Operational Noise – Joint Response on behalf of the Applicants to DPEA Procedure Notice dated 30th June 2023

Date: 21st July 2023
Version: Version 8 FINAL

Conjoined public inquiry concerning:
WIN-370-4 Craiginmoddie Wind Farm, Dailly, South Ayrshire, KA26.
WIN-370-5 Carrick Wind Farm, Approximately 6 km South of Straiton, South Ayrshire, KA19.
WIN-370-6 Knockcronal Wind Farm, Knockcronal, Straiton, South Ayrshire, KA19.

Agreement between:
James Mackay, TNEI (WIN-370-4 Craiginmoddie Wind Farm)
James Powlson, WSP (WIN-370-5 Carrick Wind Farm)
Mark Jiggins, Hoare Lea (WIN-370-6 Knockcronal Wind Farm)

1. Background & Introduction

1.1 This joint response uses the core document references that are detailed in the official inquiry core documents list. Note that the Save Straiton for Scotland (SSfS) submission: *Matters for the Reporters Noise* [CD017.023], which this document responds to, uses different core document reference numbers that are not aligned with the official inquiry core document list. The correct core document reference numbers have been used within this document.

1.2 SSfS submitted two documents [CD017.032 and CD017.033] to the conjoined public inquiry, just prior to the hearing session for the topic of noise, held over two days on 30th and 31st May 2023. Following discussion with the Applicants during the hearing session, the Reporters allowed these documents to be submitted into the inquiry and proposed they be dealt with by way of further written submissions.

1.3 The DPEA subsequently confirmed four matters[1] to be addressed by parties to the hearing session: (1) SSfS to provide the documents referred to during the noise hearing, (2) SSfS to submit the Den Brook planning decision and copies of Scottish planning decisions which contain planning conditions which deal with amplitude modulation, (3) SSfS to submit DEFRA NANR45 documents, and (4) participants in the noise hearing to provide copies of reports or studies which they specifically referred to at the hearing but were not part of the Core Documents (e.g. referred as footnotes from other documents) where they consider that such reports were to be of intertest to Reporters for these cases.

1.4 The DPEA subsequently confirmed[2] the items submitted under Matter (1) had been received and that the applicants had until 10th July 2023 to provide any comments on these documents. This date was subsequently extended to 21st July – see below. SSfS confirmed their reliance on those submitted documents and how they were to be used in their further written submission [CD017.023].

1.5 During the hearing session on conditions held on 20th June 2023, SSfS submitted a further document [CD017.034] detailing their comments / suggested amendments to the operational noise condition (as submitted by the Applicants and amended[3] by SAC [CD015.031]). That document [CD017.34] was therefore only available to the Applicants as of the morning of that hearing session. The Reporters at the conditions hearing agreed verbally that the written submissions deadline of 10th July be extended again, to allow its scope to encompass comments on this further document. In the procedure notice dated 30th June 2023, the Reporters confirmed a final deadline for all parties to respond to CD017.034 (reference N2) was 21st July 2023.

[1] DPEA email to all parties 6th June 2023 detailing a further written submissions procedure, relating to four matters.
[2] DPEA email to applicants 19th June 2023 (https://dpea.scotland.gov.uk/Document.aspx?id=957093).
[3] Primarily adding control of amplitude modulation to the condition proposed by the Applicants.

1.6 This is a joint response on behalf of the three Applicants (Craiginmoddie Wind Farm (CMWF), Carrick Windfarm (CWF) and Knockcronal Wind Farm (KWF)) to the procedure notice. It has been produced to respond to matters (1) to (3) of the 'four matters', including documents submitted by SSfS during both the noise and condition hearing sessions.

2. SSfS Further Written Submissions

2.1 Below is a list of the additional document submissions by SSfS, together with a short comment to indicate how these are being dealt with:-

	Core Document	Comment
•	CD017.026 – HusonPaper2_wtn2015	No further comment as the document was fully discussed at the noise hearing and is referenced in noise evidence for KWF [Para 4.41 of CD012.028] and for CWF [Annex C of CD012.027].
•	CD017.022 – DEFRAnanr45-criteria	These documents are discussed further below.
•	CD017.023 – Matters for Reporters Noise	
•	CD017.024 – DEFRAnanr45-procedure	
•	CD017.025 – Den Brook appeal decision - 11 Dec 2009 conditions	
•	CD017.027 – NANR277 windfarm noise statutory nuisance	
•	CD017.028 – Rushforth et al 2002 – Case study of Low Frequency Noise	
•	CD017.029 – Tickell Model Comparison	
•	CD017.030 – DEFRAnanr45-fieldtrials	
•	CD017.031 – Compliance testing Hadyard Hill Summary and conclusions	
•	CD017.032 – DOC 20230526 EIR 2023 3305 ATTACHMENT 1	
•	CD017.033 – DOC 20230526 EIR 2023 3305 ATTACHMENT 2	
•	CD017.034 – Save Straiton Amendments to Operational Wind Turbine Noise Condition 37	

3. TNEI Compliance Assessments of Hadyard Hill Wind Farm

3.1 This section addresses the additional submission references CD017.032, CD017.033 and aspects of CD017.023 (Sections 1 and 2). Document CD017.031 simply replicates sections of documents CD017.032 and CD017.033, and so is not considered further.

3.2 The two TNEI reports submitted by SSfS [CD017.032 and CD017.033] were two versions of the same report dated April 2016 and July 2016 respectively. These reports are an assessment of compliance with the planning noise limits controlling operational noise from Hadyard Hill Wind Farm (HHWF). The assessment was completed by TNEI on behalf of Scottish and Southern Energy (SSE), the operators of HHWF. The noise measurements were completed at a property beyond the western boundary of HHWF called Tralodden Cottage, which is well removed (approximately 8 km the closest turbine of CMWF) from the three proposed developments. The later re-issued report dated July 2016 [CD017.033] differs from the earlier April version [CD017.32] only by removal of photographs of the measurement positions and with the analysis in Annex 7 extended up to a wind speed of 12 m/s (previously 11 m/s).

3.3 SSfS have set out in their further written submission [CD017.023] the main points they draw from these reports and how they suggest these results should be accounted for by the Reporters. In conjunction with consideration to comments raised in CD017.034, the main points contended by SSfS are summarised as:-

- Measured noise levels from HHWF are higher than noise levels predicted using the ETSU-R-97 / IOA GPG method, e.g. by 13.5 dB(A) at a wind speed of 12 m/s.
- The combined noise assessment (i.e. that contained within the SoAM [CD015.014]), which uses the ETSU-R-97 / IOA GPG prediction method, will also therefore underestimate predicted noise levels.
- The assessment presented in the SoAM [CD015.014], and the derivation of the Site Specific Noise Limits (SSNLs) that it contains is therefore incorrect and should be revised using the measured data for HHWF and based on predictions with revised input parameters.
- It is unsurprising that Ms Trayner, a resident on the other side of HHWF, experienced severe adverse reactions to noise from HHWF and contacted the operators to request that turbines be turned off, an arrangement that was automated following her concerns.

3.4 The July 2016 TNEI report [CD017.033] shows the results of measurements at Tralodden Cottage, which indicated noise from HHWF to be above the noise limits applicable at that receptor location, at that time. The TNEI report goes on to note: *"The results indicate that mitigation is required to reduce wind turbine noise levels to within the agreed noise limits at Tralodden Cottage"*.

3.5 Evidence submitted by SSfS [CD017.004 PDF page 246] provides a response on 2nd May 2017 from South Ayrshire Council (SAC) which discusses the submission of a subsequent (third) report from TNEI (not submitted into evidence by SSfS) showing

the results of measurements gathered subsequently (between August 2016 and Nov 2016), post implementation of a revised wind farm control regime at HHWF. SAC commented on this subsequent report: ***"Due to the amended operational control regime which has been put in place, levels were found to be in compliance with the agreed noise levels"*** [our emphasis]. Whilst this additional report is not before this Inquiry, SSfS evidence confirms its existence, as referenced in the e-mail from SAC, and that an amended wind farm control regime was implemented.

3.6 The above correspondence confirms that the results shown in the April and July 2016 TNEI compliance reports [CD017.032 and CD017.033] can no longer be considered to represent the levels of operational noise from HHWF at Tralodden Cottage, due to subsequent changes to the way SSE operates HHWF in order to meet its noise limits.

Evidence from Ms Trayner

3.7 During the hearing session on noise (31st May 2023) we heard[4] evidence from Ms Trayner who lives at Dobbingstone Farm, which is north of the eastern end of HHWF. Dobbingstone Farm is a relevant noise sensitive receptor location for CMWF being exposed to existing levels of operational noise from HHWF and from the proposed CMWF and is referred to in the SoAM [CD015.014] as 'NAL2'. Noise levels from both CWF and KWF are sufficiently low[5] at Dobbingstone Farm that they need not be accounted for within the cumulative assessment for that property.

3.8 Ms Trayner described during the hearing how SSE had responded to their complaints that the HHWF turbines were emitting unusually high levels of noise, and that SSE were able to quickly put in place, and subsequently automate, a method of control to ameliorate that situation:-

> *"It was about 2016/2017. We started to get noise from the existing Hadyard Hill turbines which was unbearable. It was a whumping and a roaring, you couldn't go outside. We go to a place which is about half a mile from the house where we do a lot of wildlife photographing, we couldn't be there because it was just so bad and so loud, it was the whumping went through your whole body. We raised complaints, we raised them with South Ayrshire and also raised them with SSE. This takes me back to what I've said about the Craiginmoddie proposal, to some extent. Instead of going through South Ayrshire and harassing the life out of South Ayrshire, because you raise a complaint with them, they then say we will send somebody out, but they won't be at work until Tuesday, they are on leave. All right, well the noise might not be there next Tuesday. So that happens all the time, so instead of doing that we liaise directly with SSE. The noise manager at that time was a woman called Claire McKeown, whom James knows, and I explained the problem to her. She then asked me to record the times that we were*

[4] Manual transcript of audio from the video recording of the hearing session, produced by us, beginning from approximately 04:49:30. Video available from the DPEA https://dpea.public-i.tv/core/portal/webcast_interactive/776869.

[5] See paragraphs 5.14 and 5.15 of the IOA GPG [CD015.002] which suggests a threshold of within 10 dB(A) for a wind farm to be acoustically relevant to include within a cumulative assessment for a specific receptor location.

getting that particular horrible noise. I then logged that, gave it to her, she then put that to the manager of the wind farm. Who then did a subsequent, er I don't know what you call it: survey, of what was happening with the turbines at those particular times. They then identified that there was a specific issue, at that time, and this is all in our submission. They could identify the wind speed the wind direction ***and it was when they were constrained off due to grid, er not being able to take the power*** [our emphasis]. *They then identified a method of fixing that where it would be trials. It was supposed to be trials and it wasn't, which meant that we got followed up further incidents of the same type of noise. That then was automated, the system to correct it. In other words shut down the turbines near us, there's six of them, they shut them down under those particular conditions, wind direction, wind speed and constrain. They all get shut down and we have not had that noise since that was done."*

3.9 There are a number of points of relevance from the above transcript, taken together with aspects of the TNEI reports, as follows:

- There is confirmation that from approximately 2015[6], noise from HHWF worsened and that this type of "*horrible noise*" was not noted or was significantly less prevalent in the years of operating HHWF prior to this (from 2006 when it began operating[7]). This tallies with the increased number of complaints as listed in the SSfS submissions for the years 2016 and 2017 (last page of CD017.004, also CD017-002 page 3) [note that there were low numbers of complaints reported up to and including 2015, then a return to such low numbers again after 2017 (i.e. post implementation of the amended operational control regime)].
- The statement specifically mentions that grid energy export restrictions were discussed with Ms Trayner and that it was during those periods that the issue arose.
- It is confirmed that during those periods (i.e. when HHWF was subject to grid constraint[8]), the implemented mitigation measure was to operate with some turbines stopped to meet the export restrictions (instead of all turbines remaining operational but in a manner that delivered less power and higher noise levels).

These points are further considered below.

Operational Characteristics of the Hadyard Hill Wind Turbines

3.10 The model of turbine installed at HHWF is the Bonus (Siemens) 82-2.3 MW. Those turbines are a 2-speed type, having a low speed and a high speed mode, and use an 'active-stall' power control technique. Turbines using active-stall to control their power output do so by powered control of the pitch angle of the blades over a relatively narrow range of angles. This controls when the turbine blades are moved

[6] Ms Trayner commentary suggests that there was a change in the noise from *"about 2016/2017"*, 2015 is used here to denote a time before Ms Trayner observed that this effect had *"started"*.
[7] Taken from https://www.sserenewables.com/onshore-wind/great-britain/hadyard-hill/ on 2nd June 2023.
[8] Where a wind farm is requested to limit the amount of total exported energy (by the grid operator, e.g. National Grid for example) below the normal maximum.

into a mode of operation where the blade/aerofoil experiences aerodynamic stall. Aerodynamic stall is where the angle of attack of an aerofoil is increased, moving the aerofoil beyond the critical angle of attack[9] such that 'lift' begins to decrease. For a wind turbine, this allows control over the amount of energy generated from the wind passing over the turbine blades.

3.11 Based on our professional experience, this active-stall method of power control (as used on the turbines at HHWF) has not been in use on more recent turbine models (of a comparable size) for approximately ten years. Current models of turbines are now commonly pitch-regulated variable speed (not active-stall regulated), where powered control of the pitch angle is over a larger range of angles and power control is achieved by reducing the angle of attack of the aerofoil, to reduce the amount of lift, thereby reducing energy[10]. Modern turbine models also utilise variable speed, where the rotor speed will vary and will not be set at one or more fixed speeds (as in the case of the turbines on HHWF being two speed). The consequence of using variable speed in modern wind turbines is that electronic power converters are then usually required to provide the fixed electrical frequency required to deliver energy into the electricity grid.

3.12 When a turbine utilises the active-stall control mechanism, this energy reduction process can generate increased levels of noise. Ordinarily this only happens at the higher wind speeds within the range considered by ETSU-R-97. This has been referred to hereafter as 'normal operation'.

3.13 Where a wind farm using active-stall regulated turbines is required to limit the amount of total exported energy (for example due to grid constraint), this can be achieved by application of active-stall at lower speeds, to control the power output of the individual wind turbines to produce less energy than would normally be the case at those speeds. This process can therefore result in active-stall related increased noise emissions at lower wind speeds than would normally be the case. This approach to control power has been referred to here after as 'non-normal operation'.

3.14 Where a wind farm consists of many individual wind turbines, an alternative approach to such non-normal operation, is to selectively stop individual turbines to achieve the same reduction in total wind farm energy output, to meet the grid energy export limits being requested. The turbines left 'on' then remain under 'normal operation'.

EXAMPLE: HHWF has a rated capacity of 117.3 MW (51 turbines at 2.3 MW each). Were the grid to ask the wind farm to reduce the energy output to 50%, this would result in approximately 26 turbines being stopped and 25 remaining under normal operation, rather than all 51 turbines remaining on but being subject to non-normal

[9] *"This then can be referenced to a specific angle of attack and that angle of attack where that stall occurs is referred to as the critical angle of attack".* From https://www.flyaeroguard.com/learning-center/airfoil-stalls/

[10] For example the turbines on Dersalloch Wind Farm are pitch regulated variable speed and should Dersalloch be requested to reduce energy for a grid export restriction, this would be achieved by operating turbines in lower energy output and would NOT result in higher noise emission levels.

operation to limit their individual energy delivery to approximately 1.15 MW each (and resulting in higher overall wind farm noise levels).

3.15 Based on the information available and in front of this inquiry, it is concluded that the way HHWF is being controlled, when requested to reduce exported energy, has changed since approximately 2016/2017 to eliminate increased levels of noise associated with grid constrained related use of active-stall regulation. In brief, SSE previously controlled energy output from HHWF by applying the active-stall method of constraint (non-normal operation), but subsequently changed to switching individual turbines off and leaving the remaining on turbines under normal operation (i.e. without application of grid constrained related use of active-stall regulation). This has resulted in the expected (or lower where some turbines are switched off during periods of grid constraint) levels of noise arising from HHWF since application of the revised control regime.

3.16 This is also consistent with our experience of this scenario on other wind farms, where similar models of turbines are used. Some of the examples we have knowledge of are confidential, however we are aware of another example which is in the public domain, of a wind farm where use of active-stall control under grid constraint periods (non-normal operation) has been moved away from for the same reasons. For the planning appeal for Pauls Hill 2 Wind Farm (PH2WF)[11] the applicant submitted a noise compliance report which provides levels of operational noise from the existing Pauls Hill Wind Farm (PHWF) measured during March to August 2019 (see ANNEX A[12]). PHWF became fully operational in 2006 and consists of 28 Siemens 2.3 MW turbines with an 82 metre rotor diameter[13], the same turbine type as installed at HHWF. The PHWF compliance report identified noise levels due to (non-normal) curtailed mode (i.e. active-stall regulation) were higher:-

> Executive Summary: *"Periods of elevated noise levels were identified, when the operation of the wind farm was curtailed due to grid restrictions where the rotational speeds of certain turbines are restricted, resulting in higher levels of stall noise. During these grid restriction periods, measured noise levels as extrapolated to Corglass Farm, exceed the noise limit. In light of the elevated noise levels during curtailment periods it is proposed that an alternative means of curtailment, e.g. shutting down rather than restricting the rotational speed of the turbines, is now employed to reduce noise levels during these periods."*

3.17 The PHWF compliance report goes on to provide numerical differences between 'normal' operational noise levels and those which can occur in 'non-normal' operation, when active stall regulation was used to address grid constraints (see

[11] Pauls Hill 2 Wind Farm, Upper Knockando, Ballindalloch, AB37 9BS. DPEA Case Reference: WIN-300-3 (Section 36 Wind Farm) (https://dpea.scotland.gov.uk/CaseDetails.aspx?id=120129).

[12] Paul's Hill Wind Farm – Noise Compliance Assessment, October 2019, Hayes McKenzie Report HM: 3261_R01_EXT3: 04/10/19 (https://dpea.scotland.gov.uk/Document.aspx?id=643443).

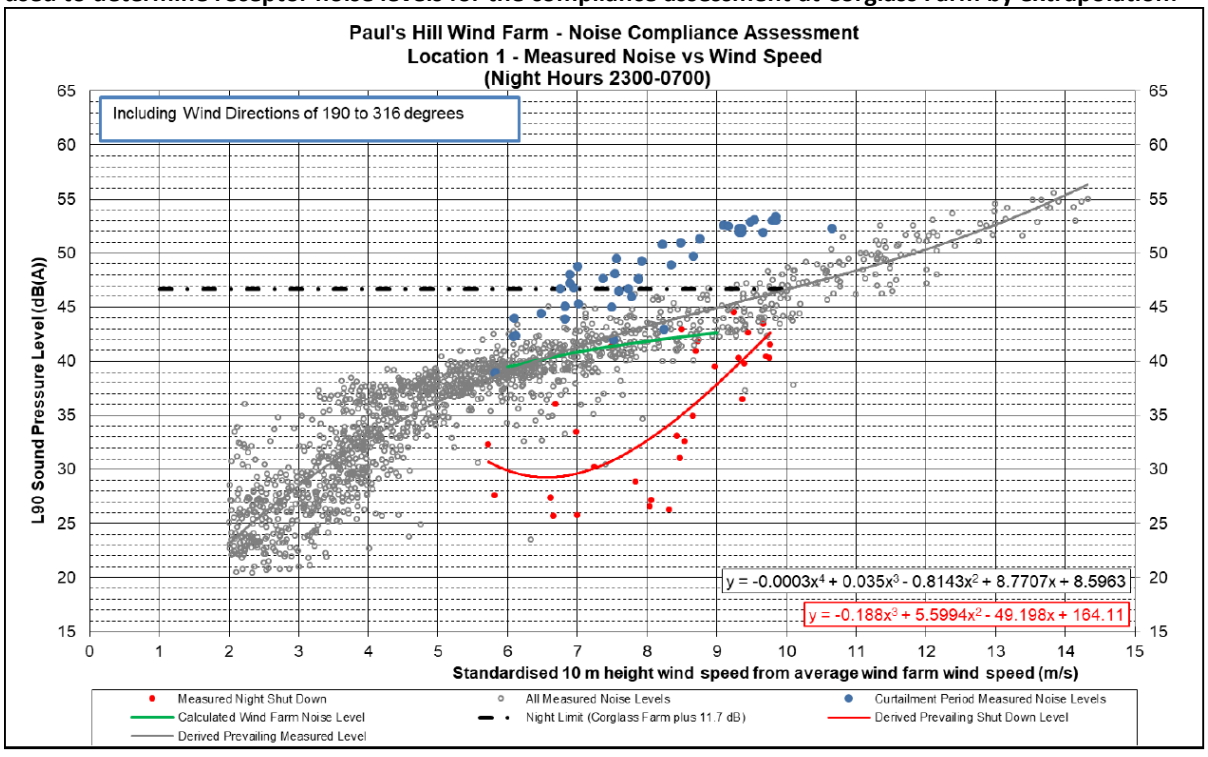
[13] Fred Olson Renewables Pauls Hill Wind Farm (https://fredolsenrenewables.com/windfarm-collection/united-kingdom/paul-s-hill/). Retrieved 2023-06-27.

Table 1 below). A further submission (see ANNEX B[14]) to the PH2WF appeal provides a chart highlighting the data where constraints were used (see Figure 1 below). This chart shows a specific trend of data much higher than data related to normal operation and the tabular values indicate that at wind speeds of 8 m/s to 10 m/s the increase in noise levels is around 8 dB(A). Whilst the tabular data does not extend up to 12 m/s the trend of data for normal operation (Figure 1 green line) and non-normal operation (Figure 1 blue dots) appear to run parallel over the wind speed range of available data, indicating a similar difference is likely at 11 m/s and 12 m/s.

Table 1 – Noise data taken from the PHWF noise compliance assessment (dB $L_{A90,\ 10\ minutes}$). Values shown are results taken from 'Table 2' for normal operation and 'Table 3' for curtailed operation of the PHWF noise compliance assessment. The final row shows the amount noise levels increase due to use of curtailed (active-stall regulated) operation. These results were measured at Location 1 and extrapolated to Corglass Farm.

Data	Wind speed measured at hub height and standardised to 10 m height (m/s)						
	6	7	8	9	10	11	12
Normal Operation - Location 1 extrapolated to Corglass Farm	28.2	29.4	30.5	31.9	33.8	36.3	39.1
Non-normal / Curtailed Operation - Location 1 extrapolated to Corglass Farm	29.4	35.2	38.3	40.1	41.7	-	-
Difference	**1.2**	**5.8**	**7.8**	**8.2**	**7.9**	**-**	**-**

Figure 1 – Chart taken from the PHWF compliance assessment. Blue highlighted data related to periods where turbine curtailment has been used (non-normal operation) and associated increased levels of noise compared to normal operation. Results on this chart were directly measured at 'Location 1' closer to the turbines and used to determine receptor noise levels for the compliance assessment at Corglass Farm by extrapolation.



[14] Paul's Hill Wind Farm, Measured Noise Levels During Grid Curtailment, for Fred Olsen Renewables, Rob Shepherd & Andy McKenzie, Hayes McKenzie Partnership Ltd, 3331_N10_EXT3, 12 November 2019 (https://dpea.scotland.gov.uk/Document.aspx?id=644945).

3.18 In the above example, the grey measurement dataset was obtained during 'normal' operation. The blue measurement dataset was obtained during active-stall regulated (i.e. non-normal) operation[15]. This confirms that when under active-stall (i.e. non-normal) regulation, the turbine type installed at HHWF generates significantly higher levels of noise than when operated under 'normal' operation.

3.19 It is understood that since approximately 2016/2017, the revised operational regime at HHWF is such that active-stall regulated operational is no longer applied during grid related energy export restrictions (i.e. non-normal operational is no longer used).

Hadyard Hill Sound Power Levels

3.20 The noise assessment for KWF contains a detailed consideration of the sound power levels from HHWF, based on the results from a measurement survey completed in 2010 for the Assel Valley Wind Farm [CD003.193 PDF Page 66]. These 2010 measurement data predate the investigation by SSE at Tralodden Cottage and the data-set obtained for the noise survey detailed in the April and July 2016 TNEI reports [CD017.033]. The 2010 measurement results were also obtained at Tralodden Cottage and show a marked difference from the results in the April and July 2016 TNEI reports, being significantly lower in level[16]. This indicates that instances of the excess noise noted by Ms Trayner at Dobbingstone Farm, and which triggered the SSE investigation at Tralodden Cottage, were not present or were significantly less prevalent in 2010 than in subsequent years. Consequently, the data-set gathered for the July 2016 TNEI report [CD017.033] is unlikely to represent the noise immission levels due to normal turbine operation without grid constraints applied to HHWF, nor would the noise immission levels be typical of the method by which SSE have operated HHWF subsequent to approximately 2016/2017 (to remain within the noise limits by stopping certain turbines, rather than applying active-stall regulation).

3.21 The 2010 survey results obtained for Assel Valley Wind Farm indicated that when adopting the sound power levels presented within the noise assessment for the now withdrawn Hadyard Hill Wind Farm Extension, predicted noise levels at Tralodden Cottage were higher than those measured in 2010. The sound power levels used for those predictions were provided in Table C6 and C7 of the KWF noise assessment [CD003.193 page 66], with a maximum sound power level of 107.5 dB(A). In the Statement of Agreed Matters (SoAM) [CD015.014] it was confirmed that a further 2 dB(A) was added to those sound power levels when considering the cumulative effects of HHWF operating together with the three proposed developments, consequently values reach a maximum value of 109.5 dB(A). Application of those data in the SoAM [CD015.014] therefore ensures that due account has been given to worst

[15] It should be noted that whilst Table 1 and Figure 1 relate to the same datasets (and show the same trends) the numbers are not directly comparable due to the fact that the data on Figure 1 was measured at 'Location 1' (a location close to the wind turbines) whilst Table 1 presents data which has been extrapolated to represent the levels at Corglass Farm.

[16] For example at a wind speed of 8 m/s the sound immission level chosen to represent Tralodden Cottage was set at a value of 38 dB(A), being at the upper end of the scatter of measurement data, whilst the 2016 TNEI report shows a level of between 45.4 dB(A) and 45.8 dB(A) for the trendline fitted to the data.

case noise levels from HHWF as measured prior to 2016, and as operated since approximately 2016/2017.

3.22 It is concluded that HHWF would either be fully operational without non-normal use of stall regulation (in which case the sound power levels are appropriate), or would be operating normally but with turbines stopped, resulting in lower receiver noise levels than have been assumed. In both cases, predicted noise levels from HHWF, as utilised in the SoAM [CD015.014], are duly precautionary. The assessment presented in the SoAM [CD015.014] and the site specific noise level limits that it presents for each of the three proposed developments are therefore also duly precautionary, and can be relied upon.

Key Findings

1. Measurement surveys undertaken for Assel Valley windfarm in 2010 identified HHWF noise levels significantly lower than those reported in the submitted April and July 2016 TNEI compliance reports [CD017.032 and CD017.033].
2. Subsequent to the submitted April and July 2016 TNEI compliance reports [CD017.032 and CD017.033], an amended operational control regime was implemented at HHWF [CD017.004 page 246]. Further compliance monitoring was then undertaken and reported in late 2016. That work found lower operational noise levels from HHWF, returning HHWF to be compliant with applicable noise level limits.
3. The period of increased noise levels circa 2016 was due to non-normal turbine operation during periods when HHWF was subject to grid constraint.
4. That non-normal operation is no longer used at HHWF following implementation of an amended control regime. The noise level data presented in the submitted April and July 2016 TNEI compliance reports [CD017.032 and CD017.033] is therefore no longer representative of operational noise levels from HHWF.
5. Active-stall regulation is not a feature of more modern pitch-regulated variable speed turbines that would be installed at the three proposed developments.

3.23 Accounting for the above, any suggestion that the noise level prediction methods used in the submitted noise assessments [CD02.011, CD003.193 and CD012.024] were not sufficiently conservative (for either HHWF or the three proposed developments) is unfounded. Likewise, any suggestions of inaccuracies in the SoAM [CD015.014] and the SSNLs that it presents are also therefore unfounded.

4. ISO9613-2 Ground Factors

4.1 This section addresses the additional submission reference CD017.029 and aspects of CD017.023 (Paragraph 6.2).

4.2 Significant written and oral evidence has already been presented discussing the topic raised by SSfS, where SSfS propose that a ground factor of G=0 be used instead of the IOA GPG recommended value of G=0.5 [Summary Box SB20, page 21 of CD012.002]. A further document has been submitted by SSfS [Tickell et al CD017.029] to support their argument. This is a document referenced during the hearing session by their consultant Mr Huson. Mr Huson maintains that this paper is evidence that the difference between G=0 and G=0.5 is ~4 dB(A), referring in their further submission [CD017.023] to Table 1 of Tickell [CD017.029]. The differences presented by Tickell (rows 'CadnaA G= 0' versus 'CadnaA G=0.') are 4 dB(A).

4.3 The values provided in Tickell Table 1 [CD017.029] do not specify the receiver height used in these calculations, which the IOA GPG stipulates as 4 metres: it is likely the results presented in Tickell used 1.5 metres height. Relevant results presented in Tickell have been replicated using the ISO9613-2 prediction model (see Table 2 below). The absolute values presented in Table 2 are unimportant, what is relevant are the relative differences at a given distance. Rows 1 & 2 show that with G=0 the receiver height makes no difference, whereas with G=0.5 the receiver height becomes important (rows 3 & 4). Row 5 provides a comparison between G=0 and G=0.5 for the IOA GPG recommended receiver height of 4 metres, indicating a difference of ~2 dB(A). Row 6 provides a comparison where a receiver height of 1.5 metres is used (contrary to the IOA GPG) with a difference of ~4 dB(A).

Table 2 – Comparison of ISO9613-2 predictions for different options of ground factor (G) and receiver height. Predictions were made using the source data and frequency spectrum for the turbines on KWF [Table C1 & C2 of CD003.193] based on completely flat ground (no barrier or concave ground corrections), conditions of 10°C and 70% Rh and a wind speed of 8 m/s. Calculations produced by Hoare Lea and validated by TNEI and WSP to be within 0.1 dB(A).

	ISO9613-2 Parameters	Sound Level dB(A) at Distance (metres)			
		1000	1500	2000	2500
1	G=0.0 & Receiver Height 4.0 m	34.5	30.1	26.8	24.1
2	G=0.0 & Receiver Height 1.5 m	34.4	30.1	26.8	24.1
3	G=0.5 & Receiver Height 4.0 m	32.5	28.1	24.7	22.0
4	G=0.5 & Receiver Height 1.5 m	30.9	26.4	23.0	20.2
5	**Diff (IOAGPG Receiver Height 4.0 m & G=0.0 or G=0.5)**	**1.9**	**2.0**	**2.1**	**2.1**
6	*Diff (*Receiver Height *1.5 m & G=0.0 or 0.5)*	*3.6*	*3.7*	*3.8*	*3.9*

4.4 The above comparison shows that the difference between the method recommended by the IOA GPG (G=0.5 and 4 m), which was used in the noise assessments and the SoAM [CD015.014], and that proposed by SSfS (G=0 & 1.5 m) is around 2 dB(A). This is consistent with verbal evidence from Mr Mackay and Mr Jiggins as given in the hearing session on noise. Mr Husons suggestion that changing the prediction settings from those recommended by the IOA GPG could give rise to a 4 dB difference is therefore not correct. A 4 dB difference only arises if deviating from the recommendations of the IOA GPG, so is not relevant. Regardless, it remains that the recommendation of

the IOA GPG is to use G=0.5 and a receiver height of 4 m, which were applied in the submitted noise assessment work for each of the proposed developments [CD02.011, CD003.193 and CD012.024], and therefore the SoAM [CD015.014]. The Applicants remain agreed that the application of those settings is appropriate and in accordance with good practice.

5. Rushforth 2003 Paper

5.1 This section addresses the additional submission reference CD017.028 and aspects of CD017.023 (Paragraph 6.1). The submission [Rushforth et al CD017.028] is made by SSfS to support their argument that a planning condition should be included which assesses noise using the approach set out in the NANR45 methodology [CD017.022, CD017.024 &CD017.030].

5.2 The SoAM [Para. 3.2 of CD015.014] set out the Applicants' evidence on the subjects of infrasound and low frequency noise *"assessment on the basis of 'A' weighted sound levels (the approach in the ETSU-R-97 assessment methodology) provides sufficient control over the potential impact of low frequency noise"*. Further oral evidence was presented at the noise hearing that imposition of a condition based on the NANR45 procedure would not be reasonable or necessary.

5.3 SSfS state [Page 6 of CD017.023]:-

> *"The Rushforth paper is referenced in DEFRA NAN-R45 and it has significance in that a pulsing sound observed periodically at 12.5Hz was the cause of noise complaints that were identified to be from a bag plant in a factory nearby. The instantaneous peak-pressure-amplitudes of the 12.5 Hz bursts reached values of 0.2 Pa and 0.1 Pa at H3 and H2 respectively, equivalent to root-can-square sound pressure levels of 77 dB and 71 dB (e.g. Figure 12 showing peak to trough maxima of 0.6 Pa). This is well below the commonly referenced ISO or DIN 45680 hearing thresholds but were clearly observed by residents in their homes. Pressure pulses from wind turbines are at similar sound levels."*

5.4 Firstly the Applicants can examine the statement that the cause of the noise complaints being investigated was noise at 12.5 Hz. Rushforth comments:-

> *Section 4.6: "Disturbance was recorded at house H1 where the DIN 45680 recommended limit was exceeded at 40 Hz. On some occasions, the DIN limit for the 12.5 Hz third-octave band may have been exceeded during the loudest parts of the pulsing cycle."*
>
> *Section 5.4: "The times when residents at the 'near' end of the estate made complaints or comments referring to perception of a fluctuating sound, corresponded to times when the 40Hz third-octave band levels at house HI exceeded the DIN 45680 limit for that band."*

5.5 The above is a consistent theme within the Rushforth paper, that the primary area of investigation related to the prevalence of spectral peaks around 40 Hz, rather than focussing solely on a frequency of 12.5 Hz, which the statement from SSfS suggests.

We should also note from Rushforth that the DIN 45680 threshold at 40 Hz is 48 dB, whilst at 12.5 Hz it is 86.5 dB[17], indicating that even though the measured levels in the 12.5 Hz band may be greater on some occasions, the presence of this frequency band is (by ~38 dB) less relevant to perception of the noise than the 40 Hz band.

5.6 SSfS refer to data presented in Figure 12 of Rushforth and suggest that these charts show levels *"peak to trough maxima of 0.6 Pa"*. However to take the peak to trough of this signal does not relate to how this would be perceived, which is half of this, based on using the 'root-mean-square' of the signal. It is more instructive to follow the level versus time shown in Figure 13 of Rushforth, which shows how the 40 Hz band changes with time, clearly indicating periods where it exceeds the DIN 45680 criteria. This does not therefore provide any support for the statement from SSfS that *"This is well below the commonly referenced ISO or DIN 45680 hearing thresholds but were clearly observed by residents in their homes."*. The contrary is true: levels were above the DIN 45680 criteria and were therefore potentially audible. In fact the authors of the paper confirm that they were able to hear the sound when they visited the property to undertaken the measurements as they note in Section 5.3:-

> *"The authors' personal judgement from a listening position upstairs, outside the bedroom where the monitoring equipment was installed, was that fluctuations were audible when BP1* [bag plant 1] *was on, but were inaudible when it was off."*

5.7 The statement from SSfS that *"Pressure pulses from wind turbines are at similar sound levels"* has no relevance in this context: the amplitudes of unweighted signals do not on their own provide a relevant metric of perception. What is relevant are whether the levels exceed hearing thresholds (or criteria such as DIN 45680) at specific frequencies, noting the very large reduction in sensitivity as frequencies reduce. The Applicants have not identified any data presented by SSfS which shows levels of wind turbine noise which would be above either the DIN 45680 or NANR45 criteria.

5.8 The Applicants conclude that SSfS's interpretation of the Rushforth paper is incorrect and does not support the use of a separate noise criteria being applied to control low frequency noise or infrasound, such as that contained within NANR45. Notwithstanding that conclusion, the Applicants provide additional context on how the authors of NANR45 suggest it should be used. Section 1.1 [CD017.024] states:-

> *"this guidance provides a procedure to determine whether low frequency sound that* ***might be expected to cause disturbance*** *is present in a complainant's premises"….. "The procedure is intended to assist in the evaluation of existing problems It is not intended as a means of prediction when disturbance might occur, for example in a planning situation, and would* ***not be reliable to use as such****."……"Levels of sound above the criteria based on the average threshold of hearing are* ***frequently found to be acceptable*** [our highlight]*."*

[17] The NANR45 criteria is 49 dB at 40 Hz and 87 dB at 12.5 Hz, and is therefore very similar to DIN 45680.

5.9 Section 4.3 of NANR45 [CD017.024] continues:-

> *"This document is intended to provide a procedure to help determine whether a low frequency environmental noise exists that **could** be the cause of complaints. It is **not intended to provide a prescriptive indicators of nuisance** since there are other factors that may need to be considered in reaching this decision* [our highlight].*".*

5.10 The Applicants are satisfied that appropriate control of levels of noise from the proposed developments would be provided by controlling 'A' weighted noise levels and that separate control of low frequency noise or infrasound is not necessary, nor would it be practical to do so.

6. Financial Involvement

6.1 In an email sent by the DPEA[18], the Reporters requested additional information on several matters, and this included a request to confirm the nature and scope of the financial involvement of properties proximate to the proposed developments. Whilst that request relates to residential visual amenity, the Applicants provide further comment below in relation to noise for the avoidance of doubt.

6.2 The SSNLs proposed in the SoAM [CD015.014] and included in the conditions proposed by the Applicants [CD015.035, CD015.036 & CDCD015.037] have been calculated on the basis that no dwellings have been financially involved with any of the proposed developments in relation to operational noise. This position has not changed and all locations are not financially involved in terms of operational noise. For the avoidance of doubt, the SSNLs in the proposed conditions therefore take a precautionary approach in controlling operational noise and remain valid.

[18] DPEA email of Procedural Notice to participants 30th June 2023.

7. Conditions

7.1 This section addresses the additional submission references CD017.025, CD017.027 and CD017.034.

7.2 SSfS submitted their comments and suggested amendments to the condition [CD017.034] along with further submission of documents and justifications just prior to the conditions hearing on 20th June 2023. Those comments and suggested amendments were shown (in red text) added to the condition submitted by SAC (as amended by their consultants ACCON UK) [CD015.031]. The ACCON UK amendments were primarily additions associated with amplitude modulation (AM). The condition from SAC was based on the original version submitted by the Applicants [CD015.030] which did not include control of AM. Note that SAC have subsequently (during the Conditions Hearing Session, 20th June 2023) accepted that an AM clause is not required by ETSU-R-97 nor is it supported by policy (see paragraph 7.20) and have accepted the latest condition wording without an AM clause [CD015.035, CD015.036 & CD015.037].

7.3 Each of SSfS's amendments are discussed below. To assist the reader, each addition made by SSfS is reproduced in italics within a box outline with a response then provided for each point in turn.

> Comment (page 1): *"Conditions can only be a contingency in the event the applications are approved. The Reporters should request that the background noise tables are completely reassessed due to ongoing non compliance of Hadyard Hill operational noise levels and the conjoined applicants unsound reliance on flawed data. See CD 17.23."*

7.4 It appears that the reference to 'background' noise tables should in fact relate to tables of Site Specific Noise Limits (SSNLs). This matter is dealt with above in relation to the TNEI compliance assessments for HHWF. Proper account was taken of HHWF and the resulting SSNLs provided in the SoAM [CD015.014] remain valid. For the avoidance of doubt it is confirmed that the background noise levels that were presented in the SoAM (upon which the limits are based) have been derived appropriately in accordance with ETSU-R-97 [CD012.001] and the IOA GPG [CD012.002].

> Proposed amendment to the wording (page 1): *"at any ~~dwelling~~ noise sensitive receptor as reference CD012.016".*

7.5 SSfS propose to replace 'dwelling' with 'noise sensitive receptor' and make reference to their evidence. This change is based upon their suggestion that there are receptors other than dwellings which should be protected (e.g. caravans, tents etc.). This matter was discussed at length in the noise hearing session and the notion that control be

extended to other non-residential receptors is rejected. ETSU-R-97 [CD012.001] requires noise limits be set only at dwellings and the use of ETSU-R-97 is Scottish Government planning policy [CD005.016] for controlling noise from wind farms.

Proposed amendment to the wording (page 1-2): *"and also to an independent acoustic consultant commissioned/employed by a complainant on their request".*

7.6 This matter was also discussed in the noise hearing session and the suggested additional text is unnecessary. A compliance assessment, should one be required, would be undertaken by an independent consultant in accordance with paragraph (c) of the condition. Should residents wish to request copies of the data they can do so via SAC.

Proposed amendment to the wording (page 2): *"The Planning Authority's approved list of independent consultants and any subsequent amendments must be made available on request, within 7 days of such a request to any interested party or complainant."*

7.7 This is an obligation placed on SAC rather than the operator of the developments, accordingly it fails the test of a valid condition. Any third party could request this information from SAC.

Proposed amendment to the wording (page 2): *"and the procedure described in DEFRA NAN R277".*

7.8 SSfS's have suggested inclusion of the procedure of NANR 277 be followed in addition to the guidance notes. NANR 277 [CD017.027] has a title of "Wind Farm Noise Statutory Nuisance Complaint Methodology". Its purpose is to provide assistance to those investigating whether noise amounts to a statutory nuisance and is therefore separate and distinct to the controls available within the planning system. Inclusion of the text is inappropriate for two reasons:

- firstly, the inclusion would fail the test of precision as the NANR 277 is discursive rather than being prescriptive meaning it is unclear which elements of the document should be followed; and
- secondly, reference to the document is not 'relevant to planning' as it seeks to duplicate the effect of other controls (in this case SAC's existing statutory nuisance powers).

Proposed amendment to the wording (page 2): *"All noise and operational data used in the complaints investigation is to be made available to the complainant and an independent acoustic consultant commissioned/employed by a complainant at their request at no cost."*

7.9 The additional text is considered to be unnecessary for the same reasons detailed in paragraph 7.6 above.

Proposed amendment to the wording (page 2): *"The Noise Limits if not those in Tables 1 and 2 shall be assessed using ON/OFF testing in accordance with IoAGP*[sic]*~~; are to be those selected from Tables 1 and 2,"~~*

7.10 This proposed amendment would require, in the event that a complaint is received from any property which is not listed in the Tables of noise limits, that additional measurements would be undertaken with the wind farm turned off to determine new background noise levels, which would in turn be used to set the applicable noise limits. This is not a requirement of ETSU-R-97 [CD012.001] or the IOA GPG [CD012.002] and is considered to be unnecessary. The approach set out in the condition proposed by the Applicants is consistent with the example condition contained within the IOA GPG [clause e) of CD012.002], which states:-

> *"Where a dwelling to which a complaint is related is not listed in the tables attached to these conditions, the wind farm operator shall submit to the Local Planning Authority for written approval proposed noise limits selected from those listed in the Tables to be adopted at the complainant's dwelling for compliance checking purposes. The proposed noise limits are to be those limits selected from the Tables specified for a listed location which the independent consultant considers as being likely to experience the most similar background noise environment to that experienced at the complainant's dwelling."*

7.11 In addition, the condition must be relevant to the proposed development and enforceable; each individual operator would not have control over neighbouring wind farms to allow all turbines to be switched off, as may be necessary to enable determination of relevant background noise levels. The wording of the condition as proposed by the Applicants addresses this potential scenario by utilising already documented background noise levels from another location considered most relevant. The condition as proposed by the Applicants also accounts for the need for SSNLs to reflect an appropriate apportionment of the Total ETSU-R-97 Noise Limits, relevant to the complainants location.

7.12 For the avoidance of doubt, it should be noted that the proposed conditions <u>do</u> include a mechanism for the turbines of an individual development to be turned off, if required, to enable the calculation of the specific contribution from that wind farm. This is then achieved by logarithmically subtracting the measured noise levels with the

turbines off (referred to as L3 in Guidance Note 4[19] of the conditions from the Applicants') from the total noise levels measured with the wind farm operating (L2) to determine the specific noise from the development (L1). This on/off requirement in the Applicants' proposed conditions is different from that discussed by SSfS for determination of background noise levels, which are those without *any* wind turbine noise contribution.

Comment (page 2): *"the NOISE LIMITS in Tables 1 & 2 are no longer considered to be valid and sound, and are thus inadmissible: reference SS CD017.023"*

7.13 This point has already been addressed in Paragraph 7.4 above. The SSNLs proposed by the Applicants remain appropriate.

Proposed amendment to the wording (page 2-3): ~~*"In the event that the consent of the complainant for access to their property to undertake a compliance assessment is withheld, the assessment protocol shall set out details of the proposed alternative representative measurement position.*~~ *A compliance assessment is required at the complainants property. A compliance assessment need only be completed if access to the property is allowed by the complainant.* ~~*e) Where the proposed measurement location is close to the wind turbines, rather than at the complainant's property (e.g. to improve the signal to noise ratio), then the protocol shall include a method to determine compliance at the complainant's property based on the noise levels measured at the agreed location."*~~

7.14 In the event that complaints are received, it is clearly desirable for them to be appropriately investigated. This would ideally be undertaken at the complainant's property but the text included in the condition submitted by the Applicants' would allow the appointed independent consultant to investigate, even if consent to monitor at the complainant's property is refused. This approach is consistent with the example condition in the IOA GPG in Annex B Example Planning Condition [CD012.002], as shown below. No changes should therefore be made to the condition proposed by the Applicants.

> *"In the event that the consent of the complainant for access to his or her property to undertake compliance measurements is withheld, the wind farm operator shall submit for the written approval of the Local Planning Authority details of the proposed alternative representative measurement location prior to the commencement of measurements and the measurements shall be undertaken at the approved alternative representative measurement location."*

7.15 The text deleted by SSfS which was shown as paragraph e) accords with the guidance included in the IOA GPG SGN5 [CD012.022] which states:-

[19] This is Guidance Note 5 in the version of the condition used by SSfS as it includes an additional Guidance Note which discusses AM.

"In such cases where noise limits are less than ETSU-R-97 limits (e.g. apportionment of noise impacts due to cumulative impacts) compliance measurements may need to be undertaken in closer proximity to the wind farm to ensure background noise levels do not unduly influence the readings."

This is particularly relevant in this case given that the noise limits have been apportioned between several wind farms (including Hadyard Hill Wind Farm, Dersalloch Wind Farm and the proposed developments). It is recommend that the text is retained.

Proposed amendment to the wording (page 3): *"~~is a building in residential use~~ is a noise sensitive receptor reference SAC CD012.016, CD017.005 Hearing Statement - W L Huson & CD 17.17 Conditions Noise Sensitive Receptors (NSR)".*

&

Proposed additional condition (page 4): *"Target noise limits outside any camp site area at night are determined as the base noise limit of 28 dBA, L90 or Background plus 5 dB, whichever is the greater, over the operating wind speeds of the chosen wind turbines."*

7.16 These matters (and related SSfS comments – page 3-4) have already been covered in Paragraph 7.5 above. This topic was discussed at length in the noise hearing session. The text originally proposed by the Applicants remains appropriate. The inclusion of a separate condition for camp sites is not appropriate or necessary.

Comment (page 4): *"Given Concerns over Background measurements Tables 1 & 2 need new background noise measurements Table 1 & 2 Noise Limits now considered to be inadmissible."*

7.17 This has already been covered in Paragraph 7.4 above and the SSNLs proposed by the Applicants remain appropriate.

There are a number of comments and amendments relating to AM which begin (page 5 onwards): *"CD 17.17 Save Straiton Proposed Noise condition: AMPLITUDE MODULATION, 9. SUMMARY, Application of the IoA AM Method significantly underestimates the true amplitude modulation experienced at a dwelling".*

7.18 In addition to the comment above, additional text is included on pages 8, 9 10 of the SSfS submission [CD017.034] to support their suggestion that control of AM should be included. The changes in this section are difficult to follow and for brevity all of the text is not repeated here, but it appears that SSfS propose:

- AM should be controlled using the approach adopted at Den Brook;
- That the penalty scheme originally suggested by SAC [CD015.031] should not be used;
- That Guidance Note 4 (which relates to AM in the version edited by SSfS) should be replaced with a requirement for impulsiveness to be penalised in accordance with BS 4142.

7.19 SSfS stated on page 10: *"Applicants need to resubmit conditions that do not contradict each other in respect of AM"* which follows text which suggests that *"Each of the applicants have removed a proposed AM Condition contrary to Final Agreed Version 7 2023-03-03".* The position of each of the Applicants in relation to the inclusion of an AM condition has been clear and consistent: none of the draft conditions submitted by the Applicants has included consideration of AM. The version of the condition included at the end of CD015.039 (including control of AM) is not the agreed position with the Applicants, but reflects the condition proposed earlier in the inquiry process by SAC [in CD015.031]. The main table in that document states clearly (on page 43) this condition was not agreed for AM.

7.20 It is important to note that SAC subsequently confirmed at the hearing session on conditions, following feedback from their noise consultants ACCON UK, that SAC agreed the noise conditions as proposed by all three Applicants [CD015.035, CD015.036, CD015.037], now accepting that control of AM is not required by ETSU-R-97 and is not supported by planning policy. It is noted that, despite being invited to by the Reporter in the hearing session and in Matter 2 of the procedure notice[1], SSfS have not submitted any examples of Scottish Planning decisions where AM conditions have been adopted.

7.21 Notwithstanding the fact that all three Applicants and SAC agree that a condition relating to AM should not be included, it is reiterated that inclusion of a condition in the style used at Den Brook is not appropriate for the reasons set out in the noise hearing session. Mr David Hardy highlighted in the noise hearing session, that CMS (acting on behalf of the Applicant for CMWF) would in due course make legal submissions regarding the suggestion by SSfS that the Den Brook condition has been verified in court.

7.22 The SSfS submissions suggest a requirement be imposed to control for impulsiveness, which is to be penalised in accordance with BS 4142. This requirement has not been explained by SSfS, nor is it considered necessary or applicable. This requirement is contrary to the requirements of ETSU-R-97 [CD012.001] and SSfS have not provided any examples where such a condition has been imposed on a wind farm. It is therefore recommend that SSfS's suggested amendment is rejected.

7.23 Having considered the submissions made by SSfS in detail, it is agreed that none of the proposed changes by SSfS should be made to the conditions submitted by the Applicants and agreed by SAC [in CD015.035, CD015.036 & CD015.037].

8. Conclusions

8.1 This joint submission on operational wind turbine noise, responds to the procedural notices of 6th June 2023[1] and the 30th June 2023 and has been prepared by the acoustic consultants acting on behalf of the three applicants of the Craiginmoddie Wind Farm (CMWF), Carrick Windfarm (CWF) and Knockcronal Wind Farm (KWF). The authors also prepared the noise SoAM [CD015.014].

8.2 The following key conclusions are drawn in this joint submission:-

- The two submitted HHWF compliance reports [CD017.031 and CD0170.32] can no longer be considered to represent the levels of operational noise from HHWF. Those reports present data from a period in 2016 when increased noise levels were generated by HHWF due to non-normal operation of turbines (application of active-stall regulation during periods of gird constraint). Subsequent to those reports, an amended wind farm control regime was implemented at HHWF [CD017.004 page 246]. The change was to switch individual turbines off leaving the 22 remaining on turbines under normal operation (rather than all turbines being active-stall regulated). A later (third) report from TNEI (not before this inquiry) presents the results of measurements gathered later in 2016 after implementation of the amended control regime. SAC commented on this subsequent report: *"Due to the amended operational control regime which has been put in place, levels were found to be in compliance with the agreed noise levels"* [CD017.004 PDF page 246].
- The period of increased noise levels in 2016, as presented in CD017.031 and CD0170.32, was associated with non-normal application of active-stall regulation during grid constraint periods. Active-stall regulation is not a feature of more modern pitch-regulated variable speed turbines that would be installed at the three proposed developments, so there are also no implications for the noise level predictions undertaken for the three proposed developments, as adopted in the operational noise SoAM [CD015.014].
- The ETSU-R-97 / IOA GPG [CD012.001 and CD012.002] noise level prediction method, as applied in the submitted noise assessments [CD02.011, CD003.193 and CD012.024] and the operational noise SoAM [CD015.014], remains appropriate and there is no need to undertake revised noise level predictions with alternative parameter settings.
- The further submissions made by SSfS do not change the Applicants joint view that appropriate control of low frequency noise from wind turbines is achieved by assessment of A-weighted noise levels in accordance with ETSU-R-97 [CD012.001] and the IOA GPG [CD012.002].
- The Site Specific Noise Limits (SSNLs) presented in the operational noise SoAM [CD015.014] have been calculated on a precautionary basis, assuming that no receptors are financially involved. Accounting for any financial involvement of local receptors would only serve to result in the calculation of more lenient (higher) SSNLs, which is not proposed for any receptor.

- The comments raised by SSfS and suggested textural amendments to the noise condition have all been reviewed and considered in turn in Section 7. None should be accepted for the reasons given in that section.
- The noise conditions presented in CD015.035, CD015.036 & CD015.037, are agreed by the Applicants and SAC, and it is noted that SAC have accepted that a condition or clause relating to AM should not be included. Furthermore, SAC accepted the conditions as proposed by the Applicants which do not include any of the changes proposed by SSfS.

8.3 It is agreed that any suggestion that the noise level prediction methods used in the submitted noise assessments [CD002.011, CD003.193 and CD012.024] and the operational noise SoAM [CD015.014] were not sufficiently conservative (for either HHWF or the three proposed developments) is unfounded. It is also agreed that the assessment presented in the SoAM [CD015.014] remains duly precautionary and can be relied upon. This includes the SSNLs that are presented for each of the three proposed developments. Those SSNLs are fit for purpose and appropriate for use in the noise conditions as agreed with SAC [CD015.035, CD015.036 & CD015.037].

8.4 Having considered all of the information submitted to the inquiry in relation to noise it is agreed that noise should not be a reason for refusal of the proposed developments, either individually or cumulatively (in any combination). If Scottish Ministers are minded to grant consent for any or all of the proposed developments, the noise conditions presented in CD015.035, CD015.036 & CD015.037, as now accepted by SAC, remain appropriate for use without any change. This is the case regardless of the combination of consents granted.

ANNEX A

Paul's Hill Wind Farm – Noise Compliance Assessment, October 2019, Hayes McKenzie Report HM: 3261_R01_EXT3: 04/10/19 (https://dpea.scotland.gov.uk/Document.aspx?id=643443).

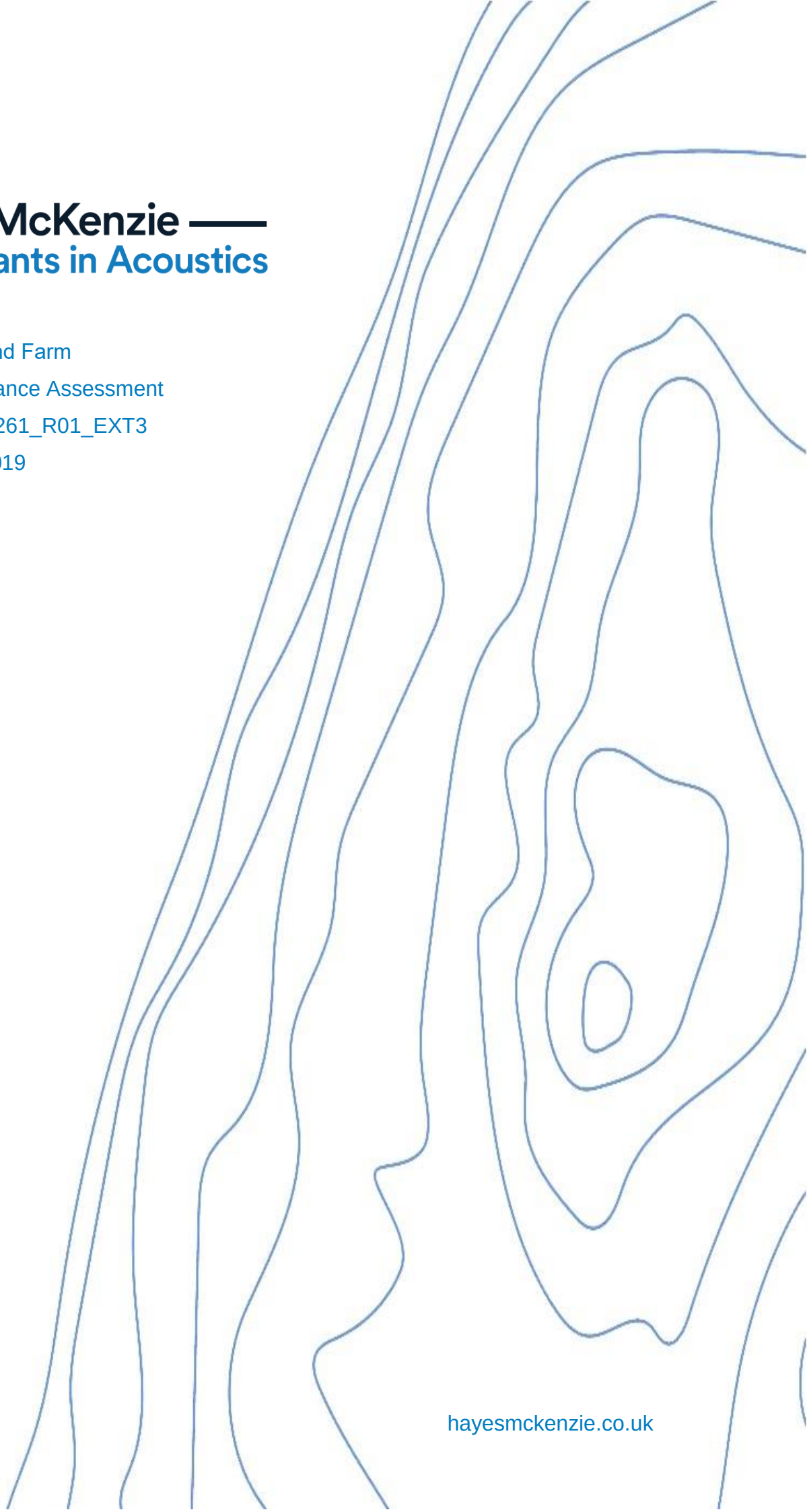
Hayes McKenzie
Consultants in Acoustics

Paul's Hill Wind Farm

Noise Compliance Assessment

Report HM: 3261_R01_EXT3

04 October 2019



hayesmckenzie.co.uk

Paul's Hill Wind Farm
Noise Compliance Assessment
Report HM: 3261_R01_EXT3,
4 October 2019

Prepared for:	Pauls Hill Wind Limited 2nd Floor, 36 Broadway, London, SW1H 0BH
Report prepared by:	Rob Shepherd MEng, MIOA Principal Acoustic Consultant
Checked by:	Robin Woodward BSc, MIOA Senior Acoustic Consultant
Approved by:	Andy McKenzie PhD, BSc, FIOA Director and Principal Acoustic Consultant

Unit 3, Oakridge Office Park, Whaddon, Salisbury SP5 3HT, UK
+44 (0)1722 710091, salisbury@hayesmckenzie.co.uk

1. EXECUTIVE SUMMARY

1.1 The Hayes McKenzie Partnership Limited (HMPL), independent consultants in acoustics, was commissioned to undertake measurements of noise levels resulting from the operation of the Paul's Hill Wind Farm following complaints from residents at Corglass Farm, which is located to the east of the wind turbines.

1.2 Measurements were carried out at Corglass Farm in 2018 in order to evaluate compliance with the noise limits included at section 7.8 of planning conditions, with the results presented in a report[1] submitted to Moray Council. However, the results of the measurements were inconclusive, due to the high scatter in the measured noise levels at the measurement location.

1.3 In order to evaluate the wind farm noise levels at Corglass Farm with more certainty, it was agreed with Moray Council that measurements would be undertaken nearer to the wind turbines at a location between Corglass Farm and the wind turbines. The results of the measurements would be used to determine whether operational noise levels would comply with the relevant noise limit as extrapolated to Corglass Farm.

1.4 The results of the measurements indicate that average operational noise levels are below the specified noise limit of 35 dB L_{A90} at Corglass Farm for 10 m height wind speeds up to 10 m/s on site under normal operational conditions.

1.5 Periods of elevated noise levels were identified, when the operation of the wind farm was curtailed due to grid restrictions where the rotational speeds of certain turbines are restricted, resulting in higher levels of stall noise. During these grid restriction periods, measured noise levels as extrapolated to Corglass Farm, exceed the noise limit. In light of the elevated noise levels during curtailment periods it is proposed that an alternative means of curtailment, e.g. shutting down rather than restricting the rotational speed of the turbines, is now employed to reduce noise levels during these periods.

[1] Report HM: 3261_R01_EXT8: 24/04/19, Paul's Hill Wind Farm, Noise Compliance Assessment

2. INTRODUCTION

2.1 The Paul's Hill wind farm consists of 28 wind turbines and had been operating without complaint since it became fully operational in 2006. Following proposals in 2017 for an extension to the Paul's Hill wind farm to the east of the existing turbines, complaints have been made by residents of Corglass Farm about noise when the existing turbines are operating. The complaints related to the overall noise from the wind farm as well as amplitude modulation (AM) of the sound.

2.2 The planning conditions set out the noise limit for the site as a level of 35 dB L_{A90} that is not to be exceeded for wind speeds of up to 10 m/s as measured at a height of 10 m above ground level at the wind turbines.

2.3 Noise compliance measurements were carried out at Corglass Farm in 2018 which indicated that there was no significant AM present in the measured noise, but the results indicated a high level of scatter in measured noise levels both with the wind farm operating and shut down. This made it impossible to reliably calculate the wind farm noise level to ascertain with certainty whether the noise limits were being met.

2.4 In order to evaluate the wind farm noise levels with more certainty, it was agreed with Moray Council, that measurements would be carried out nearer to the wind farm, such that the results could be used to infer whether the noise limits are being met at Corglass Farm. The methodology is in line with the Institute of Acoustics (IOA), Supplementary Guidance Noise 5 (SGN5), *Post Completion Measurements,* which states:

> *'It should be noted, however, that where the shut-down noise approaches the operational noise, the level of shut-down noise has an increasing effect on the calculated turbine noise such that when the difference between the two is 3 dB or less, it may no longer be appropriate to use this correction with any degree of accuracy and some other method of determining turbine noise in the presence of high levels of background noise may need to be agreed with the planning authority. In the event that the typical background noise is greater than the turbine noise limit, and if the additional contribution of the turbine noise to the prevailing background is difficult to discern with confidence from the data, then it is likely that compliance with the ETSU-R-97 limits would be demonstrated. In such cases where noise limits are less than ETSU-R-97 limits (e.g. apportionment of noise impacts due to cumulative impacts) compliance measurements may need to be undertaken in closer proximity to the wind farm to ensure background noise levels do not unduly influence the readings*.'

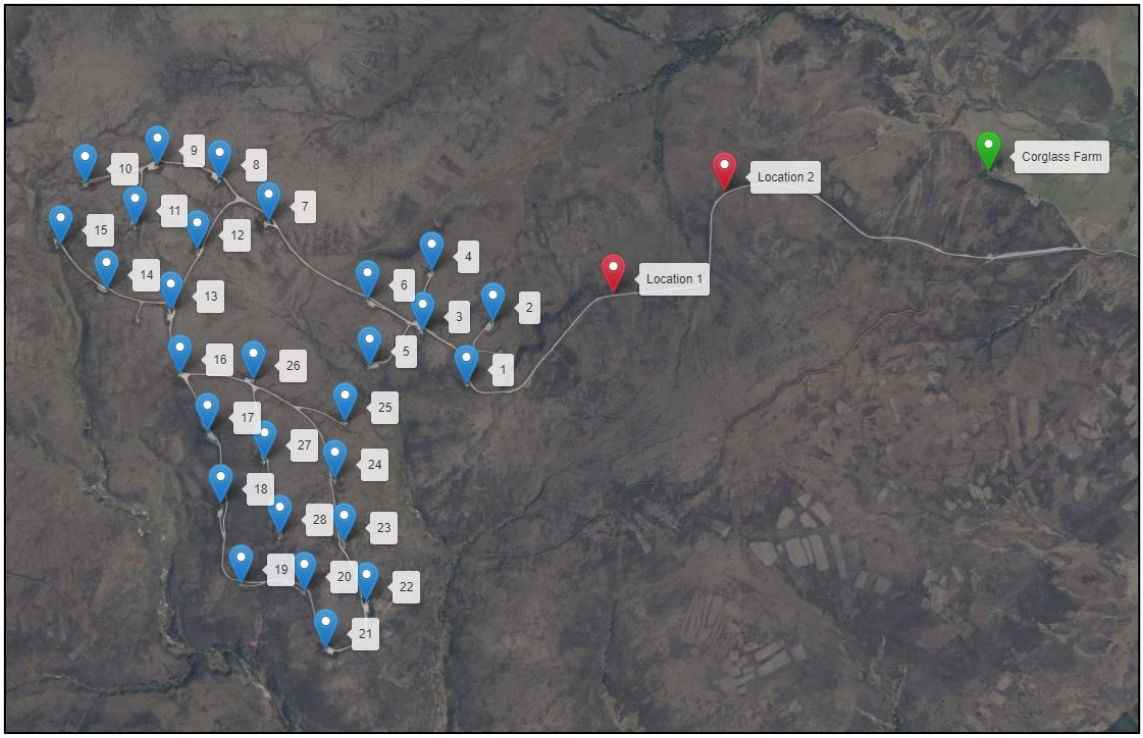
2.5 This paragraph from SGN5 is primarily concerned with the situation where the average background noise level, measured during periods of turbine shut-down, is close to, or even above, the overall measured noise level with the turbines operating (operational noise). It also applies, however, where there is high scatter in background noise levels in the vicinity of the measurement location. Both of these situations result in it not being possible to calculate the wind farm noise level with any degree of accuracy, and which can be overcome by carrying out measurements closer to the turbines.

2.6 Prior to carrying out noise compliance measurements, Hayes McKenzie Partnership Ltd (HMPL) submitted and discussed the proposed assessment methodology (developed in line with SGN5) with Moray Council, with the final agreed methodology shown in Appendix A of this report. It should be noted the agreed methodology assumed that if the noise limit was met at wind speeds up to 9 m/s this was an indication that the limit would be met for all wind speeds, however it has been ensured that the measured noise data covers all wind speeds up to 10 m/s.

3. NOISE SURVEY

3.1 Two positions were chosen near to the Paul's Hill Wind Farm adjacent to the access track to the site. The noise measurement locations, and turbine locations, are all shown at Figure 1. The blue markers show the turbine positions, the red markers show the measurement locations, and the green marker shows the location of Corglass Farm. A description of the siting of the monitoring equipment and measurement procedure is given below.

Figure 1 – Noise Measurement & Turbine Locations



Instrumentation

3.2 The noise measurements were made with RION model NL-52 Sound Level Meters, fitted with 1/2" microphones, which comply with the Class 1 standard in IEC 61672-1:2002[2]. The microphones were fitted with 45 mm radius foam ball windshields surrounded by a 125 mm radius secondary windshield of 40 mm thickness (based on recommended design specifications within ETSU W/13/00386/REP[3]) and mounted on a tripod at a height of approximately 1.3 metres above ground level. Calibration was carried out using Brüel & Kjær model 4231 acoustic calibrators (serial numbers 3022368/2699280/3009009). The calibration of the meters was set at the beginning of the survey, checked during the interim site visits and again at the end of the monitoring period.

Measurement Procedure

3.3 The measurement equipment was installed on 22nd March and visited approximately every 17 days to download the data, calibrate the equipment, and to change the batteries. The equipment was collected on 8th August 2019. The results presented here represent measured data up to 31st July 2019.

[2] IEC 61672-1:2002, Sound level meters - Part 1: Specifications, International Electrotechnical Commission, 2002
[3] ETSU W/13/00386/REP, Noise Measurements in Windy Conditions, Davis R A, Lower M C, 1996

3.4 The sound level meters were programmed to measure a number of statistical noise indices, including the L_{A90}, together with the maximum and minimum levels and the $L_{Aeq,}$ over consecutive 10-minute periods. Results were automatically stored at the end of each period and the equipment was time-synchronised to the turbine Supervisory Control and Data Acquisition (SCADA) systems, as well as a LiDAR[4] unit located on the Paul's Hill II wind farm site. In addition to the measured overall 10-minute A-weighted noise levels and statistical indices, the meters were also set up to record the first 2 minutes of audio in every 10-minute interval during the survey period, and also to record one third octave band 100 ms L_{Aeq} data.

3.5 Calibration of the noise measurement equipment was carried out before the monitoring period commenced, during the interim site visits and was checked at the end of the survey. Changes of no more than 0.2 dB were noted at any of the site visits, which is within normal tolerances.

3.6 Wind data was taken from the LiDAR (located on the Paul's Hill II proposed wind farm site and near to Location 2), and from the turbine SCADA[5] system, in 10-minute intervals. The SCADA wind speed data was taken from the nacelle-mounted anemometers on each turbine, corrected for the influence of blade effects, and averaged across the whole wind farm. Wind direction was taken at 59 m height from the LiDAR data.

3.7 Weather stations were installed at both measurement locations, which recorded a number of meteorological parameters, including logging rainfall in 10-minute intervals, time synchronised to the noise, LiDAR, and SCADA data.

3.8 During the course of the measurements, the wind turbines were shut down to record baseline noise levels when the wind farm was not operating to allow correction of the measured overall noise levels to that for the wind turbines only.

4. NOISE LIMITS

4.1 The noise limits for Corglass Farm were extrapolated to the measurement positions (using the prediction methodology described in Appendix B), whereby the difference between the

[4] Light Detection and Ranging device for measuring wind speed at various heights above ground level from a ground based unit.
[5] Supervisory control and data acquisition

predicted noise levels at the measurement positions and Corglass Farm were added to the noise limit applicable to Corglass Farm. The resultant noise limits and downwind angles (see paragraph 5.2 below) applicable to the measurement locations are detailed below. The range of downwind angles has been calculated as the bearing to the most extreme turbines with an additional 45° added either side as being representative of wind directions where propagation to the measurement positions can be considered to be downwind.

Table 1 – Applicable Limits for Measurement Locations

Location	Easting	Northing	Predicted Level Difference (dB)	Applicable Limit (dB L_{A90})	Angles to Outer Turbines +/- 45°
Corglass Farm	315399	841877	-	35.0	190-316°
Near site Location 1	313477	841252	11.7	46.7	175-332°
Near site Location 2	314050	841755	6.7	41.7	177-319°

4.2 Compliance with the noise limit has been explored, firstly, on the basis of the results of the measured operational noise correlated with the average wind farm wind speeds (standardised to 10 m height). Where these results indicate that the noise limit is met, then a further exercise has been carried out to determine if the noise limit set relative to measured 10 m height wind speeds (the metric required by the planning condition) is met in practice. This has been done by reviewing the results of the measurements in relation to measured 10 m height wind speeds on site (noting that there will inevitably be a poorer correlation between measured operational noise and wind speed).Where these results also show compliance with the limit then it can be concluded that the wind farm is operating within its planning conditions.

4.3 It should be noted, that in any case, at measured 10 m height wind speeds of 10 m/s the average wind shear exponent between 10 and 59 m has been shown from LiDAR data to be lower than that assumed for standardised conditions. This means that if the results presented for standardised 10 m height wind speeds meet the limits then this would also be the case for measured 10 m height wind speeds.

4.4 The approach set out above has been taken because it is important to be able to define as accurately as possible the wind farm noise levels (by relating measured noise to hub height wind speeds) as well as evaluating whether the planning condition noise limit is met for measured 10 m height wind speeds.

5. DATA PROCESSING

5.1 The measured data was filtered as described in the following paragraphs, to establish valid data for the determination of noise levels with and without the wind turbines operating.

Directional Filtering

5.2 Valid data for the periods when the wind farm was operating normally was filtered to include only wind direction corresponding to periods when Corglass Farm was downwind of the wind farm, i.e. wind directions of 190-316° as a worst case, which is within the downwind angle range for each measurement location.

Wind Farm SCADA Analysis

5.3 The wind farm SCADA data was analysed to determine periods when the wind farm was considered to be operating normally and when it was shut down. Data from other periods was excluded from analysis.

5.4 The wind farm was considered to be operating normally, in each 10-minute period, if at least 26 of the 28 turbines were operating. i.e. according to the following:

- The minimum rpm was greater than or equal to 9 rpm, and
- The minimum power output was greater than 50 kW.

5.5 The number of turbines operating normally selected as defining normal operation for the wind farm was set at 26 (rather than all 28) to maximise the amount of useable operational data without significantly compromising the results. Turbine 1 had an issue with its rotor speed sensor (although was subsequently defined as operating as expected for the duration of the measurements) therefore was not defined as operating normally according to the filtering described above. Therefore, if 27 turbines are classified as operating normally, in reality it is likely that all 28 turbines were operating normally. If the nearest turbine to the nearest measurement location was not operating the reduction in predicted noise level is 1.3 dB, if any of the other turbines was not operating (and the remainder are) then the maximum reduction is 0.6 dB. On this basis, as discussed above, it can be assumed that using a filter of 26 turbines operating normally, as defining normal operation for the wind farm, will not have a significant effect on the results.

5.6 There is an additional consideration that, because the turbines are twin speed machines, and the wind farm covers a large area, there are periods during lower wind speeds where some turbines that are downwind of others experience lower wind speeds and therefore do not start to rotate, at their low rotational speed, at the same time as all the others. Therefore having some flexibility in the number of normally operating turbines comprising normal operation for the wind farm ensures that data where the wind farm is still operating normally (but where some turbines have not yet reached their low speed rotational speed) are not excluded from the analysis.

5.7 The wind farm was determined to be shut down, and the corresponding noise data suitable to be representative of baseline noise levels with no contribution from the turbines, if the maximum rotation speed of **all** turbines was less than 3 rpm. A maximum rpm of 3 was chosen because, during a shut down period, the turbines may still rotate at a very low speed, but not create any noise measureable at the microphone locations. This ensures that, for the purposes of obtaining background noise levels during a shut down, at the measurement positions, measured noise does not include any wind turbine noise.

5.8 As noted at paragraph 5.3 above, any periods where the wind farm was not classified as either operating normally, or shut down, were excluded from the analysis.

Wind data processing and filtering

5.9 The hub height wind speed was determined from the average nacelle wind speed from the installed turbines. The nacelle wind speed was corrected for the presence of the rotating blades by correlating the measured nacelle wind speed, (for periods determined as normal operation as above), with the measured 59 m height LiDAR wind speed and applying the average ratio to the nacelle wind speed. It should be noted that turbine 1 was excluded from the derivation of the average wind speed due to the fault with the rotational speed sensor data (described at paragraph 5.5) resulting in the turbine being classified as not operating normally), which meant that its corrected wind speed could not be calculated .

5.10 The 59 m height wind speeds were converted to standardised 10 m height wind speeds assuming a logarithmic wind shear profile and a ground roughness length of 0.05 m. The standardised 10 m height wind speed (from the average wind farm hub height wind speed) is used as the primary wind speed because it is the wind farm hub height wind speeds that control the noise output of the turbines and hence measured noise levels. The results are standardised to 10 m height, for historical reasons, and to allow for comparison with the noise limit that applies up to a measured 10 m height wind speed of 10 m/s, although it should be noted that wind shear needs to be considered when making this comparison. The intention is to obtain the best correlation of measured noise with wind speed to enable

the wind farm noise levels to be established as accurately as possible, and was agreed with Moray Council (see Methodology in Appendix A).

Noise data filtering

5.11 Measured noise data was filtered to only include periods when no rainfall was logged on the rain gauge located on the meteorological logging equipment adjacent to the noise measurement equipment.

6. ASSESSMENT

6.1 The results of the measurements are shown below in the following figures. Each chart shows the measured noise levels plotted against standardised 10 m height wind speed during wind farm operation, and with the wind farm shut down, together with the extrapolated noise limit (see section 4) relevant to the measurement position. A polynomial best fit regression line has been plotted through the measured operational and measured shut down noise levels to derive the prevailing measured and prevailing shut down noise levels. The wind farm noise levels have been calculated by logarithmically subtracting the derived prevailing shut down noise from the derived prevailing operational noise levels, where the difference between prevailing operational and prevailing shut down levels are greater than 3 dB. Where the difference is less than 3 dB a logarithmic subtraction cannot be reliably undertaken, and therefore the results are not presented, but is an indication that the prevailing wind farm noise level is equal to or below the prevailing shut down noise level. Additional discussion on decibel subtraction is provided at Appendix C.

6.2 In interpreting the results presented below, a certain amount of professional judgement is required, as there are instances where it has been possible to calculate the wind farm noise level, but the results are unlikely to be representative of the actual situation. This is particularly the case where the calculated prevailing noise levels are based on data with a high level of scatter caused either by poor correlation with on-site wind speed, or caused by variation in background or operational noise levels.

6.3 The results of the measurements are shown below at Figure 2 and Figure 3 below for the night hours of 2300-0700 (when non-wind farm related noise is likely to be at its lowest).

Figure 2 – Noise Assessment Chart –Location 1 (2300-0700 hours)

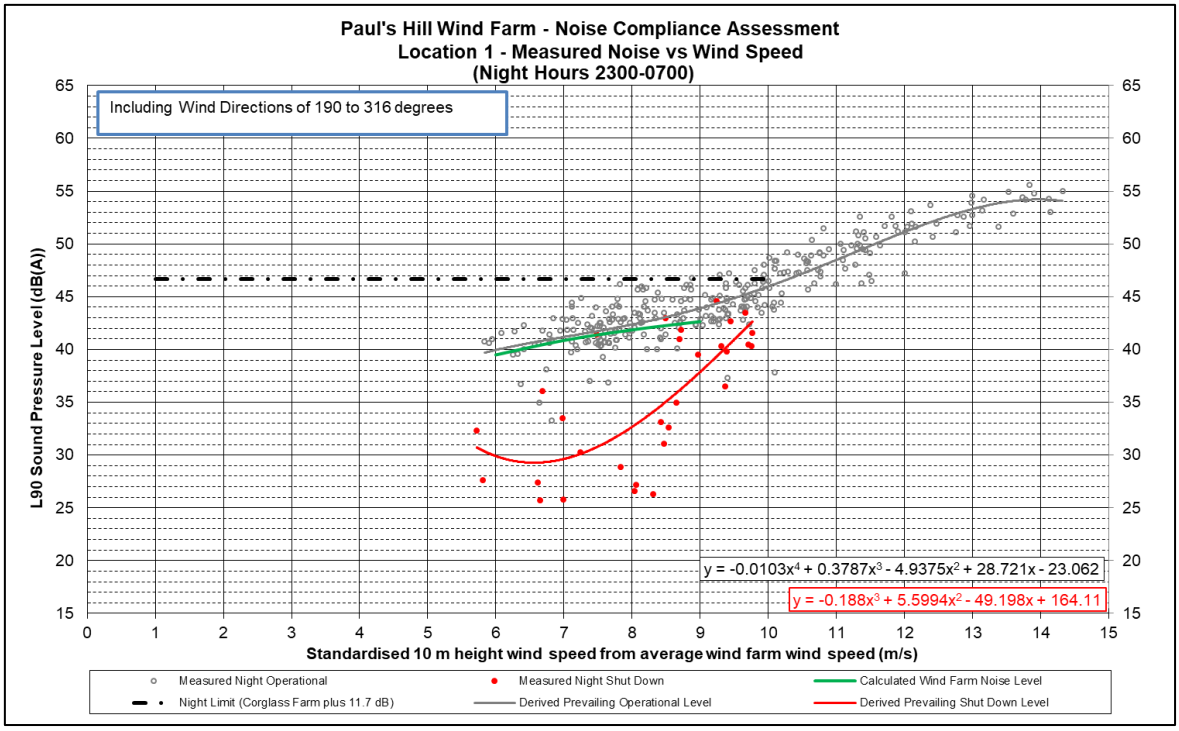
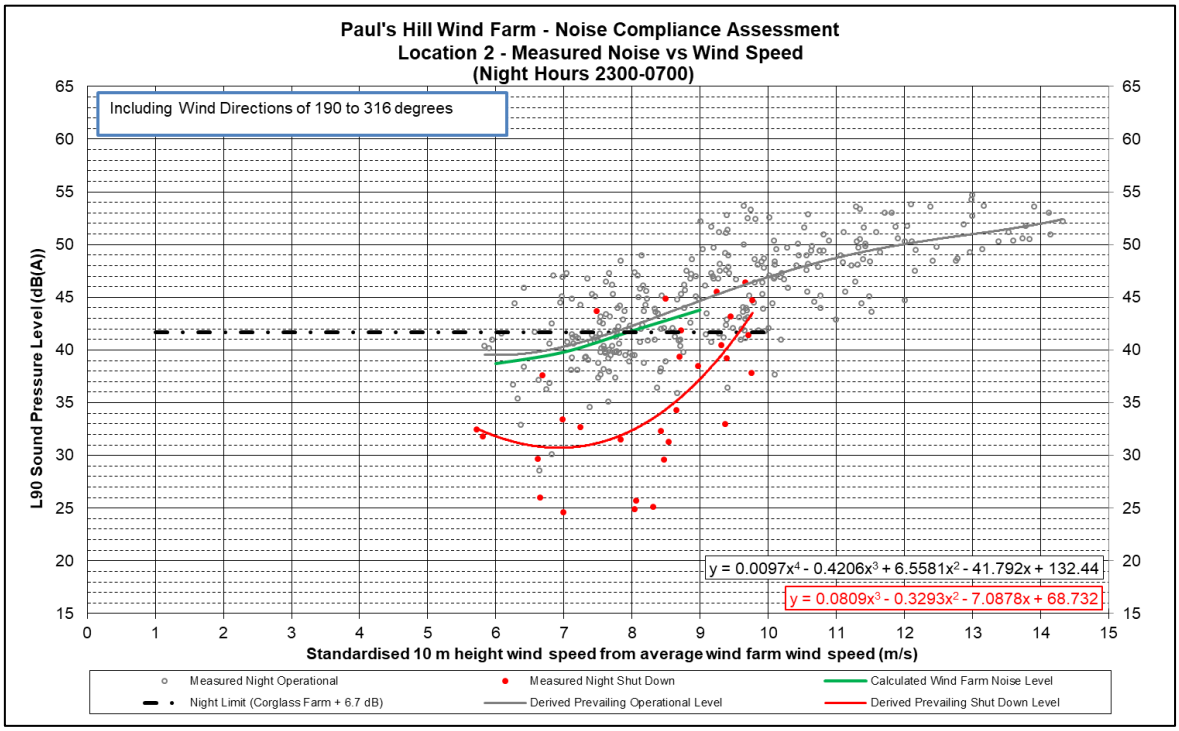


Figure 3 – Noise Assessment Chart –Location 2 (2300-0700 hours)



6.4 The results of the measurements indicate that noise levels at the Location 1 correlate reasonably well with average wind farm wind speeds and that the derived prevailing measured noise levels (without correcting for the influence of background noise) are below the limit applicable to this location.

6.5 The results at Location 2 indicate that both prevailing measured noise levels and calculated wind turbine noise levels are above the limit applicable to this location, for wind speeds above about 8 m/s. However, it can be seen that the measured noise levels do not correlate with the on-site wind speeds as well as at Location 1 which indicates that there is likely to be a significant contribution from background noise, as it can be seen that similar noise levels were, at times, measured during shut down periods as during operational periods. Whilst the measured and calculated levels are above the limit, given that at 10 m/s the average measured levels are the same as at Location 1 (where predicted noise levels indicate that wind turbine noise levels should be about 5 dB higher), this is a clear indication that the average measured noise levels are not accurately representative of the actual wind farm noise levels. It is, therefore, not considered that this indicates an exceedance of the noise limits in practice at Corglass Farm.

6.6 It can be seen at Figure 2 and Figure 3 that background noise levels do not correlate well with the average wind farm wind speed, and are likely to correlate better with measured wind speeds from the LiDAR which was located closer to the measurement positions. Further assessment charts have been provided at Figure 4 and Figure 5 where the measured noise data has been plotted against the standardised 10 m height wind speed derived from the 59 m height LiDAR wind speed. Both the operational measured levels and the shut down measured levels are correlated with the LiDAR standardised 10 m height wind speed because the operational and shut down noise levels should be compared on a like-with-like basis, i.e. with reference to the same wind speed conditions.

Figure 4 – Noise Assessment Chart – Location 1 (2300-0700 hours) Correlated with LiDAR 59 m height wind speeds.

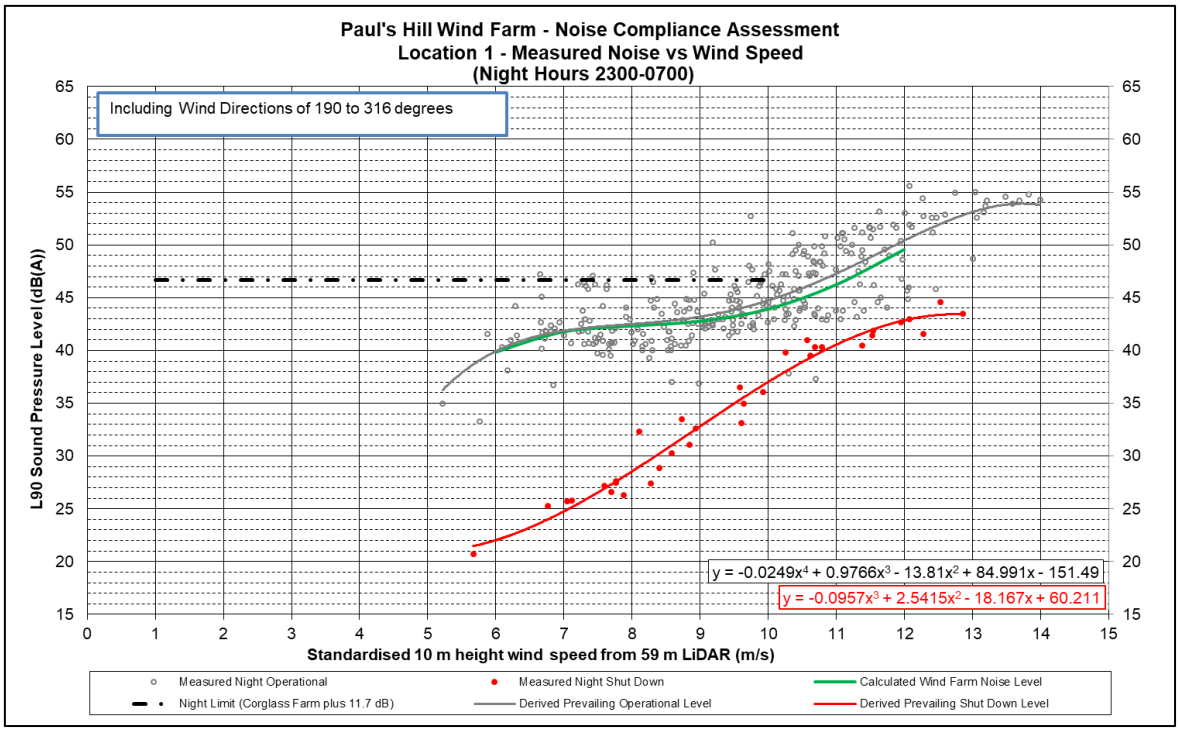
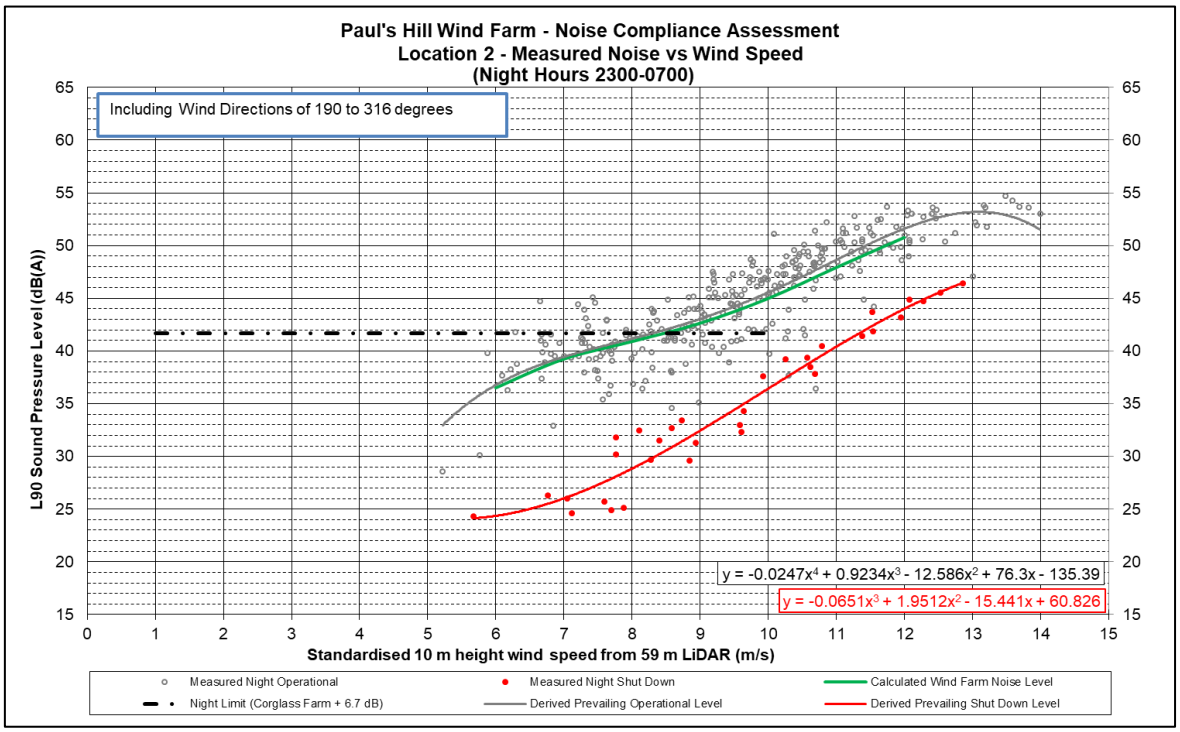


Figure 5 – Noise Assessment Chart – Location 2 (2300-0700 hours) Correlated with LiDAR 59 m height wind speeds.



6.7 The results of the noise measurements plotted at Figure 4 and Figure 5 show that

measured noise levels during wind farm shut down periods correlate better with the LiDAR standardised 10 m height wind speed than the average wind farm wind speed (presented at Figure 2 and Figure 3). The measured noise levels, however, do not correlate as well during operational periods. This is as expected as the LiDAR is located closer to the noise measurement locations and therefore more representative of local wind conditions, and less represented of average wind farm wind speed conditions. The results again show that at Location 1 measured noise levels are below the relevant noise limit across all wind speeds, but at Location 2 measured levels are above the limit above wind speeds of about 8 m/s, although it is considered that this does not prove an exceedance of the noise limits at Corglass Farm, as discussed below.

6.8 It appears that the significant difference between the operational and shut down noise levels is predominantly due to the wind direction conditions prevailing during the shut down periods being different to those occurring for the majority of the measured operational data collected. This is investigated further at paragraphs 6.11 to 6.12 and Figure 8 to Figure 11 below, which shows that wind direction is likely to have a significant effects on the shut down noise levels. In addition, measured noise levels for the same wind speed conditions are at times higher at Location 2 than measured at Location 1, and therefore measured noise levels cannot be dominated by wind turbine noise which would be expected to reduce with distance from the turbines.

6.9 The noise limits are set relative to measured 10 m height wind speeds, and (as discussed at paragraph 4.2) plots have also been presented where the measured noise data has been plotted against the 10 m height wind speed calculated from the LiDAR wind speeds at 34 and 18 m height. This enables comparison with the measured 10 m height wind speed noise limit as closely as possible. It should be noted, however, that the measured noise data is least likely to correlate well with the operational characteristics of the wind turbines due to the variation in the relationship between wind speed at the 'measured' 10 m height location and the hub height wind speed at the turbines. These additional assessment charts have been provided at Figure 6 and Figure 7.

Figure 6 – Noise Assessment Chart – Location 1 (2300-0700 hours) Correlated with Equivalent 'Measured' 10 m height wind speeds from the LiDAR.

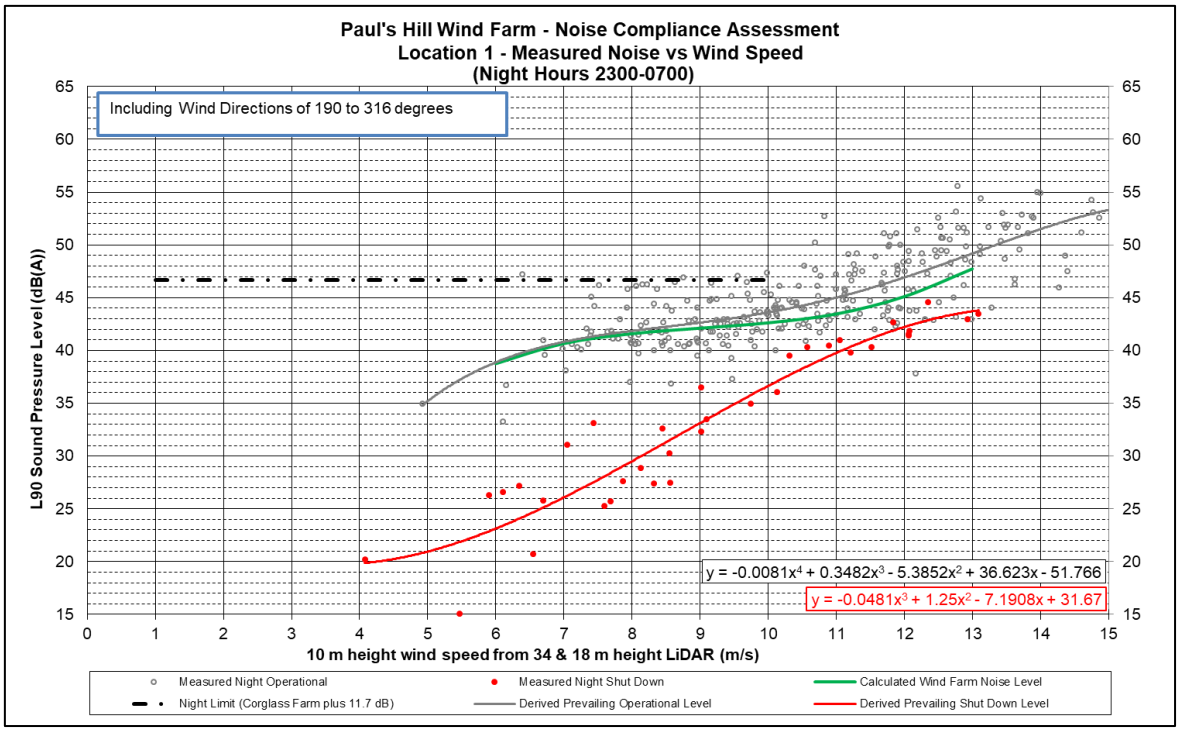
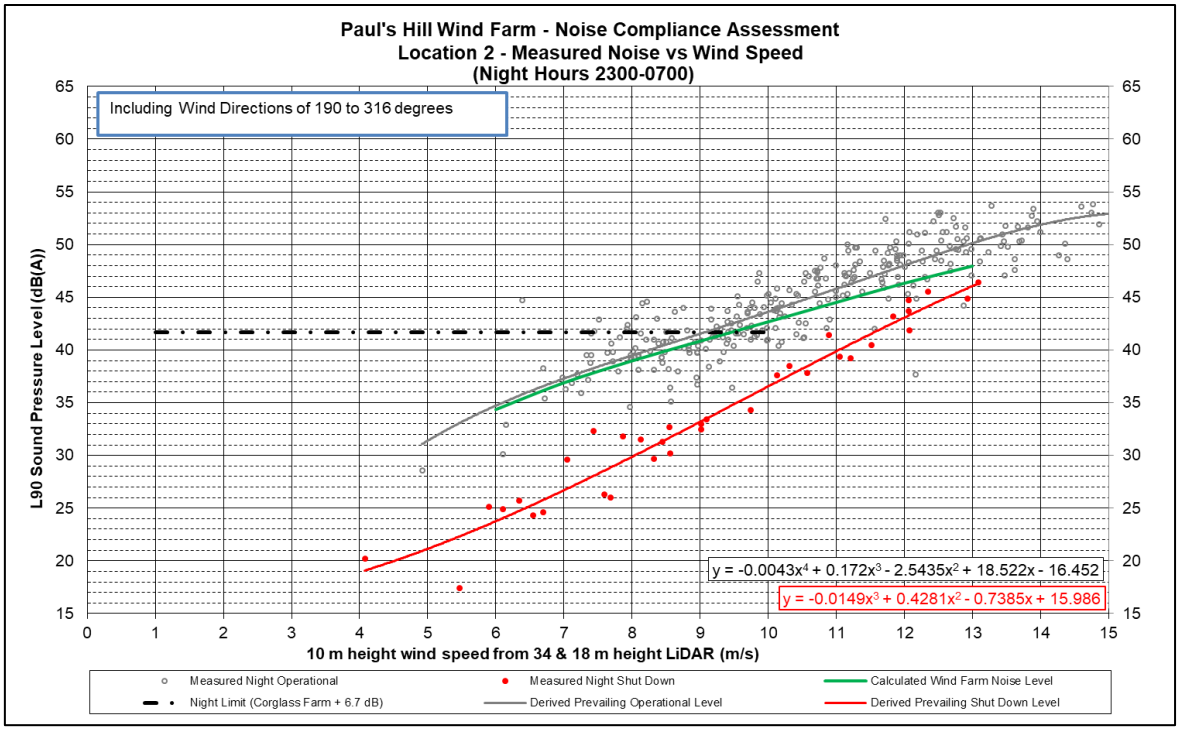


Figure 7 – Noise Assessment Chart – Location 2 (2300-0700 hours) Correlated with Equivalent 'Measured' 10 m height wind speeds from the LiDAR.



6.10 The results of the noise measurements, when correlated with the effective measured 10 m

height wind speed, indicate that at Location 1 measured noise levels are below the relevant limit across all wind speeds, and at Location 2 the calculated wind farm noise level is above the limit for wind speeds above 9.5 m/s. As above, (i.e. because measured noise levels for the same wind speed conditions are similar, or at times higher, at Location 2 than measured at Location 1) it is not considered that the results of the measurements at Location 2 proves an exceedance of the noise limits at Corglass Farm, as this indicates that the measured levels are dominated by background noise.

Additional Analysis of Shut Down Periods

6.11 The measured noise levels during the wind farm shut down periods occurred during wind directions of 205 – 230° (which is still within the downwind angles relevant to Corglass Farm and the measurement locations), and therefore additional analysis has been carried out whereby the operational noise data has also been filtered for this wind direction range for consistency. Due to the topography of the site, it is possible that background noise levels could be significantly affected by wind direction. The results for this reduced range of wind directions are shown at Figure 8 to Figure 11 where the measured noise data is plotted against the average wind farm wind speed and then the 59 m LiDAR wind speeds (both standardised to 10 m height).

Figure 8 – Noise Assessment Reduced Downwind Angle Chart – Location 1 (2300-0700 hours)

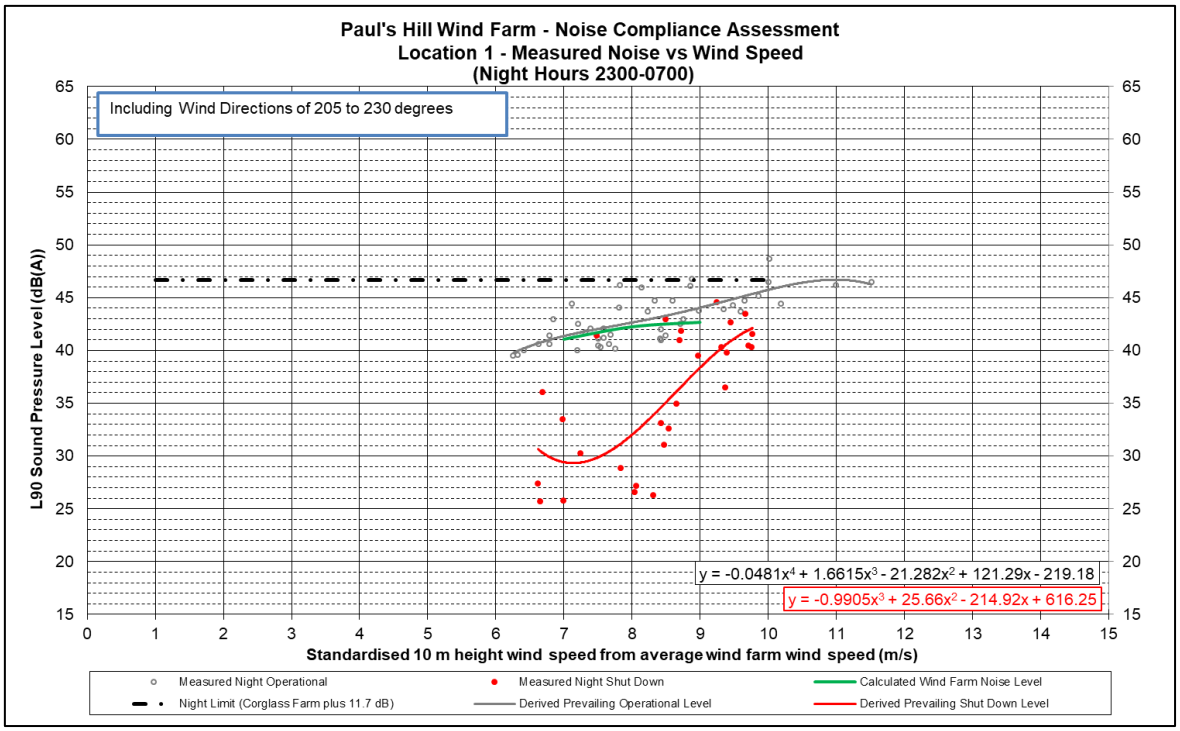


Figure 9 – Noise Assessment Reduced Downwind Angle Chart – Location 2 (2300-0700 hours)

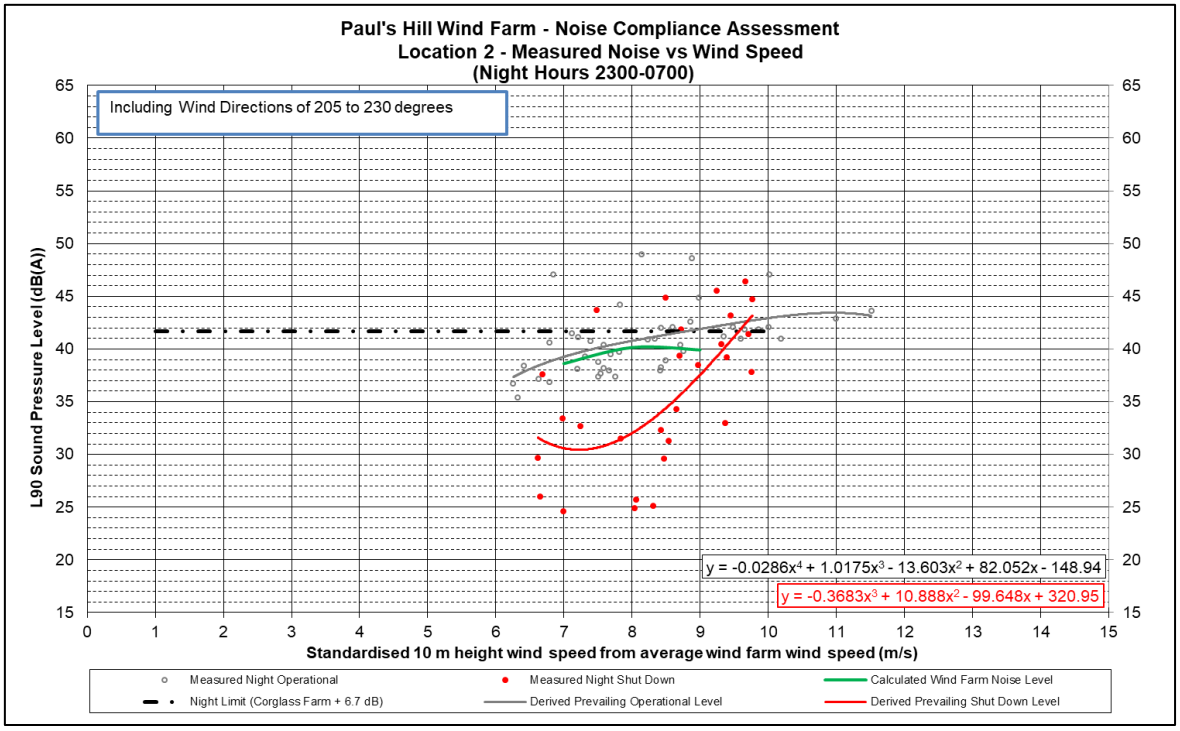


Figure 10 – Noise Assessment Reduced Downwind Angle Chart – Location 1 (2300-0700 hours) Correlated with Equivalent 'Measured' 10 m height wind speeds from the LiDAR.

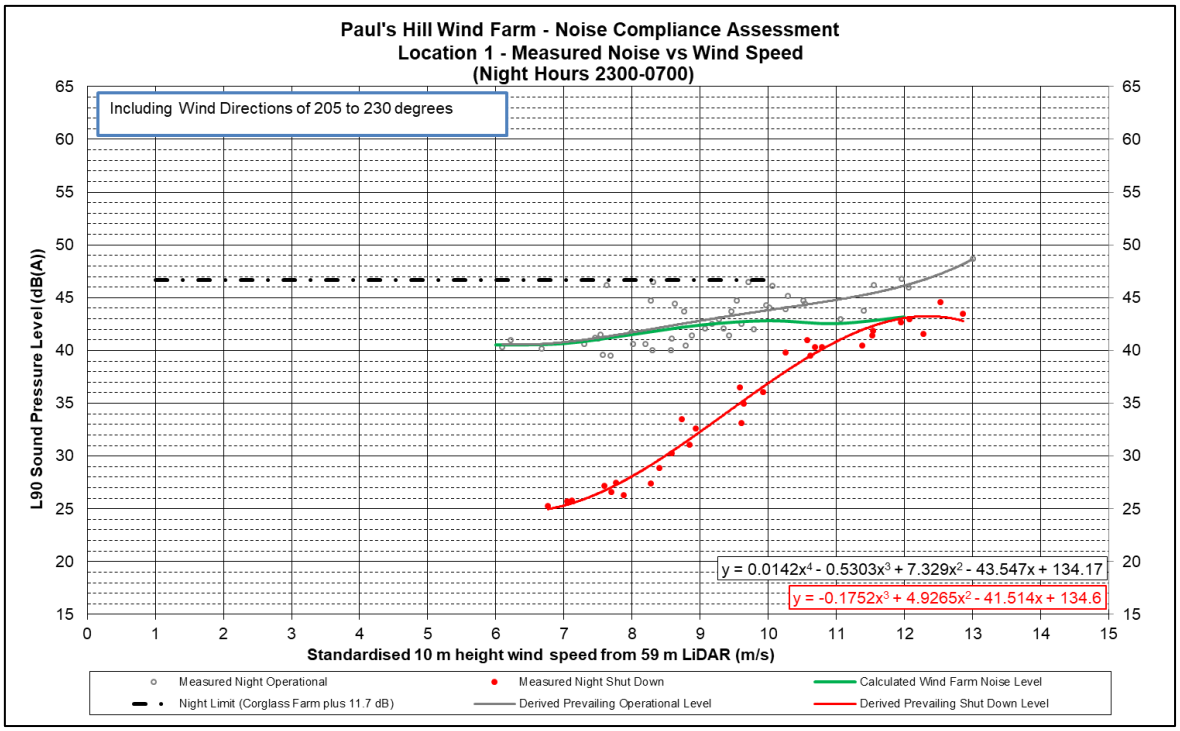
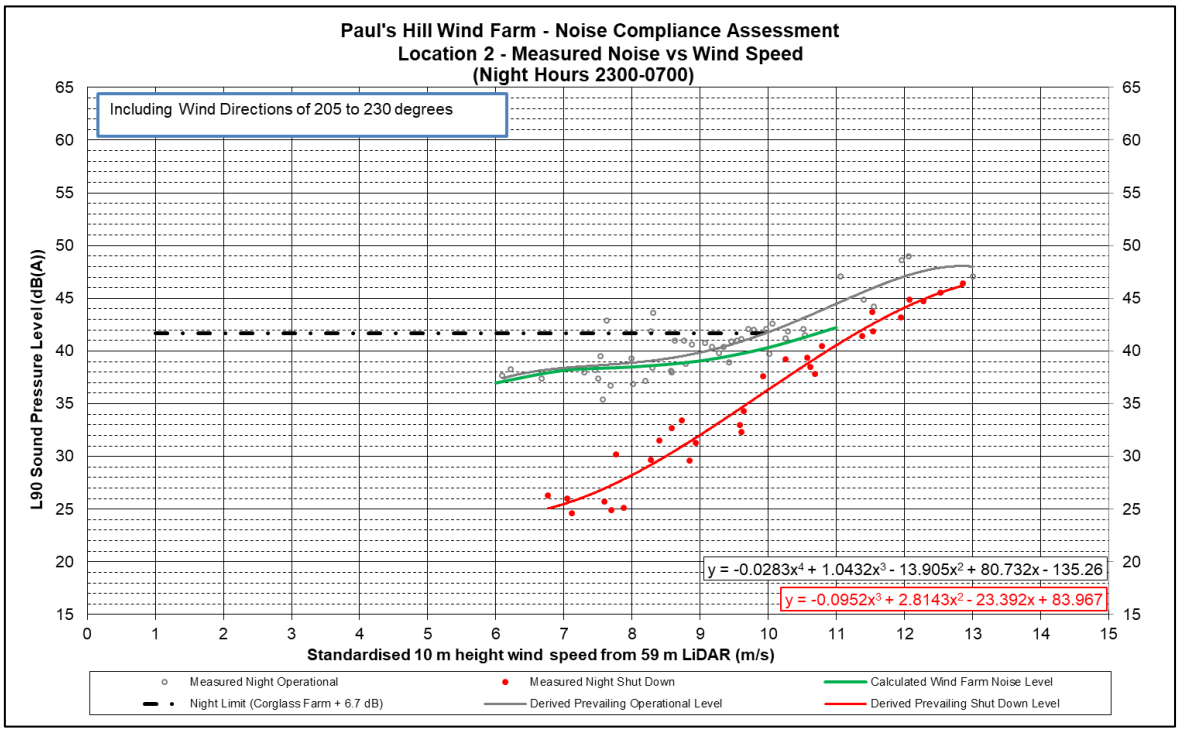


Figure 11 – Noise Assessment Reduced Downwind Angle Chart – Location 2 (2300-0700 hours) Correlated with Equivalent 'Measured' 10 m height wind speeds from the LiDAR.



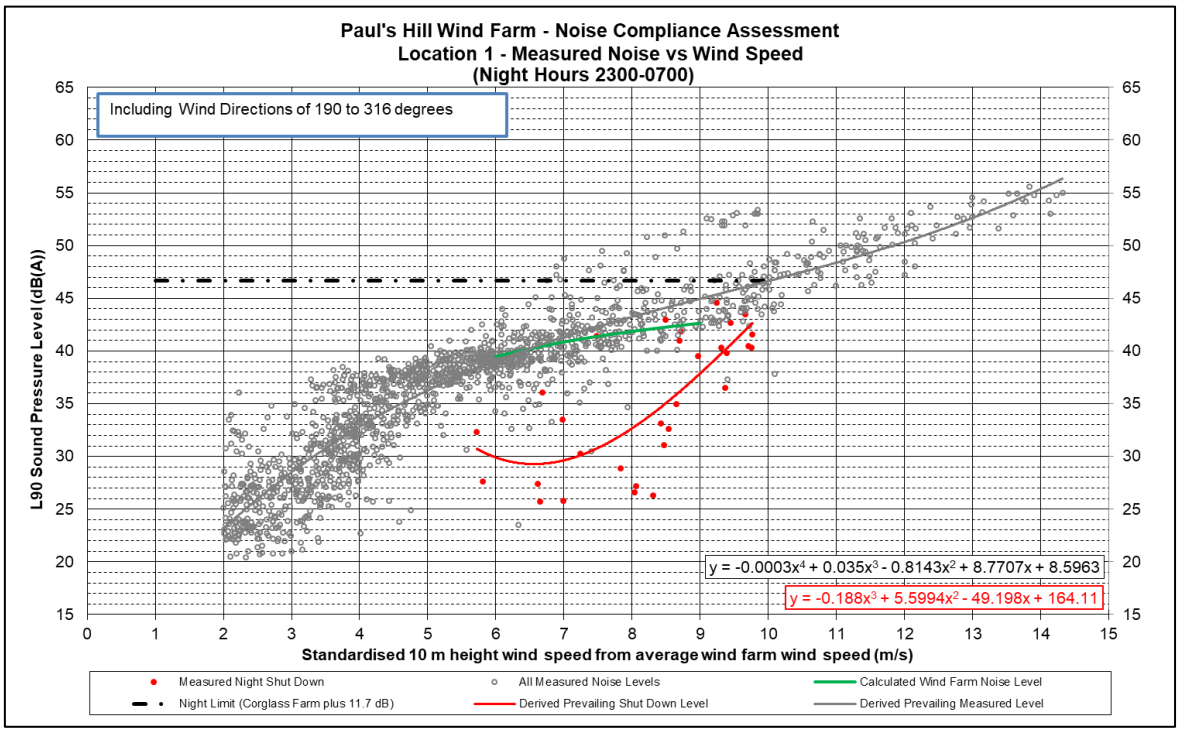
6.12 The results of the assessment for the reduced downwind angle show that, where the wind

farm noise level can be calculated, noise levels are below the relevant noise limits at both measurement locations. These results indicate that the relevant noise limit is met at Corglass Farm for periods where the background level can be subtracted from the overall noise level under the same wind direction conditions. It should be noted that these results cannot be relied upon in isolation to prove compliance with the noise limit under all wind direction conditions, but are useful in understanding the relationship between measured operational and shut down noise levels at the measurement locations.

Additional Analysis for Curtailment Periods

6.13 There are periods when curtailment is applied to the wind turbines due to grid restrictions imposed. During these periods, the wind farm, for the purpose of the compliance assessment, is not deemed to be operating normally, and therefore the data is excluded from the analysis. Further analysis of the measured noise data, however, suggested that noise from the wind turbines is higher during periods of curtailment than under normal operation. Figure 12 below shows all measured downwind noise levels at Location1, where the operational periods have not been filtered to include all data except when it is known that all turbines are shut down.

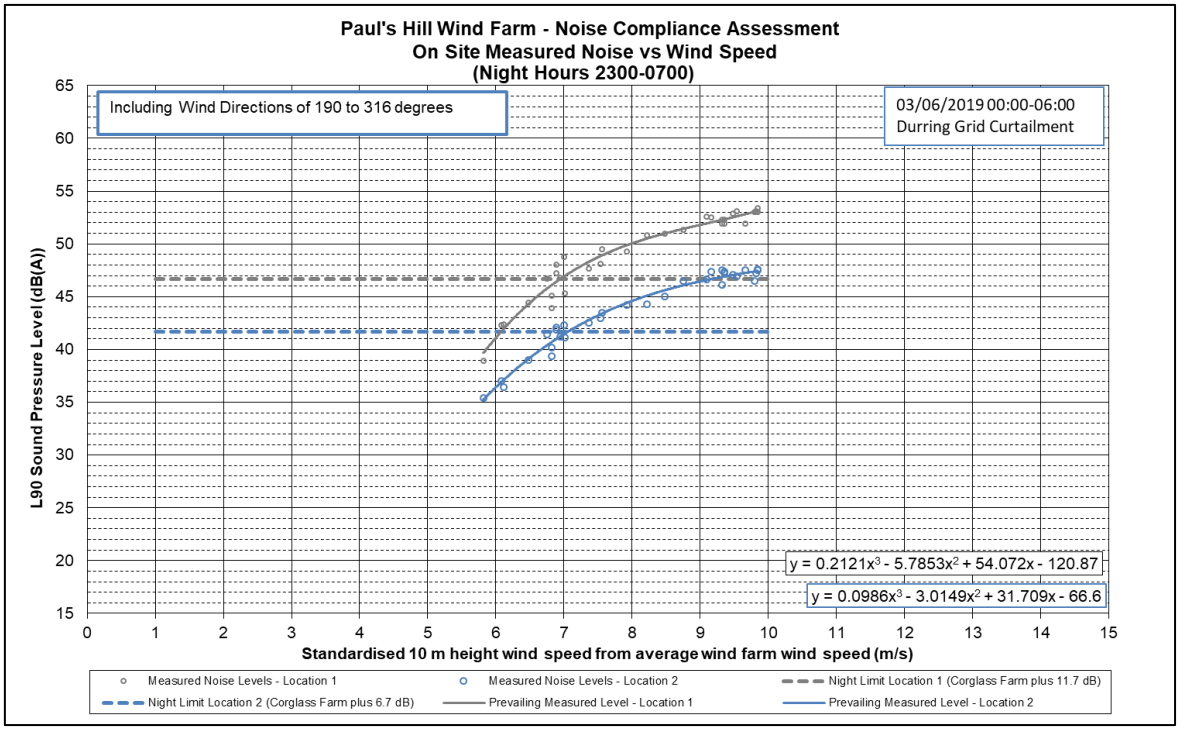
Figure 12 – Noise Assessment Chart – Location 1 (2300-0700 hours) not filtered for normal operation.



6.14 Figure 12 shows that the prevailing measured noise levels (without correction for background noise) are below the relevant noise limit. However, there are measured noise

levels above the limit at wind speeds between 7 and 10 m/s. Closer inspection of this data indicates that these higher noise levels occurred during a period of curtailment applied to the wind farm due to grid restrictions. One such grid curtailment occurred overnight between 2nd and 3rd June 2019, and the measured data for the period 00:00 to 06:00 on 03/06/2019 has been plotted at Figure 13 for both the on-site measurement locations.

Figure 13 – Noise Assessment Chart – Locations 1 & 2 Measured Noise Levels During Curtailment Period



6.15 Measured noise levels during the curtailment period indicate noise levels that are above the relevant noise limit by up to about 7 dB at both measurement locations above a wind speed of 7 m/s. The results also indicate that the difference in measured noise level, when it is very likely that wind farm noise is the dominant noise source at both locations, between the two locations is about 5 dB, which agrees well with the predicted wind farm noise level difference at the measurement locations.

7. RESULTS TABLES

7.1 The most pertinent results of the compliance measurements are shown below in tabulated

form wherein the results of the measurements have been extrapolated to Corglass Farm for comparison with the noise limit. As described at paragraph 4.2, the most relevant results are obtained from the correlation of measured noise levels with the average wind farm wind speeds (standardised to 10 m height) as this enables the wind farm noise levels to be derived with the highest levels of certainty.

7.2 To provide a conservative presentation of the measurement results, Table 2 below shows the measured operational noise levels correlated with the wind farm average wind speed, and shut down noise levels correlated with the measured LiDAR wind speeds, which minimises the background noise correction applicable to the measured operational noise levels to provide the wind farm noise level. The wind speed reference for both is the 59 m hub height wind speed standardised 10 m height wind speeds. The results are provided for Location 1 because they allow the wind farm noise level to be accurately established, whereas the results from Location 2 are less reliable.

Table 2 – Table of Results During Normal Operation at Location 1 (dB L_{A90})

Data	Standardised 10 m height wind speed (m/s)						
	6	**7**	**8**	**9**	**10**	**11**	**12**
Measured Location 1 operational noise level	40.0	41.2	42.4	44.0	46.1	48.7	51.4
Measured Location 1 shut down noise level	22.0	24.8	28.5	32.8	37.0	40.5	42.8
Calculated wind farm noise level at Location 1	39.9	41.1	42.2	43.6	45.5	48.0	50.8
Extrapolated wind farm noise level at Corglass Farm	28.2	29.4	30.5	31.9	33.8	36.3	39.1
Margin between wind farm noise and 35 dB L_{A90} limit	6.8	5.6	4.5	3.1	1.2	*	*

* the noise limit applies for wind speeds up to 10 m/s

7.3 The results of the compliance measurements indicate that, during periods when the wind farm is operating normally, the noise limit at Corglass Farm is met by at least 1.2 dB.

7.4 The results presented at Table 2 are for standardised 10 m height winds speeds, but the measurement results (discussed in section 6) also indicate that noise levels correlated with measured 10 m height wind speeds on site would also comply with the noise limit.

7.5 Results are also presented in tabular form for the curtailment periods presented at Figure 13 and at Table 3 below. No background noise correction has been applied, as it is likely that operational noise levels are more than 10 dB above the background (shut-down) levels.

Table 3 – Table of Results During Curtailment Period (dB L_{A90})

Data	Standardised 10 m height wind speed (m/s)				
	6	7	8	9	10
Measured Location 1 operational noise level	41.1	46.9	50.0	51.8	53.4
Measured Location 1 shut down noise level	36.4	41.5	44.6	46.5	47.6
Extrapolated wind farm noise level from Location 1 at Corglass Farm	29.4	35.2	38.3	40.1	41.7
Extrapolated wind farm noise level from Location 2 at Corglass Farm	29.7	34.8	37.9	39.8	40.9
Minimum margin between wind farm noise and 35 dB L_{A90} limit	5.3	-0.2	-3.3	-5.1	-6.7

7.6 The results of the compliance assessment for the period identified when the wind farm was curtailed, indicate that noise levels at Corglass Farm are above the noise limit for wind speeds of 7 m/s and above, and exceed the limit by up to 6.7 dB at 10 m/s (although the maximum wind speed at which data is available is 9.8 m/s). The results of the noise measurements during the curtailment period at the two measurement locations, as extrapolated to Corglass Farm, agree well, and therefore agrees well with the predicted noise level difference calculated between the two measurement locations.

8. DISCUSSION

8.1 The noise limits for Corglass Farm are set relative to measured on-site 10 m height wind speeds. The noise output of the wind farm depends on the hub height wind speed, which varies relative to the measured 10 m height wind speed depending on the instantaneous levels of wind shear, and the resultant lack of correlation between the two makes interpreting the results difficult. It can therefore be very difficult to establish whether noise from a wind farm complies with a limit set relative to measured 10 m height wind speeds if noise levels are correlated with measured 10 m height wind speeds.

8.2 In this case, measured noise levels have been primarily correlated with the average wind farm wind speeds (which shows a good correlation with measured noise levels at Location 1) to enable the wind farm operational noise levels to be established as accurately as possible. The results indicate that the noise limits are met at Corglass Farm by at least 1.2 dB Consideration then needs to be made to the fact that limits are set relative to measured (rather than standardised) 10 m height wind speeds.

8.3 It was not possible to accurately evaluate the wind farm noise levels at Location 2 because the signal to noise ratio (i.e. difference between the wind farm and background noise levels) was lower when the full range of wind directions corresponding to downwind propagation was considered. The results indicate that wind farm noise levels are about 5 dB lower than at Location1, but it appears that background noise levels were generally higher. The results of the Location 2 measurements should therefore be treated with some caution, and the Location 1 results should be treated as the primary results.

8.4 Where the results have been plotted against the equivalent 'measured' 10 m height wind speed from the LiDAR data it can be seen that measured noise levels do not correlate as well with the measured wind speed, but that the average measured noise levels remain below the relevant limits at Location 1. It is noted, however, that there are instances where individual measured noise levels are close to the limits, which may indicate periods that relate to higher wind shear conditions. The results indicate that on average, wind farm noise levels do meet the relevant noise limit, but that there could be occasional periods of high wind shear at higher wind speeds when the limit (relative to measured 10 m height wind speeds) could be exceeded, although these conditions are very rare. An assessment of compliance is therefore always carried out on an average basis, and the results here indicate that on average the relevant noise limit is met by a reasonable margin.

8.5 Further analysis of the measured noise data has shown elevated measured noise levels when the wind farm is curtailed due to grid restrictions. Under these conditions, noise levels may be up to about 7 dB above the relevant noise limits, and are likely to relate to periods when the residents of Corglass Farm find the noise from the wind turbines particularly disturbing. It appears that the way in which the curtailment is applied to individual turbines results in the machines being restricted to a lower rotational speed than they would normally operate in for given wind speed conditions, which causes the blades to create significantly higher levels of stall-generated noise. This effect is peculiar to stall regulated twin speed turbines. For the pitch regulated variable speed machines which are now universally proposed for commercial wind farms, energy constraint mechanisms operate by restricting the rotational speed of the turbines which results in reducing the emitted noise. The situation seen here at Paul's Hill is, therefore, very unusual, and was not anticipated by the site operator. Normally, any mitigation imposed on wind turbines would not cause an increase in noise levels such as that identified here during grid curtailment periods.

8.6 The operators of the site have committed to changing the method by which curtailment is applied due to grid restrictions to ensure that the elevated noise levels identified do not occur. It is proposed that during grid curtailment periods imposed by National Grid the wind turbines will effectively be shut down by locking the blades in the stop position. This will

ensure that there is effectively no noise from the wind farm during grid restriction periods. Once instructed by National Grid that the curtailment period has ended, the turbines will be instructed to return to normal operation.

8.7 Hayes McKenzie are informed that FORL do reserve the right to introduce alternative or additional means of ensuring that the noise planning condition is not breached if such means become available in the future.

9. CONCLUSIONS

9.1 Noise measurements were carried out at Corglass Farm in 2018 to try and establish whether the Paul's Hill Wind Farm was operating within its planning conditions relating to noise. The results of the measurements were inconclusive as it was difficult to ascertain whether the noise limits were being met, although the indications were that they were. Further measurements were, therefore, carried out at two locations between Corglass Farm and Paul's Hill Wind Farm to establish wind farm noise levels close to the site to ascertain whether the noise limits are would be met at Corglass Farm as suggested by the GPG[6].

9.2 Noise limits were derived for the two locations nearer to the wind farm based on the predicted noise level difference between each measurement location and Corglass Farm. The results of the noise measurements indicate that, during periods when the wind farm was deemed to be operating normally, operational noise levels were below the relevant extrapolated noise limits, and therefore determined that the limits are also being met at Corglass Farm.

9.3 Further analysis of the measured data indicated that during periods of wind farm curtailment, that occur when there are grid restrictions imposed on the site, the noise output of the wind turbines is actually higher than under normal operating conditions. During periods of curtailment, operational noise levels were above the relevant noise limit by up to about 7 dB, indicating that measured noise levels would also be above the relevant noise limits at Corglass Farm. The operator of the site has proposed to change the mechanism whereby the curtailment is applied during grid restrictions by shutting down the wind turbines and stopping them in their park position. This would ensure that, during grid restriction periods imposed by National Grid, there is effectively no noise output from the wind farm and no exceedance of the noise limits would occur.

[6] The Institute of Acoustics (IOA), Supplementary Guidance Noise 5 (SGN5), Post Completion Measurements

Appendix A

Agreed Noise Measurement Protocol

Paul's Hill Wind Farm

Methodology for Further Measurements

for Fred. Olsen Renewables Ltd

Rob Shepherd, Hayes McKenzie Partnership Ltd

3261_N03_EXT2, 25 March 2019

1. INTRODUCTION

1.1 Hayes McKenzie Partnership Ltd (HMPL) were appointed by Fred. Olsen Renewables Ltd (FORL), the owners of Paul's Hill Wind Farm, to carry out noise measurements, following concerns raised by the residents of Corglass Farm regarding noise from the installed wind turbines. The results of the measurements didn't allow the operational noise levels to be determined with certainty, due to the contribution from noise sources in the vicinity of the measurement location.

1.2 This note briefly sets out the measurement and assessment methodology for further measurements to be carried out nearer to the operational wind turbines to ascertain the operational noise levels from the Paul's Hill turbines more accurately.

2. METHODOLOGY

2.1 Supplementary Guidance Note 5, *Post Completion Measurements*, to the Institute of Acoustics, *A Good Practice Guide to the Application of ETUSU-R-97 for the Assessment and Rating of Wind Turbine Noise*, discusses the issue of high background noise levels interfering with compliance measurements at paragraph 2.4.8, and states:

> *In the event that the typical background noise is greater than the turbine noise limit, and if the additional contribution of the turbine noise to the prevailing background is difficult to discern with confidence from the data, then it is likely that compliance with the ETSU-R-97 limits would be demonstrated. In such cases where noise limits are less than ETSU-R-97 limits (e.g. apportionment of noise impacts due to cumulative impacts) compliance measurements may need to be undertaken in closer proximity to the wind farm to ensure background noise levels do not unduly influence the readings. This may also be significant when determining compliance with planning limits such as the ETSU-R-97 simplified limit of 35 dB L_{A90} since background noise is likely to be around this level or higher when the turbine reaches rated power, except under exceptional conditions.*

2.2 It is therefore proposed that further noise measurements are carried out between Corglass Farm and Paul's Hill wind farm to ascertain operational noise levels in the vicinity of the wind farm, where the contribution from background noise is likely to be less significant relative to that from the turbines. The results of the measurements can be used to infer operational noise levels at Corglass Farm and whether the noise limit would be met.

3. MEASURMENT METHODOLOGY

3.1 It is proposed the noise monitoring equipment, of the same specifications as the original measurements, is installed at two locations near to the operational Paul's Hill wind farm. The measurement locations have been chosen to be representative of measured noise levels where predicted noise levels from the wind turbines are 35 and 40 dB L_{A90} when the turbines are operating at their maximum noise output.

3.2 It is proposed that the noise monitoring equipment is located adjacent to the access track to the wind farm at the approximate locations indicated at Figure 1 below. The specific siting of the equipment will be chosen to minimise the influence of local noise sources such as wind in the trees/vegetation and running water.

Figure 1 – Proposed Noise Measurement Positions

3.3 A rain gauge or weather station will be installed near to the each of the measurement positions to ensure that rainfall is measured during the survey so that periods of rainfall can be excluded from further analysis.

4. DURATION OF MEASUREMENTS

4.1 The equipment will be installed for an initial period of 3 weeks. It is envisaged that measurements with the turbines shut-down will not be required as it is likely that noise levels with the turbines shut-down (at the 40 dB L_{A90} measurement position) will be at least 10 dB below operational noise levels at night at the wind speed at which the turbines reach their maximum sound power level (a standardised 10 m height wind speed of 9 m/s). If, following review of the data at the site visit after 3 weeks, it is clear that background noise may still be significantly affecting measured noise levels, shut downs of the wind farm may be required to ascertain the background noise contribution to measured levels.

5. ANALYSIS OF THE RESUTLS

5.1 Measured noise levels will be correlated with the average wind farm hub height wind speeds, which are then standardised to 10 m using a logarithmic shear profile and ground roughness length of 0.05, m in the same way as the original compliance measurements.

5.2 Measured night noise levels will be correlated with the standardised 10 m height wind speed, and filtered to include downwind periods when the wind farm was fully operational. The prevailing operational noise levels will be determined by plotting a suitable regression curve through the data. Wind direction will be determined from the nearest turbine(s) to the measurement position or from the on-site meteorological masts.

6. DETERMINING COMPLIANCE AT CORGLASS FARM

6.1 The primary assessment location will depend on the result of the measurements, but the outcomes scenarios of the assessment are explored below. It should be noted that the installed wind turbines reach their maximum sound power level at a standardised 10 m height wind speed of 9 m/s. Therefore, if compliance with the noise limit is demonstrated up to 9 m/s, it can inferred that the limit would be met over all wind speeds.

6.2 The proposed assessment method is set out below.

- If measured noise levels at the 35 dB L_{A90} measurement position are below 35 dB L_{A90} at wind speeds up to 9 m/s it can be concluded that the noise limit would also be met at Corglass Farm.

- If the measurements at the 35 dB L_{A90} measurement location are above 35 dB L_{A90} or inconclusive because of the influence of non-wind farm noise, the data at the 40 dB L_{A90} position will be reviewed to determine the operational noise levels at this location.

- Predictions will be undertaken to determine the operational noise levels at the 35 dB L_{A90} measurement position (for prediction verification purposes) and at Corglass Farm based on the measured noise levels at the 40 dB L_{A90} position. If the results of the measurements indicate operational noise levels at Corglass Farm are below 35 dB L_{A90} at wind speeds of up to 9 m/s then it can be concluded that the wind farm is operating within its noise limit.

- If the results of the measurements prove inconclusive, it may be necessary to undertake further simultaneous measurements close to the wind turbines and at Corglass Farm with meteorological logging equipment locations at both noise measurement locations.

7. REPORTING

7.1 Upon conclusion of the measurements and analysis, a report will be submitted to Moray Council detailing the measurements and results.

Appendix B

Noise Predictions and Derivation of Limits for Measurement Locations

Noise Prediction Methodology

B.1. The ISO 9613-2 standard is used for predicting sound pressure level for downwind propagation by taking the source sound power level for each turbine in separate octave bands and subtracting a number of attenuation factors according to the following:

$$Predicted\ Octave\ Band\ Noise\ Level = L_w + D - A_{geo} - A_{atm} - A_{gr} - A_{bar} - A_{misc}$$

B.2. These factors are discussed in detail below together with an additional term for taking wind direction into account where required. The predicted octave band levels from each turbine are summed together to give the overall 'A' weighted predicted sound level.

L_W - Source Sound Power Level

Table 4 – Sound Power Levels for Siemens 2.3-82 Stall Regulated Turbines[7]

Turbine	Overall (dB L_{WA})	Octave Band Centre Frequency (Hz)							
		63	125	250	500	1k	2k	4k	8k
Siemens 2.3-82 Stall	105.4	91.0	97.7	98.7	98.5	97.3	97.3	92.6	81.4

D – Directivity Factor

B.3. The directivity factor allows for an adjustment to be made where the sound radiated in the direction of interest is higher than that for which the sound power level is specified. In this case the sound power level is measured in a down wind direction, corresponding to the worst case propagation conditions considered here and needs no further adjustment.

A_{geo} – Geometrical Divergence

B.4. The geometrical divergence accounts for spherical spreading in the free-field from a point sound source resulting in an attenuation depending on distance according to:

$$A_{geo} = 20 \times \log(d) + 11$$

where d = distance from the turbine

B.5. The wind turbine may be considered as a point source beyond distances corresponding to one rotor diameter.

A_{atm} - Atmospheric Absorption

B.6. Sound propagation through the atmosphere is attenuated by the conversion of the sound

[7] Delta Measurement Report AV 297/03 Project A100699-01, 26 September 2003

energy into heat. This attenuation is dependent on the temperature and relative humidity of the air through which the sound is travelling and is frequency dependent with increasing attenuation towards higher frequencies. The attenuation depends on distance according to:

$A_{atm} = d \times \alpha$

where d = distance from the turbine

α = atmospheric absorption coefficient in dB/m

B.7. Values of 'α' from ISO 9613 Part 1[8] corresponding to a temperature of 10ºC and a relative humidity of 70%, the values specified in the UK Institute of Acoustics, A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbines Noise (IoA GPG), which give relatively low levels of atmospheric attenuation and correspondingly worst case noise predictions, as given below.

Frequency dependent atmospheric absorption coefficients

Octave Band Centre Frequency (Hz)	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Atmospheric Absorption Coefficient (dB/m)	0.000122	0.000411	0.00104	0.00193	0.0037	0.00966	0.0328	0.117

A_{gr} - Ground Effect

B.8. Ground effect is the interference of sound reflected by the ground with the sound propagating directly from source to receiver. The prediction of ground effects are inherently complex and depend on the source height, receiver height, propagation height between the source and receiver and the ground conditions. The ground conditions are described according to a variable G which varies between 0 for 'hard' ground (includes paving, water, ice, concrete & any sites with low porosity) and 1 for 'soft' ground (includes ground covered by grass, trees or other vegetation). The IoA GPG states that where wind turbine source noise data includes a suitable allowance for uncertainty, a ground factor of G=0.5 and a receptor height of 4m should be used.

B.9. In this case, the relative difference between the predicted noise levels is important rather than the absolute predicted noise levels, and a ground factor of G=0.5 has been applied, but no uncertainly has been added to the measured noise data.

8 ISO 9613-1, Acoustics - Attenuation of sound during propagation outdoors, Part 1: Method of calculation of the attenuation of sound by atmospheric absorption, International Organization for Standardization, 1992

A_{bar} - Barrier Attenuation

B.10. The effect of any barrier between the noise source and the receiver position is that noise will be reduced according to the relative heights of the source, receiver and barrier and the frequency spectrum of the noise. The barrier attenuations predicted by the ISO 9613 model have, however, been shown to be significantly greater than that measured in practice under down wind conditions. The results of a study of propagation of noise from wind farm sites carried out for ETSU[9] concludes that an attenuation of just 2 dB(A) should be allowed where the direct line of site between the source and receiver is just interrupted and that 10 dB(A) should be allowed where a barrier lies within 5 m of a receiver and provides a significant interruption to the line of site. In this case barrier attenuation has been limited to 2 dB where the tip of the turbine is not visible.

B.11. The table below shows which turbines tips are visible from each assessment location.

Turbine Number	Turbine tip visible?		
	Corglass Farm	Location 1	Location 2
1	No	Yes	Yes
2	No	Yes	Yes
3	No	Yes	Yes
4	No	Yes	Yes
5	No	Yes	Yes
6	No	Yes	Yes
7	No	Yes	Yes
8	No	Yes	Yes
9	No	Yes	Yes
10	No	Yes	Yes
11	No	Yes	Yes
12	No	Yes	Yes
13	No	Yes	Yes
14	No	Yes	Yes
15	No	Yes	Yes
16	No	Yes	Yes
17	No	Yes	Yes
18	No	No	No
19	No	No	No
20	No	No	No
21	No	No	No
22	No	No	No
23	No	No	No
24	No	No	No
25	No	Yes	Yes

[9] ETSU W/13/00385/REP, A Critical Appraisal of Wind Farm Noise Propagation, DTI 2000

Turbine Number	Turbine tip visible?		
	Corglass Farm	Location 1	Location 2
26	No	Yes	Yes
27	No	Yes	Yes
28	No	No	No

A_{misc} – Miscellaneous Other Effects

B.12. ISO 9613 includes effects of propagation through foliage, industrial plants and housing as additional attenuation effects. These have not been included here and any such effects are unlikely to significantly reduce noise levels below those predicted.

Appendix C

Decibel Subtraction

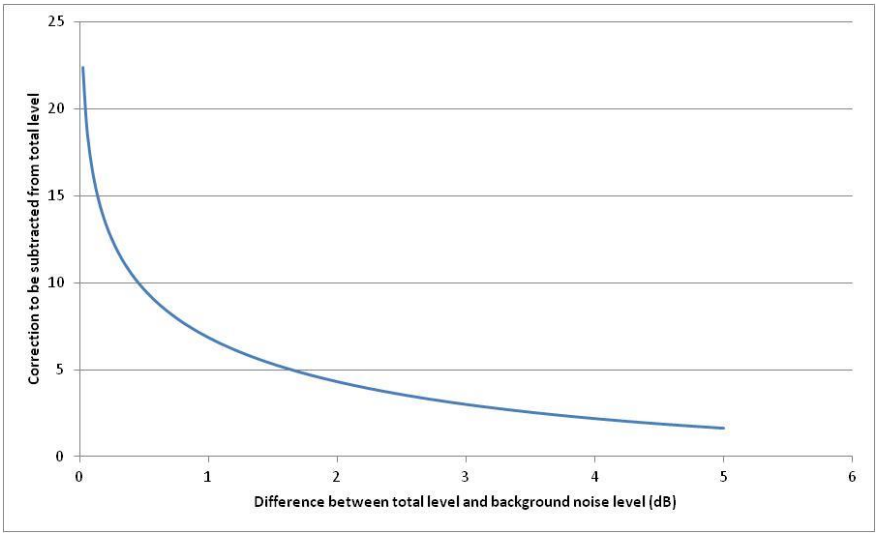
C.1. When measuring turbine noise at a wind farm site, it may be necessary to subtract a background sound pressure level from a total measured level. This is only required when trying to ascertain the level of turbine noise without the contribution from existing background noise. ETSU-R-97 states (and it is generally accepted), that when the background noise level is more than 10 dB below the total measured level, the contribution from background noise is insignificant and does not need to be subtracted. When background noise levels are less than 10 dB below the total measured noise levels, it can be assumed that: $L_{Total} = L_{Bg} + L_{Wf}$

which equates to: $L_{Total} = 10Log_{10}\left(10^{\frac{L_{Bg}}{10}} + 10^{\frac{L_{Wf}}{10}}\right)$

Where: L_{Total} = Total Measured Noise Level,
L_{Bg} = Background Noise Level,
L_{Wf} = Wind Farm Noise Level

And it therefore follows that: $L_{Wf} = 10Log_{10}\left(10^{\frac{L_{Total}}{10}} - 10^{\frac{L_{Bg}}{10}}\right)$

C.2. This formula for calculating the turbine noise from a measurement of total noise and background noise separately is considered appropriate when L_{Total} is large compared to L_{Bg}; but when background noise is less than 3 dB below the total measured noise level, a small change in the measured background noise can cause a large change in the calculated turbine noise. When measuring background noise or total noise for wind turbine assessment, a regression line is calculated to give an average level for each standardised 10 m height wind speed but variations in measurement of background noise mean that the regression line could easily move by 1 or 2 dB depending on when the measurements were taken. This level of variation means that the formula for calculating turbine noise becomes imprecise when background noise is less than 3 dB below the total noise level and should not be used. The graph below demonstrates the sensitivity of the turbine noise calculation:



ANNEX B

Paul's Hill Wind Farm, Measured Noise Levels During Grid Curtailment, for Fred Olsen Renewables, Rob Shepherd & Andy McKenzie, Hayes McKenzie Partnership Ltd, 3331_N10_EXT3, 12 November 2019 (https://dpea.scotland.gov.uk/Document.aspx?id=644945).

Paul's Hill Wind Farm

Measured Noise Levels During Grid Curtailment

for Fred Olsen Renewables

Rob Shepherd & Andy McKenzie, Hayes McKenzie Partnership Ltd

3331_N10_EXT3, 12 November 2019

Figure 1 below is a reproduction of Figure 12 of the 4th October 2019 Paul's Hill Wind Farm Noise Compliance Assessment report (ref. HM: 3261_R01_EXT3) [CD 7.21]. All night-time measured noise levels that occurred during periods of grid curtailment, as identified by Natural Power / FORL (which are broadly in line with the document dated 29th October submitted by Mr Baker entitled '*Energy Consent Periods Paul's Hill Wind Farm*'), during the monitoring period covered by the report, are highlighted as solid blue circles.

The results show that all of the noise level points outside the spread of data acquired during normal operation correspond to periods of grid curtailment.

Figure 1 – Reproduction of Figure 12 with measured noise levels during grid curtailment highlighted