-97 noise level limits would not be exceeded so no significant adverse effect would arise.

Cumulative Scenario

139. The assessment results for the cumulative scenario are presented in Table 9.47 of the CWF EIAR [CD002.011] and the corresponding Graphs 9.10.7 to 9.10.11 of Appendix 9.10 [CD002.146].

140. With the exception of Doughty Farm, during the daytime only, and with the turbines operating 'unconstrained', resulting noise levels would be below the remaining available noise level limits.

141. At Doughty Farm, during the daytime, a small limit exceedance (of up to +1.3dB) is identified, so consideration is given to mitigation in Section 9.7.3.1 of the CWF EIAR [CD002.011]. It is identified that, noise levels from CWF are approaching 10dB below the remaining available limit and as such the small exceedance is attributable to CMWF not CWF.

142. Paragraphs 348 to 357 then demonstrate the noise mitigation measures that are available to CMWF, including how the use of reduced noise turbine operating modes could be employed to ensure limit compliance. An example noise management scheme is presented in Table 9.48 of the CWF EIAR [CD002.011]. Table 9.48 and Graph 9.10.13 of Appendix 9.10 [CD002.146] present the assessment results with that example noise management scheme in place.

143. The assessment confirms that with the CMWF mitigation in place, resulting noise levels would be below the remaining available noise level limits. As such, the total ETSU-R-97 noise level limits would not be exceeded at any noise assessment location (NAL), resulting in no significant adverse effect.

144. An example limit apportionment scheme is then discussed in Section 9.7.3.2 of the CWF EIAR [CD002.011] and presented in Appendix 9.11 [CD002.147] with reference to how the resulting SSNLs could be incorporated within any planning consent. Noise from CWF meets its determined SSNLs without need for mitigation.

145. The assessment findings are fully consistent with the content of the SoAM. Paragraph 8.2 of the SoAM states:

> *"The comparison identified that all SSNLs are achieved without the need for mitigation, with the exception of at NALs 1, 5 and 7[64] during the daytime, for which some mitigation is required to be applied to CMWF."*

146. Paragraph 8.4 confirms that:

> *"The SSNLs at all other NALs can be met without applying any noise constrained modes of turbine operation."*

147. and that:

> *"No noise mitigation is required for either CWF or KWF to maintain compliance with their SSNLs."*

148. Annex E of the SoAM demonstrates that the noise reduction available to CMWF from the application of noise constrained modes of turbine operation is greater than that required in order for it to comply with its SSNLs.

149. The Tables in Annex G of the SoAM then present the results of a comparison of predicted noise levels from each of the three proposed wind farms (including CMWF mitigation where required), with their SSNLs. It is demonstrated that all SSNLs are achieved.

150. As such, the total ETSU-R-97 noise level limits would be complied with, and no significant adverse effect would arise.

6. The use of Planning Conditions

151. SAC have confirmed that they accept the findings of the noise assessments, and that the three proposed developments can operate without giving rise to an unacceptable effect on any nearby noise sensitive receptors [CD016.031]. They state that:

> *"SAC is satisfied that, subject to conditions governing operational noise limits, the operation of the Craiginmoddie, Carrick and Knockcronal Wind Farms would not result in an unacceptable effect on any nearby noise sensitive receptors."*

152. With regards to conditions to govern the operational noise levels, Paragraph 1.6 of the SoAM confirms:

> *"On behalf of the applicants, we have collaborated on an agreed noise condition which can be used within any of the planning consents to ensure that the SSNLs are imposed in a consistent way for compliance checking purposes. This has already been agreed between the applicants and submitted to South Ayrshire Council (SAC) on 9th March 2023 for comments. The tables of SSNLs presented in this SoAM would then be incorporated within a finalised version of that noise condition for each of the wind farm consents".*

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[64] NALs 1 (Delamford Cottage) and 5 (Corphin Cottage) are locations where noise from CWF is not acoustically relevant (being more than 10dB below the total ETSU-R-97 limits. NAL 7 is Doughty Farm

153. The approach of specifying SSNL's within consent conditions is well established and in accordance with current best practice [CD012.002]. The SoAM confirms at paragraph 1.5 that:

> *"It is agreed that the three proposed wind farms can coexist and that it would be appropriate that each wind farm is subject to Site Specific Noise Limits (SSNLs) by means of a consent condition."*

154. The SoAM goes on to present the SSNLs based on the limiting case, i.e., determined on the basis that all three proposed developments were to be consented and it is confirmed at paragraph 7.3 that those SSNLs:

> *"should be included in the noise condition of any respective consents, regardless of the combination of consents granted."*

155. The approach is such that if none, or only 1 or 2 of the proposed developments were to be granted consent, less of the total ETSU-R-97 noise level limits would be utilised.

156. The calculated SSNLs to be applied are those contained within Annex F of the SoAM. Paragraph 7.3 of the SoAM confirms that:

> *"...the resulting SSNLs for each of the three proposed developments are presented in Table 15 and Table 16 (KWF daytime and night time), Table 17 and Table 18 (CWF daytime and night time) and Table 19 and Table 20 (CMWF daytime and night time) in Annex F. It is agreed that these are the SSNLs that should be included in the noise condition of any respective consents, regardless of the combination of consents granted.*

157. Paragraph 9.3 of the SoAM confirms that:

> *"The application of these SSNLs in practice can be achieved through imposition of an appropriate consent noise condition for each of the proposed developments."*

158. The above approach to conditioning will provide appropriate control over noise emissions from the three proposed developments such that the total ETSU-R-97 noise level limits would not be exceeded.

159. As noted in Section 3, SAC's consultant advisor ACCON has recommended for a planning condition addressing AM to be imposed. In lieu of further, official technical guidance, the wording of a proposed condition addressing AM as received from SAC is under review.

7. Conclusion

160. This hearing statement has presented both national and local planning policy and guidance pertinent to the assessment of noise from proposed wind farms. It is clear that the required assessment methodology is that set out in ETSU-R-97 and the IOA GPG (including the Supplementary Guidance Notes). This is the approach that was laid out in the CWF Scoping Report [CD002.188], agreed in consultation with SAC's independent noise consultants [CDs 002.108 and 012.041], followed in the noise assessment reported in the CWF EIAR [CD002.011] and also followed in preparation of the SoAM [CD015.014].

161. The adopted assessment approach is therefore compliant with the requirements of both national and local policy. The adopted assessment methodology duly accounts for the potential impact of low frequency noise from the proposed wind turbines, and an assessment of wind turbine infrasound is not required.

162. The noise assessment work undertaken for CWF [CD002.011] draws on the results of an extensive and detailed baseline noise survey and noise level predictions undertaken in accordance with the requirements of ETSU-R-97 and the IOA GPG. The potential for cumulative noise effects has been fully addressed including account for noise from CWF, CMWF, KWF and other consented/operational wind farms (DWF and HHWF).

163. It is identified that all three of the proposed windfarms could be operated with resulting cumulative noise levels remaining compliant with the total ETSU-R-97 noise limits. The same conclusion is drawn in the noise assessments undertaken for CMF [CDs 001.008 & 012.024] and KWF [CD003.193].

164. I (James Powlson) have worked at length in arriving at a noise Statement of Agreed Matters (SoAM) [CD015.014] with my counterpart noise Expert Witnesses acting on behalf of the applicants for CMWF and KWF, as also being considered at the conjoined Inquiry.

165. The SoAM was prepared drawing upon the baseline survey data and predicted operational noise level data presented within the noise assessments prepared for each of the three proposed developments [CDs 002.011, 012.024 and 003.193]. A precautionary approach was adopted selecting the lowest baseline survey data and the highest predicted noise levels where choices could be made between the data presented in the three noise assessments.

166. The SoAM confirms that the conclusions of the noise assessments undertaken for the three proposed developments [CDs 002.011, 001.008 & 012.024 and 003.193] are consistent, identifying that all three could be permitted with resulting cumulative operational noise levels remaining compliant with the total ETSU-R-97 noise limits.

167. Acceptance of these findings has been confirmed by SAC after taking advice from it's independent noise consultant (ACCON UK). SSfS include the following confirmation at paragraph 4 of their Scope of Evidence (SoE) document [CD016.032]:

> *"The Council's noise consultant, ACCON UK Limited, have been internally consulted to review the submitted documents relating to noise in order to inform Council considerations as whether the noise assessments have been carried out appropriately and to advise on the acceptability or otherwise of the proposals with respect of noise. In their response, ACCON has advised that the methodologies used in the noise chapter represent good practice and are in line with ETSUR-97 (operational noise) and the Institute of Acoustics (IOA) Good Practice Guidance for wind turbines. As part of this, they also endorse the approach to deriving cumulative noise limits and subsequent site-specific noise limits which they conclude are also in line with the same guidance referenced above."*

168. SAC also confirm the following in CD016.031:

> *"SAC is satisfied that, subject to conditions governing operational noise limits, the operation of the Craiginmoddie, Carrick and Knockcronal Wind Farms would not result in an unacceptable effect on any nearby noise sensitive receptors."*

169. The approach of applying consent conditions to govern operational noise levels is well established and in accordance with current best practice [CD012.002]. The SoAM confirms at paragraph 1.5 that:

> *"It is agreed that the three proposed wind farms can coexist and that it would be appropriate that each wind farm is subject to Site Specific Noise Limits (SSNLs) by means of a consent condition."*

170. The SoAM presents the SSNLs that are agreed by the three applicants as appropriate. These have been determined based on the limiting case (i.e., on the basis that all three proposed

developments were to be consented) and can be applied regardless of the combination of consents granted. Paragraph 7.3 of the SoAM confirms that:

> *"...the resulting SSNLs for each of the three proposed developments are presented in Table 15 and Table 16 (KWF daytime and night time), Table 17 and Table 18 (CWF daytime and night time) and Table 19 and Table 20 (CMWF daytime and night time) in Annex F. It is agreed that these are the SSNLs that should be included in the noise condition of any respective consents, regardless of the combination of consents granted."*

171. The SoAM confirms how each of the three proposed developments can operate within their derived SSNLs. Application of those SSNLs will ensure an appropriate control over noise emissions from each of the three developments such that the total ETSU-R-97 noise level limits would not be exceeded. As such, no significant adverse noise effect would arise.

172. Both the noise assessment presented in the CWF EIAR [CD002.011] and the SoAM [CD015.014] confirm that CWF can operate within its SSNLs without need for mitigation. Paragraph 8.4 of the SoAM confirms that:

> *"No noise mitigation is required for either CWF or KWF to maintain compliance with their SSNLs."*

173. Noise should not be a reason for refusal of the proposed developments, either individually or cumulatively in any combination.

8. Glossary of Terms & Abbreviations

Key Terms

Amplitude modulation: within the context of wind turbine acoustics, this refers to a regular variation in the sound level that is associated with the blade rotation.

Apportionment: A term referenced in the IOA GPG and used to mean the sharing of noise limits between developments in arriving at the site-specific noise limits.

Constrained/unconstrained: Turbines running normally and which do not utilise any of the available lower noise control modes are referred to as operating unconstrained. Conversely, where turbines do utilise lower noise control modes to operate with lower noise emitted from the turbines (with some potential loss of energy generation) this is referred to as operating constrained.

ETSU-R-97 Daytime: The ETSU-R-97 daytime period from 07:00 to 23:00 on all days

ETSU-R-97 Night time: The ETSU-R-97 night time period from 23:00 to 07:00 on all days

Infrasound: this informal term is commonly applied to sound energy that is in the frequency range <20 Hz.

Frequency weighting (A-weighting; C-weighting): Sound frequency is the physical property that primarily determines the subjective perception of pitch. Frequency weightings give more or less weight to the sound measured at different frequencies, emphasising the sound level at some frequencies while de-emphasising others. This is normally to enable a single numerical value to represent the 'apparent' level over a wide frequency range. 'A-weighting' is commonly applied to environmental sound affecting humans and covers the human 'audio' frequency range of 20Hz up to 20 kHz. The A-weighting curve is applied to sound measurements to reflect the sensitivity of the human ear, which responds more to frequencies between 500 Hz and 8 kHz and is less sensitive to very low and high frequency sound (for example, see Figure 2 above). 'C-weighting' provides greater emphasis to lower and higher frequencies than A-weighting and is typically applied to environmental or occupational sounds that are impulsive, and have relatively high sound energy, such as firearms.

Low frequency sound: this informal term is commonly applied to sound energy that is in the frequency range ≤250 Hz.

Narrowband frequency spectrum: there is no formal definition, but this typically refers to a frequency spectrum resolution that is considerably finer than third-octave bands. This could be based on a smaller fractional-octave separation (e.g., the SSfS SoE Appendix 1 authors choose 1/36-octave bands), or it could be a linear frequency resolution, in which the bandwidth is constant with centre-frequency.

Noise Assessment Location (NAL): Dwellings which are closest and most relevant to control of total operational wind turbine noise levels, at which noise has been assessed and site-specific noise limits defined.

Noise Sensitive Receptor: A location considered sensitive to noise such as a dwelling.

Octave or third-octave band frequency spectrum: these are formally defined in BS EN (IEC) 61260-1:2014[65], and comprise a separation of the sonic frequency spectrum into bands with a bandwidth

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[65] *BS EN 61260-1:2014. Electroacoustics. Octave-band and fractional-octave-band filters – Specification. British Standards Institution. [URL]*

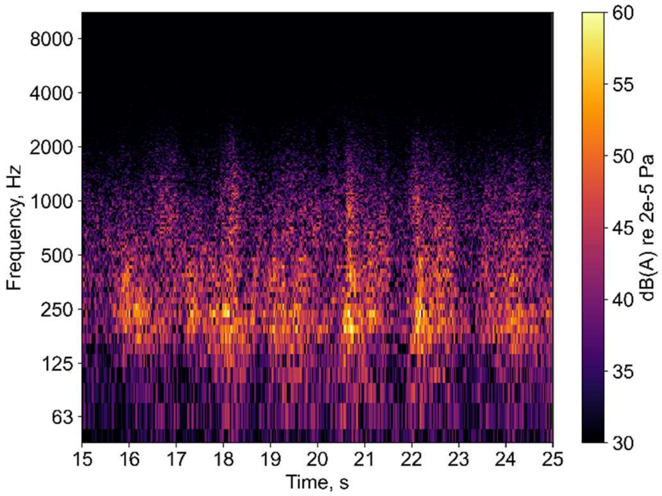
that is either one full octave, or one-third of an octave (respectively). This means the bandwidth is proportional to the band centre-frequency.

Proposed Developments: CWF, CMWF & KWF.

Remaining available noise limits: These are the noise limits which remain available, once the contribution of noise from adjacent existing operational wind farms has been subtracted. In some cases, the remaining available noise limits are equal to the total ETSU-R-97 noise limits where there are no acoustically relevant contributions from existing operational wind farms. Sometimes the remaining available noise limits are also referenced as the 'residual noise limits' or 'remaining noise budgets'.

Site Specific Noise Limits (SSNLs): Noise limits which would be suitable to be applied to an individual wind farm and which have been derived from the remaining available noise limits accounting for the other developments also proposed.

Spectrogram: a spectrogram is the arrangement of contiguous frequency spectra (usually narrowband) over time, such that variations in the frequency spectra can be visualised. It is common practice to depict spectrograms with frequency shown on the vertical axis, and time on the horizontal axis. An example of a spectrogram from a sound recording is shown in the figure below:



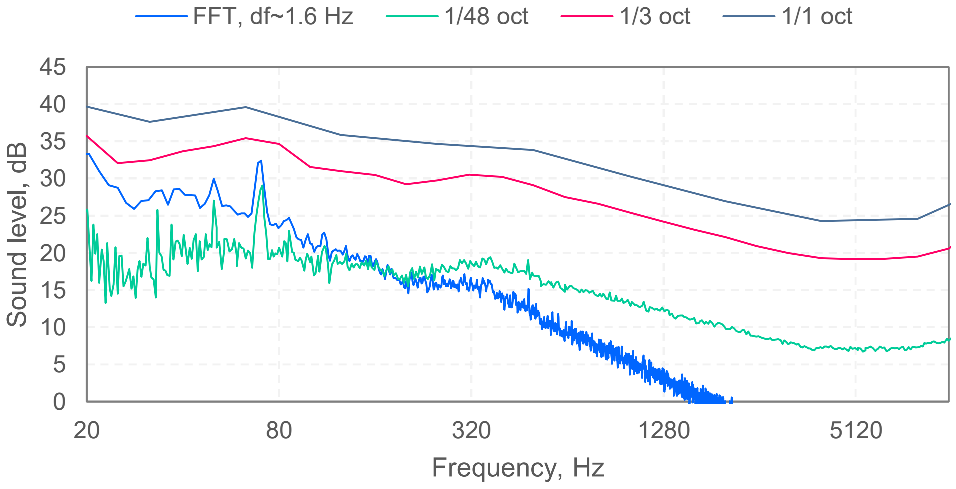
Total ETSU-R-97 noise limits: These are noise limits which are derived in accordance with ETSU-R-97 and which apply to control overall cumulative levels of operational wind turbine noise. Different total ETSU-R-97 noise limits are derived for the daytime and night time.

Note on technical terms used in Save Straiton for Scotland scope of Evidence Appendix 1

The research reported by the SSfS SoE Appendix 1 authors describes measurement and analysis of wind turbine infrasound based on the 'SAM Scribe' recording equipment. The methodology employed is based on the analysis of the frequency spectra of sound recordings made that include the spectral range 0.5-20 Hz, which would commonly be described as 'infrasound'. The measurements are analysed to derive 'narrowband frequency spectra', which depict the frequency content of a recording averaged over time, and 'spectrograms', which depict many (usually narrowband) frequency spectra arranged contiguously along a time axis, effectively showing the variations in the frequency spectrum over time.

To avoid unfortunate semantic confusion, it is important to note that the SSfS SoE Appendix 1 authors refer to the narrowband frequency spectrum as a 'spectrogram' and refer to the spectrogram (as described above) as a 'sonogram'. In our experience, this is rather unusual terminology ('sonograms' are typically associated with ultrasound sonography), and as such, this statement employs the terminology as it is in common usage among the UK acoustics community.

A comparison of the differences between octave, fractional octave, and narrowband spectral resolutions is illustrated in the figure below, which shows analysis of a single sound recording – the blue plotted line shows a 'narrowband frequency spectrum' defined using a constant (linear) resolution of ~1.6 Hz, the green plotted line again shows a 'narrowband frequency spectrum', but using a 1/48-octave (logarithmic) resolution, while the magenta and grey lines show the same spectrum in third-octave and full-octave bands, respectively. The differences in the sound levels of each spectrum representation arise solely because of the different types of frequency resolution – the total sound energy contained in each spectrum remains the same.



Abbreviations

AM:	Amplitude Modulation
CD:	Core Document
CEng:	Chartered Engineer
CMWF:	Craiginmoddie Wind Farm
CWF:	Carrick Windfarm
DWF:	Dersalloch Wind Farm
EHSGN:	Environmental Health Wind Turbine Development Submission Guidance Note
EIA:	Environmental Impact Assessment
EIAR:	Environmental Impact Assessment Report
ETSU-R-97:	Energy Technology Support Unit report R-97: The assessment and rating of noise from Wind Farms [CD012.001]
HHWF:	Hadyard Hill Wind Farm
IOA GPG:	Institute of Acoustics: A Good Practice Guide to the Application of ETSU-R-97 [CD012.002]
IOA:	Institute of Acoustics

ISO:	International Organization for Standardization
KWF:	Knockcronal Wind Farm
LDP:	Local Development Plan
LDP2:	Local Development Plan 2
MASA:	Member of the Acoustical Society of America
MIOA:	Member of the Institute of Acoustics
MSc:	Master of Science
NALs:	Noise Assessment Locations
PAN:	Planning Advice Note
PEM:	Pre-Examination Meeting
SAC:	South Ayrshire Council
SGNs	Supplementary Guidance Notes
SGWE:	SAC Supplementary Guidance: Wind Energy
SoAM:	Statement of Agreed Matters on Noise
SoE:	Scope of Evidence
SPR:	ScottishPower Renewables
SSfS:	Save Straiton for Scotland
SSNLs:	Site Specific Noise Limits.
TAN:	Technical Advice Note
UK:	United Kingdom

Annex A – Errata to Chapter 9 of the CWF EIAR

During preparation of the noise Statement of Agreed Matters, the following errata were identified as applicable to Chapter 9 of the CWF EIAR

Erratum 1

Paragraph 163, duplicate table reference removed:

> “163 Technical Appendix 6.2 of the ES of the formerly proposed Hadyard Hill Extension[9] confirms that the Hadyard Hill Windfarm has been installed with the Bonus-2.3MW wind turbine. Annex 6: *Wind Turbine Data* of that ES confirms the noise emission data for the Bonus 2.3MW wind turbine, as well as the associated octave band spectra[10]. That data is duplicated in **Table 9.17** and **Table 9.18** ~~Table 9.18~~ below. It can be seen that the data is for a wind turbine installed with 80m hub height. Applying this data to lower hub heights (as installed) represents a worst case.”

Erratum 2

Table 9.18, 4kHz octave band sound power level corrected:

“

Wind Speed Referenced to 10m Height (Standardised U_{10}), m/s	Octave Band Centre Frequency (Hz)								
	32	63	125	250	500	1k	2k	4k	8k
8m/s	-	91.0	97.7	98.7	98.5	97.3	97.3	~~95.6~~ 92.6	81.4

Table 9.18 Octave Band Sound Power Level Spectra (L_{WA}) for the Bonus 2.3MW as Installed at Hadyard Hill Windfarm,80m Hub Height, dB(A)

”

This error was checked and found to have no significant effect on the noise modelling results or assessment findings, with no change to the conclusions drawn.

Erratum 3

Table 9.23, octave band sound power levels corrected.

“

Wind Speed Referenced to 10m Height (Standardised U_{10}), m/s	**Octave Band Centre Frequency (Hz)**								
	32	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Mode PO6000 (6.0MW)									
N/A – Data normalised to 100dB(A)	~~64.7~~ -	~~73.6~~ 81.1	~~81.0~~ 88.7	~~85.6~~ 93.4	~~87.9~~ 95.1	~~87.7~~ 94.0	~~88.0~~ 89.9	~~81.4~~ 82.9	~~66.4~~ 72.9

Table 9.23 Octave Band Sound Power Level Spectra (L_{WA}) for Vestas V150-6.0 in mode PO6000, dB(A)

”

This error was checked and found to be a copy and paste error to the reporting only. The correct octave band spectra were applied throughout the noise modelling and prediction work, so there is no effect on the noise assessment results or the conclusions drawn.

Erratum 4

Paragraph 308, broken cross-reference removed:

> “308 Table 9.41~~**Error! Reference source not found.**~~ Details the cumulative noise level limits that have been applied at each of these receptors.”

Erratum 5

A bug was found in the word document associated with the table cross-references for Table 9.3, Table 9.25, Table 9.30, Table 9.32 and Table 9.36. A final global update of the cross-references caused copies of those tables to be inserted into the body text when only the Table reference (e.g., ‘Table 9.3’) should have been inserted. This applies at Paragraphs 111, 161, 236, 246, 293. The duplicated table should be ignored.

E.g.:

> “111 A series of groundborne vibration predictions have been conducted in order to determine the typical distances at which the threshold criteria detailed BS5228-2 for human perception and disturbance would arise (see

112. **Vibration Level (PPV)**	**Effect**
0.14mms-1	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction. At lower frequencies, people are less sensitive to vibration.
0.3mms-1	Vibration might be just perceptible in residential environments.
1.0mms-1	It is likely that vibration of this level in residential environments would cause complaint but can be tolerated if prior warning and explanation has been given to residents.
10mms-1	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

> Table 9.3). Predictions have employed the empirical methods detailed in BS5228-2, in the Transport and Road Research Laboratory Research Report 246: *Traffic induced vibrations in buildings* (TRRL RR 246: 1990), and within the Transport Research Laboratory Report 429 (2000): *Groundborne vibration caused by mechanical construction works*.”

The above errata have no effect on the findings of the noise assessment work, or the conclusions drawn.

Annex B – Propagation Directivity

The IOA GPG allows for propagation directivity to be accounted for in wind turbine noise level prediction, i.e., noise level reductions afforded by an NAL is subject to upwind or crosswind propagation conditions. Paragraphs 4.4.2 of the IAO GP are duplicated as flows:

> *"4.4.2 Based on evidence from the Joule project[viii] in conjunction with advice in BS 8233 and ISO 9613-2, current practice suggests that for a range of headings from directly downwind (0°) up to 10 degrees from crosswind (80°), there may be little to no reduction in noise levels; once in crosswind directions (90°) then the reduction may be around 2 dB(A); and when at sufficient distance upwind the reduction would be at least 10 dB(A). For intermediate directions between crosswind to upwind, a simple linear or polynomial interpolation can be used. Such reductions (due to "shadow zone" refraction effects) will in practice only progressively come into play at distances of between 5 and 10 turbine tip heights."*

The IOA GPG goes on to reference work undertaken by NASA with examples of resulting propagation directivities presented for both flat and complex landforms, the latter being lower than the former. The example for complex and forms is presented in Table 2.

Direction in degrees (180° = Downwind, 0° = Upwind. 90 and 270° = cross wind)	**NAL distance**		
	7.5 x Tip height	**11 x Tip height**	**18 x Tip height**
0 (Upwind)	-2.2	-5	-7.8
30	-2	-4.5	-7
60	-1.4	-2.6	-4.3
90 (Crosswind)	-2	-2	-2
120	0	0	0
150	0	0	0
180 (Downwind	0	0	0
210	0	0	0
240	0	0	0
270 (Crosswind)	-2	-2	-2
300	-1.4	-2.6	-4.3
330	-2	-4.5	-7
360 (Upwind)	-2.2	-5	-7.8

Table 2 Propagation Directivity – Complex Landforms -: Example of assumed relationship of the change of noise levels with wind direction, 180° is where the receptor is downwind of the turbine and 0° where the receptor is upwind of the turbine.

From the above, noise level reductions of up to 7.8dB can be afforded where an NAL is located upwind of the wind turbine noise source.

The completed noise assessments have assumed downwind propagation only and so do not apply any propagation directivity corrections. This represents a pessimistic worst case in the predicted and assessed noise levels.

Annex C – Noise Measurement System Noise Floors

Concern is sometimes raised regarding the noise floors of deployed equipment (i.e., the lowest sound pressure level that the equipment can measure before self-generated noise from within the measurement system itself affects the measurement results).

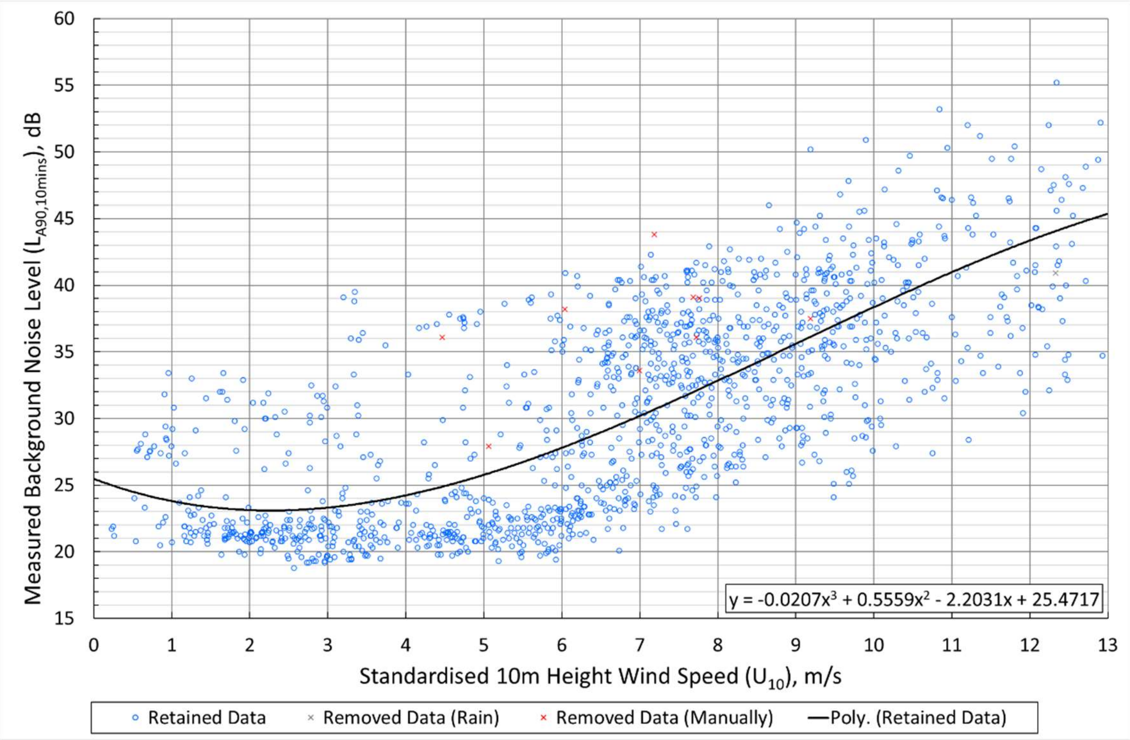
The noise floors of the equipment deployed during the baseline noise surveys were very low, and substantially below the ETSU-R-97 fixed minimum thresholds (which are the lowest and therefore most stringent parts of any ETSU-R-97 total noise level limits).

Notwithstanding this, presented below is a demonstration of how conservative corrections for measurement system noise floors would have no significant bearing on the noise assessment results.

If the noise floor of a particular sound level measurement system was 18dB(A), and that system was used to measure noise in an exceptionally quiet environment, i.e., where the prevailing sound levels fell below 18dB(A), then the sound pressure levels logged by the measurement system would not be lower than 18dB(A), that being the level generated and then recorded by the system itself.

Graphs 9.5.1 to 9.5.12 in Appendix 9.5 of the CWF EIAR [CD002.011] present the CWF baseline noise survey results. Graphs 9.5.1 and 9.5.2 (Blair Farm daytime and night-time respectively) present some of the lowest measured background noise levels obtained over the course of the CWF baseline noise survey. Levels just below 20dB(A) were measured between wind speeds of 0 and 6m/s. The lowest measured value, which recorded during the night-time, was 18.8dB(A).

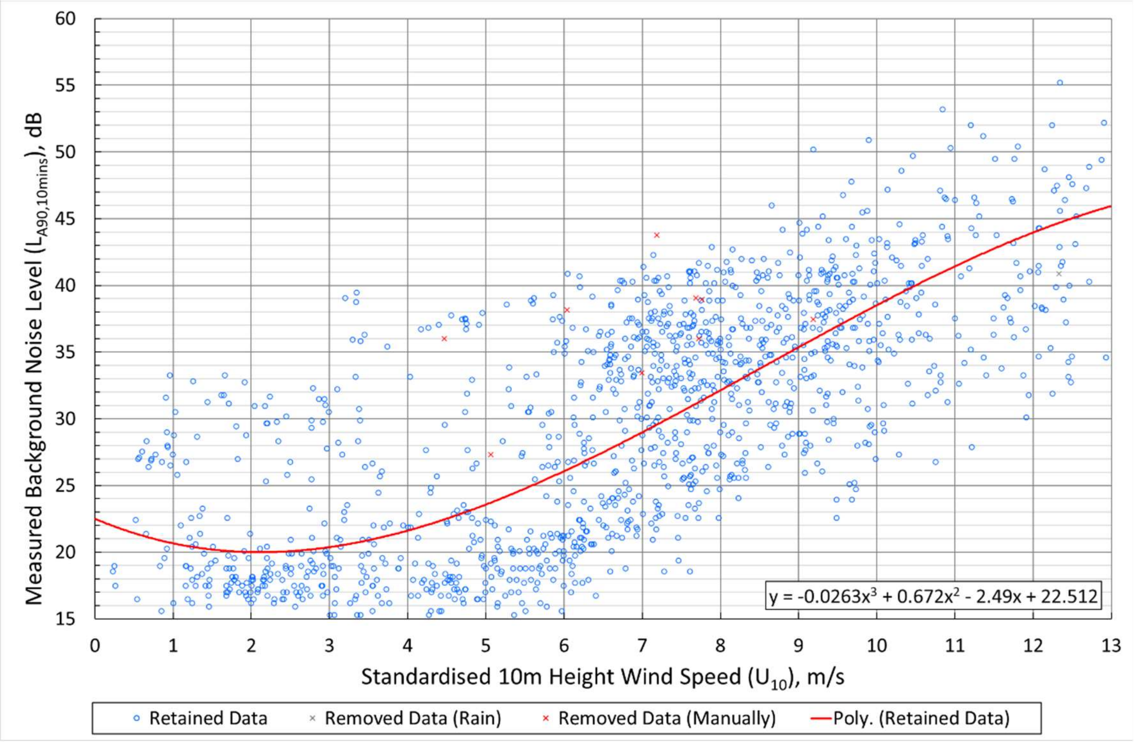
Taking the night-time as an example, Graph 9.5.2 is duplicated below as Graph 1. The presented polynomial line of best fit (continuous black line), is that which defines the background noise environment and how it changes with wind speed. It is that polynomial line of best fit which is used to define the part of the total ETSU-R-97 noise level limit that is set at the background noise level + 5dB. The equation for the polynomial line of best fit is also presented on the graph.



Graph 1 (Graph 9.5.2 of CWF EAIR Appendix 9-5): Location A Blair Farm – Night-time Background Noise (dB(A)) Versus Wind Speed (m/s)

It can be seen that levels below 18.8dB(A) were not measured, so a conservative assumption would be to assume that that figure is the measurement system noise floor. i.e., the worst-case noise floor of the measurement system was 18.8dB.

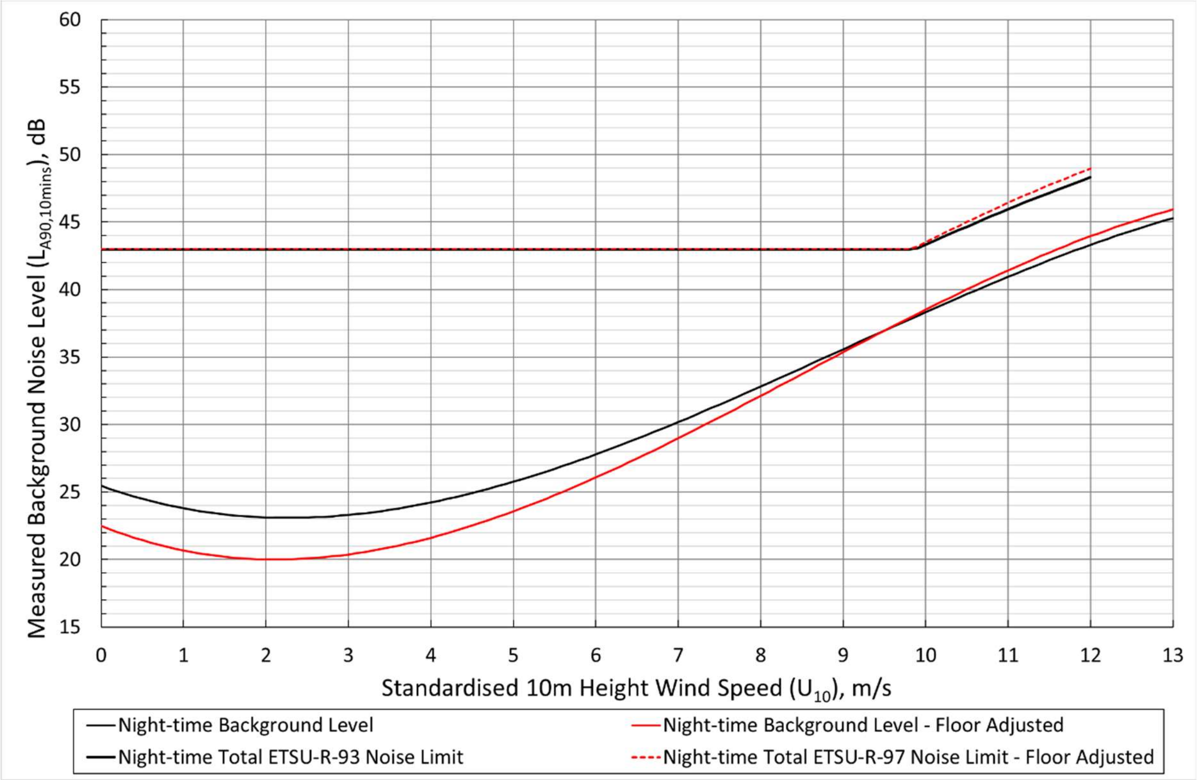
It is then possible to subtract that worst case value from the measurement data set, thereby removing the noise floor, and replot the updated data set with a revised polynomial line of best fit. This is presented in Graph 2 where the solid red line is the revised polynomial line of best fit.



Graph 2: Location A Blair Farm – Night-time Background Noise (dB(A)) Adjusted for Worst Case Noise Floor Versus Wind Speed (m/s).

Comparison of the above two graphs shows a downward shift in the measurement data as a result of the noise floor correction. That shift is most apparent in the lowest measurement data points (i.e., where there was the greatest potential for any noise floor to have had any effect on the measurement results). Those data are significantly below the fixed minimum threshold values used in the total ETSU-R-97 noise level limits (38dB(A) during the daytime and 43dB(A) during the night-time) and so have no significant bearing on the resulting assessment. In fact, the effect of that downward shift to the lower measured values is to cause a steeper incline in the polynomial line of best fit (when considered from left to right). This causes a slight leniency in the element of the resulting total ETSU-R-97 noise level limit that is set at the background noise level + 5dB.

This is better seen by plotting the two polynomial lines of best fit together, as well as their resulting total ETSU-R-97 noise level limits, as show in Graph 3 below.



Graph 3 Comparison of Polynomial Lines of Best Fit and Resulting Total ETSU-R-97 Noise Level Limits With and Without a Worst Case Noise Floor Adjustment.

It can be seen from Graph 3 that:

1. Where the worst-case noise floor adjustment causes the biggest difference in the polynomial lines of best fit (lower wind speeds), there is no effect on the resulting total ETSU-R-97 noise level limits, due to that part of the limit being set at the fixed minimum threshold value (43dB(A) in this example).
2. Where the total ETSU-R-97 noise level limit is set at the background noise level +5dB (higher wind speed), the limit with the noise floor adjustment is more lenient (higher) than the limit without the noise floor adjustment.

This demonstrates how any equipment noise floors have had no significant bearing on the completed assessment and the conclusions drawn, and that applying a noise floor correction may also serve to result in slightly more lenient assessment results.