Figure C11 View of the monitoring location at Queensland Caravan Park looking south-east

Figure C12 View of the monitoring location at Queensland Caravan Park looking north-west

Table C5 – Information on the measurement location, equipment and noise data at White Cairn.

Measurement Location Name	White Cairn
Measurement Location Description	Isolated property located up on the hill west of Barrhill and south of the A714, on the edge of a train line. Chosen measurement location in the rear (north) garden of the property mainly due to a row of large trees on the front side of the property which are clearly audible in windy conditions. The chosen location was relatively sheltered and distant from tall vegetation. A stream runs on the west side of the property but was not clearly audible at the selected measurement location. Train movements are intermittent on this line and therefore unlikely to affect the measured background noise levels. SLM Location: 222270 / 582601

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-31	00110032	07/08/2017
Pre-amplifier	Rion UC-53A	102143	07/08/2017
Microphone	Rion NH-21	00134	07/08/2017
Calibrator	Rion NC-74	34172705	28/11/2017
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
1	28/11/2018 09:30:	05/12/2018 11:20	94.0	93.9	-0.1	No significant drift
2	13/12/2018 14:30	25/12/2018 11:20	94.0	93.9	-0.1	No significant drift

Data Exclusions
Periods 10 minutes before and after rainfall was detected were also removed (based on the rain gauge installed at Brooklyn). South-easterly winds (120 to 180 degrees from north) were excluded from the analysis as the property appeared to be more exposed in these conditions and this would not be representative of periods in which the property is downwind of the proposed Development.

Figure C13 View of the monitoring location at White Cairn looking north-west

Figure C14 View of the monitoring location at White Cairn looking north-east

Figure C15 View of the monitoring location at White Cairn looking south-east

Annex D – Wind Speeds and Directions

Figure D1 Wind speed and direction range during quiet day-time periods (East Altercannoch data shown, Railway Bridge mast).

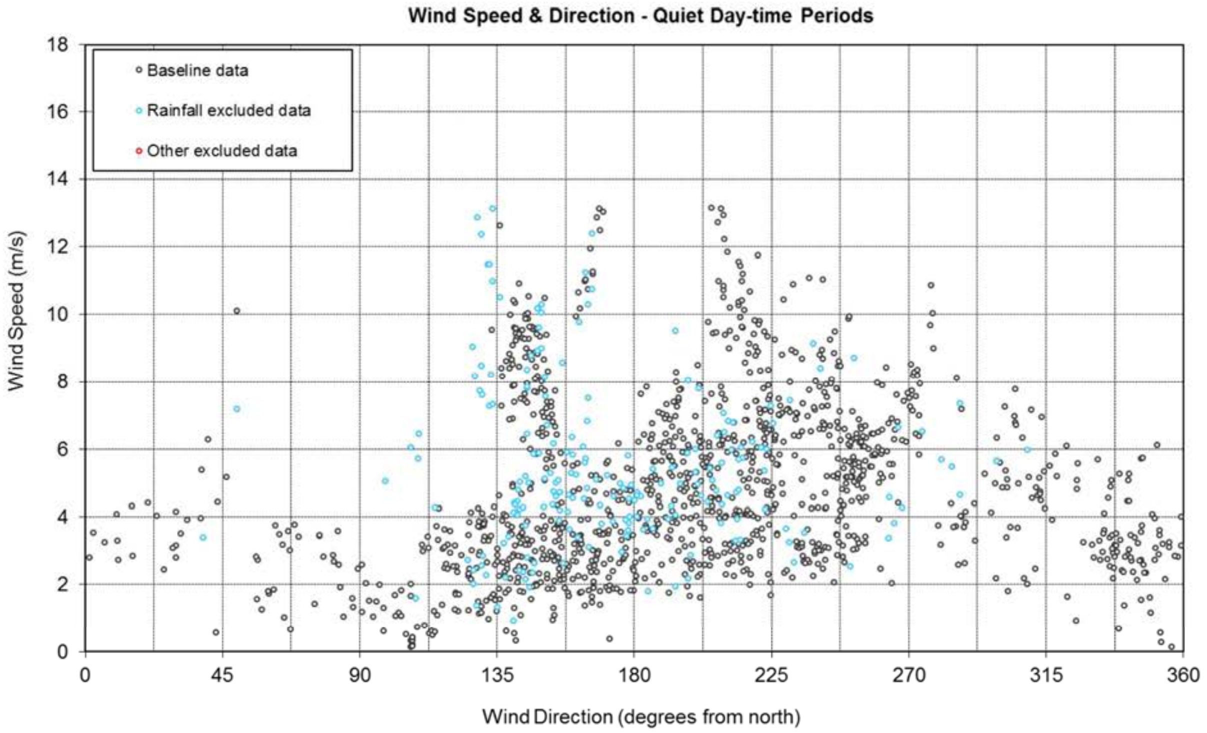


Figure D2 Wind speed and direction range during night-time periods (East Altercannoch data shown, Railway Bridge mast)

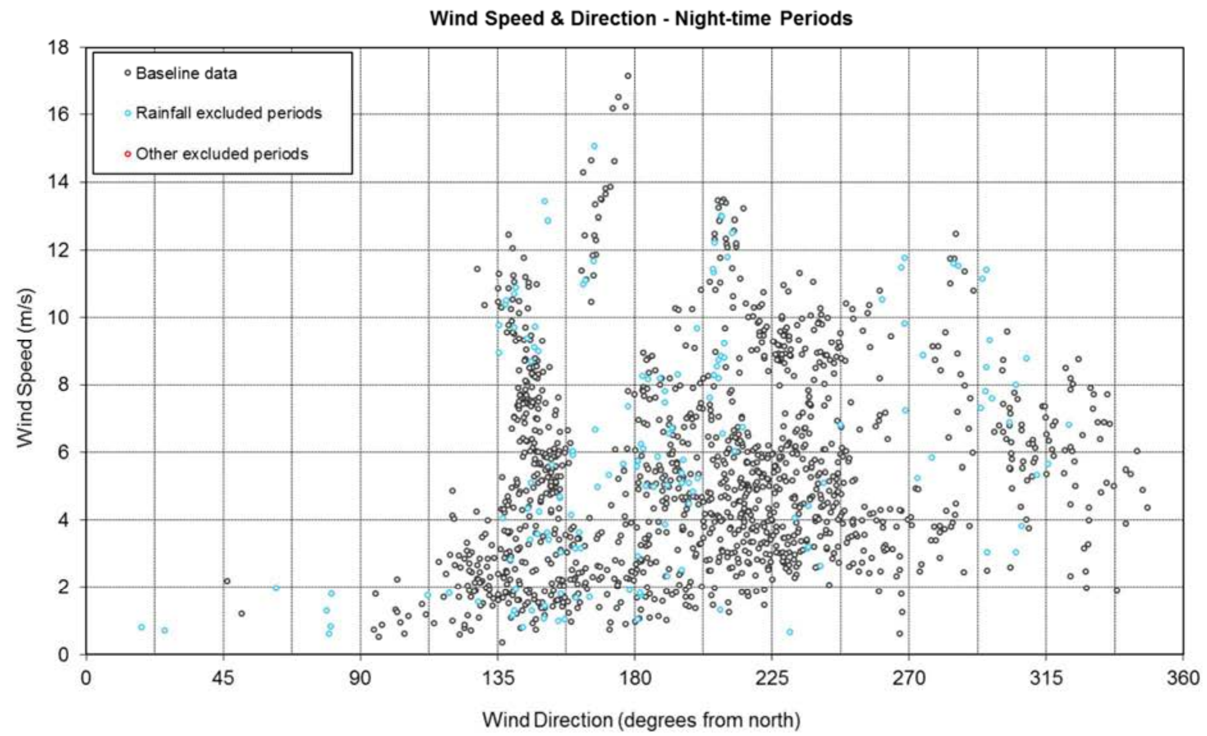


Figure D3 Wind speed and direction range during quiet day-time periods (4 Gowland Terrace data shown, Shiel Hill mast).

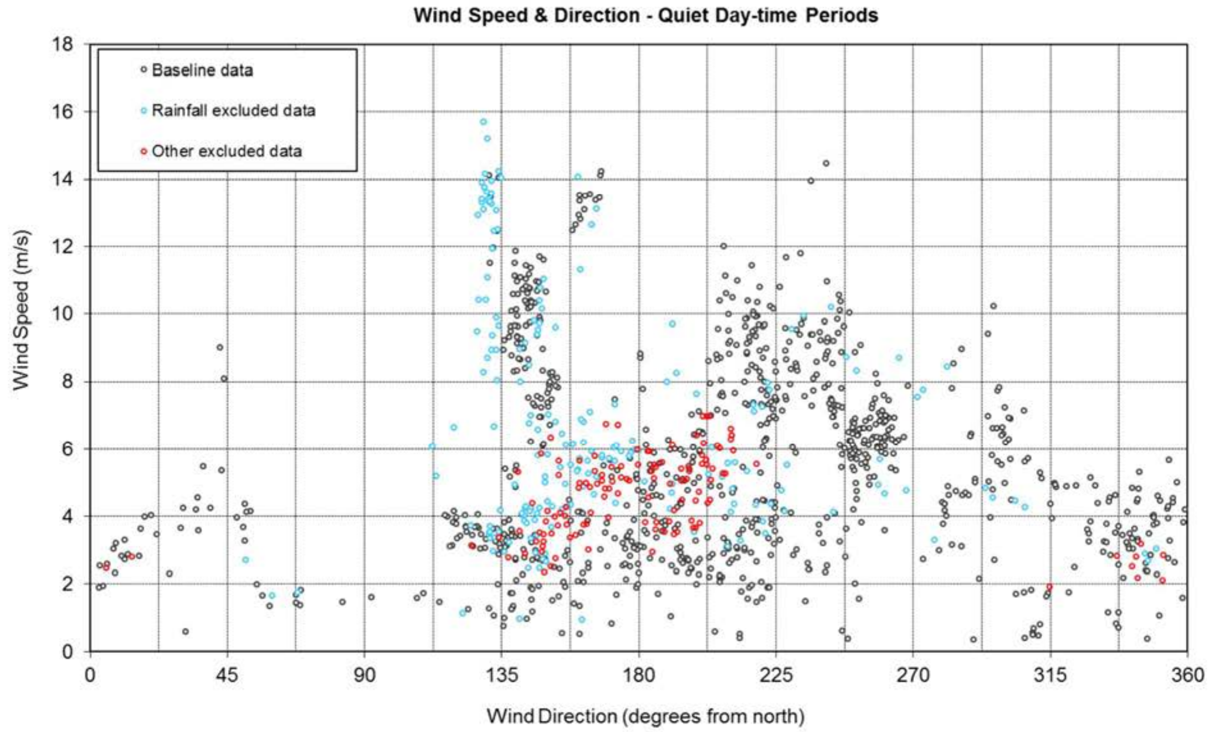
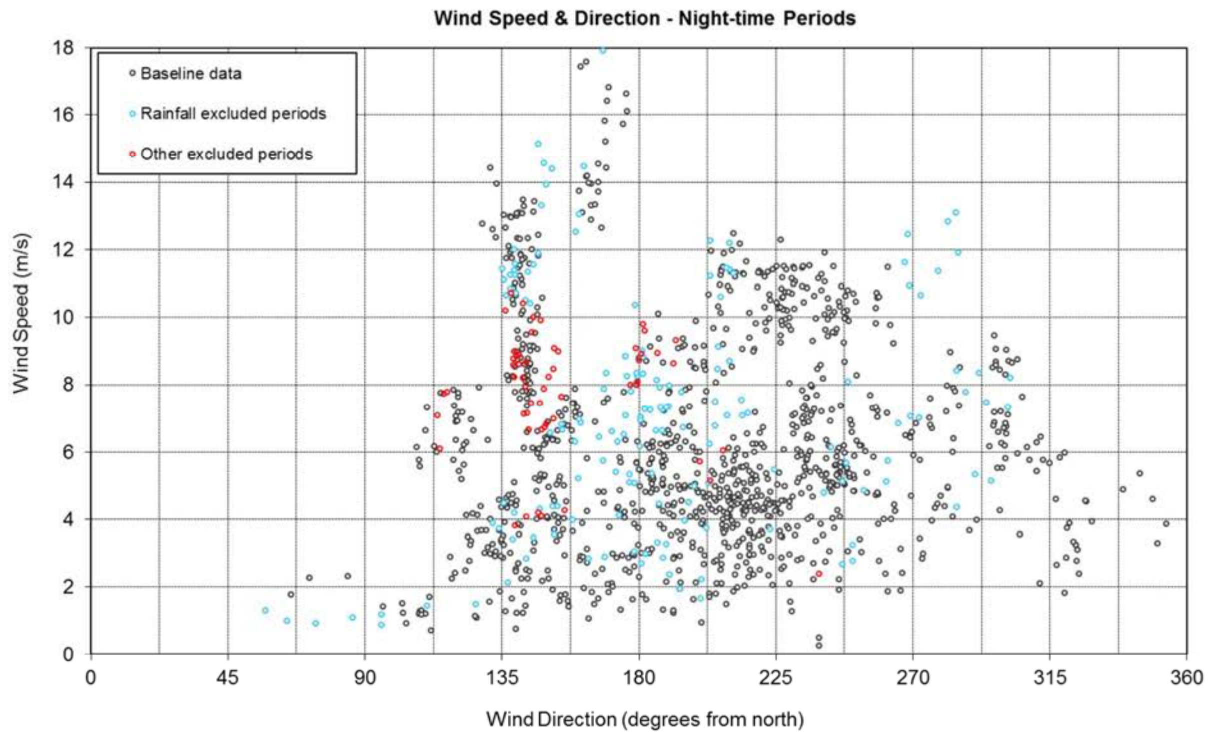


Figure D4 Wind speed and direction range during quiet day-time periods (4 Gowland Terrace data shown, Shiel Hill mast).



Annex E – Background Noise and Noise Limits

Figure E1 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for East Altercannoch during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

Assessment and baseline data at East Altercannoch during day-time periods
(Some baseline data excluded)

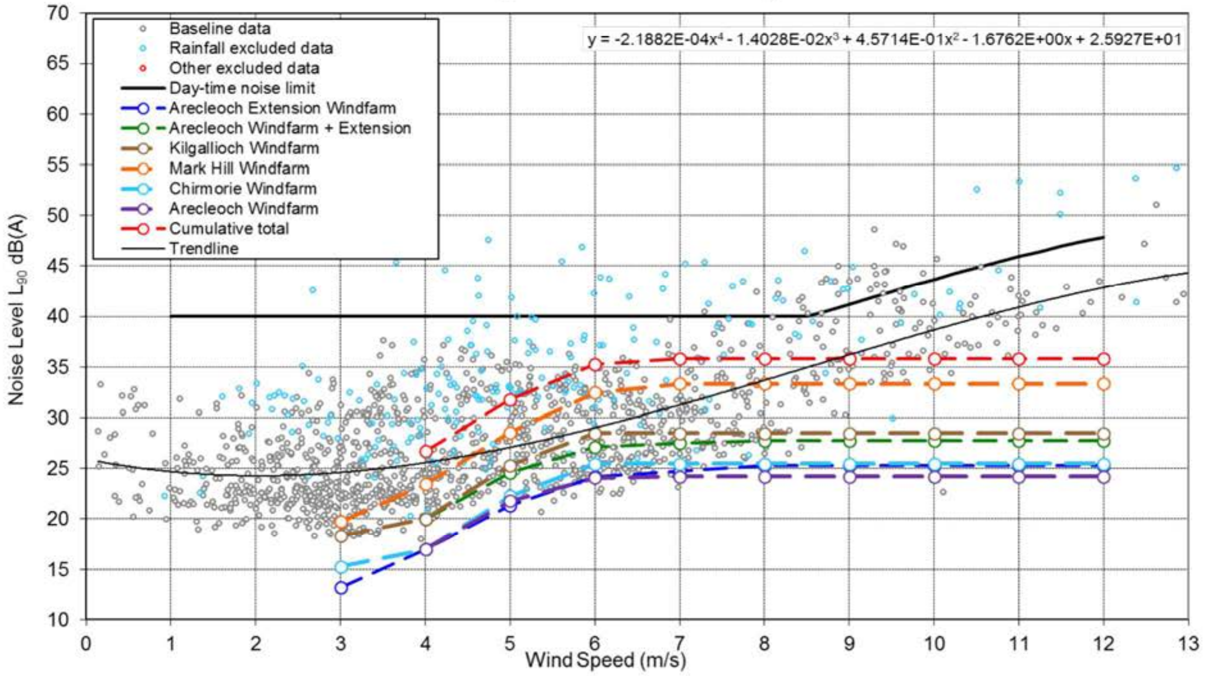


Figure E2 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for East Altercannoch during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

Assessment and baseline data at East Altercannoch during night-time periods
(Some baseline data excluded)

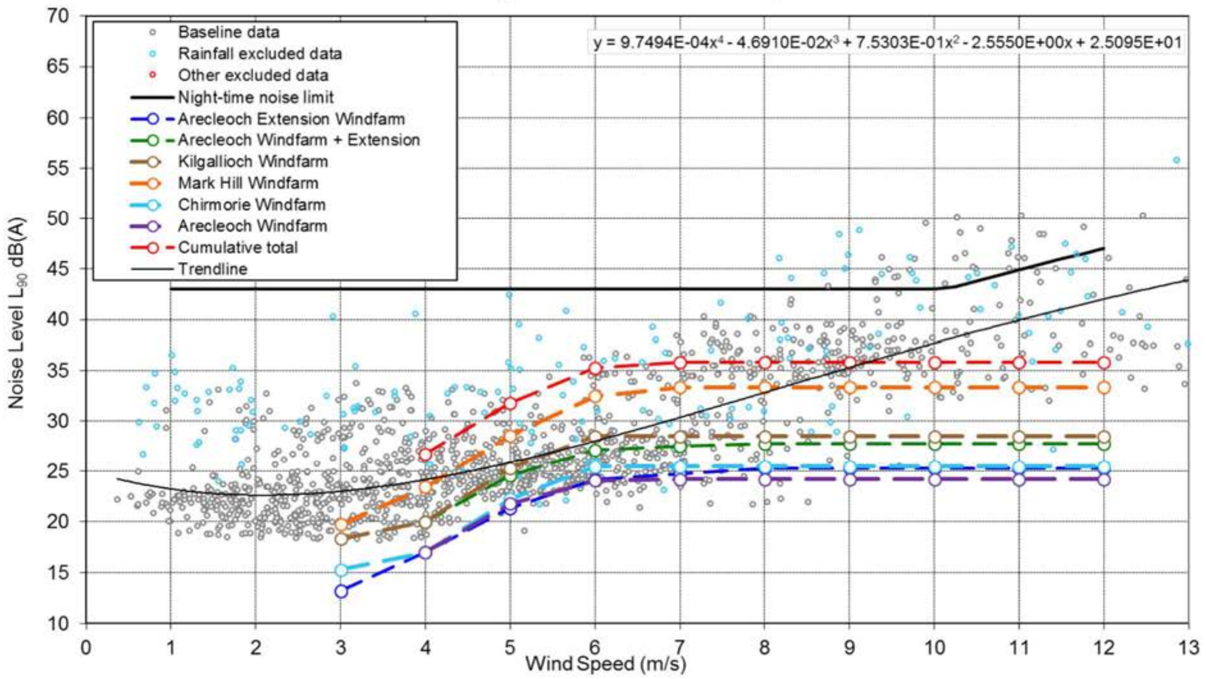


Figure E3 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Brooklyn during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

Assessment and baseline data at Brooklyn during day-time periods
(Some baseline data excluded)

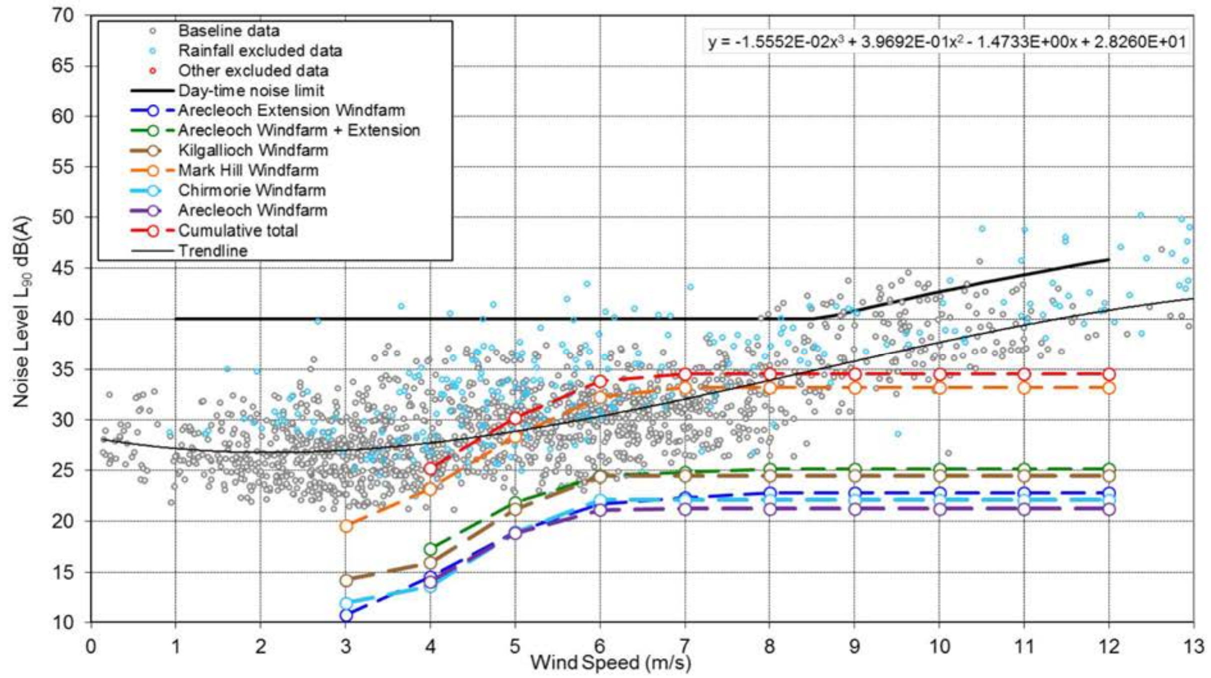


Figure E4 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Brooklyn during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

Assessment and baseline data at Brooklyn during night-time periods
(Some baseline data excluded)

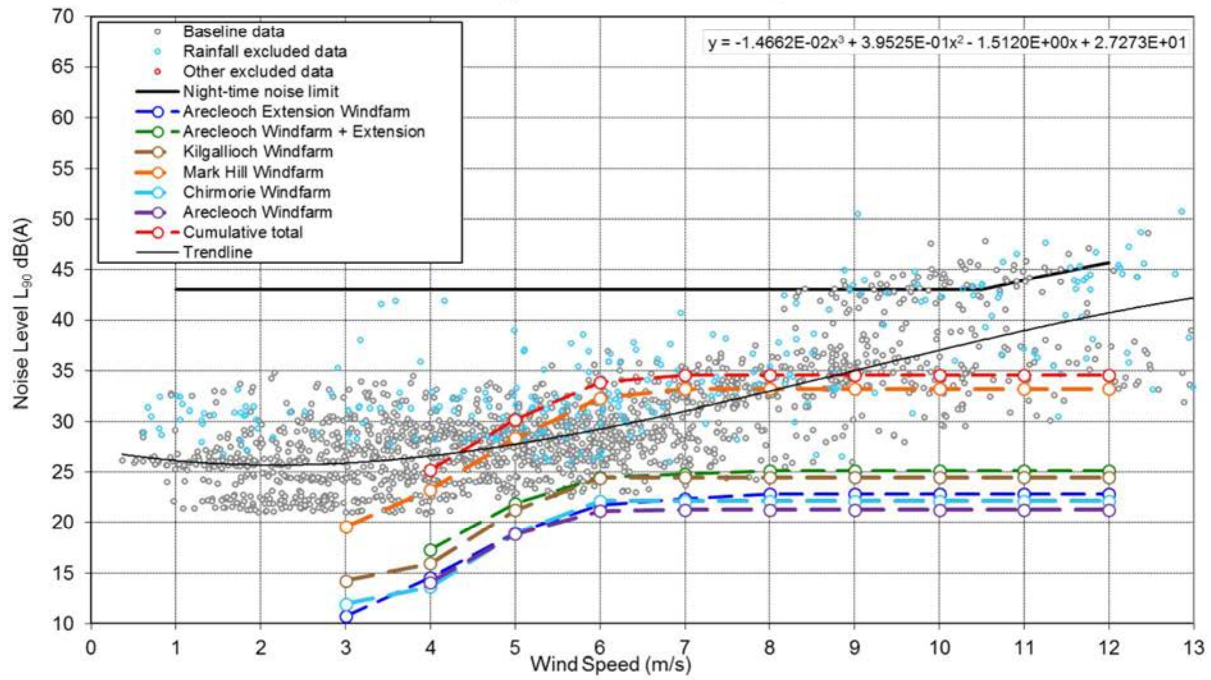


Figure E5 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for 4 Gowlands Terrace during quiet day time periods. Predicted immission noise levels at Gowlands are also shown for the proposed Development and the other windfarms considered and the cumulative total.

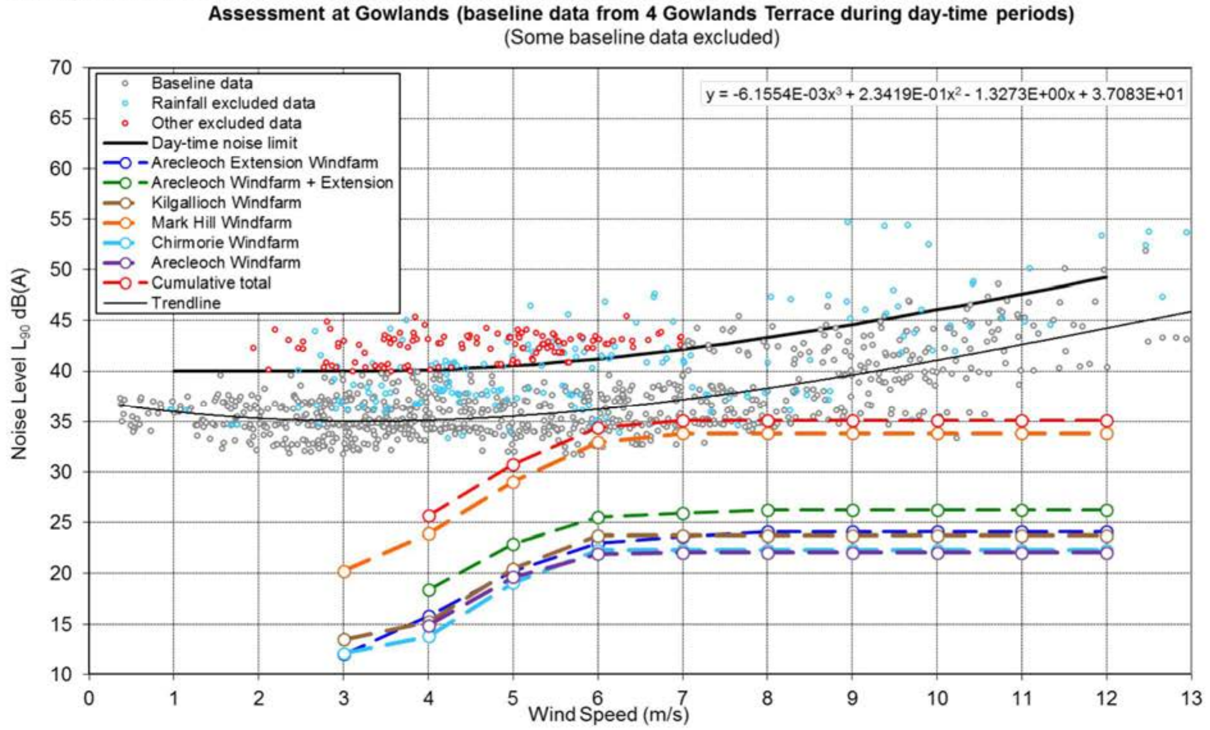


Figure E6 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for 4 Gowlands Terrace during night time periods. Predicted immission noise levels at Gowlands are also shown for the proposed Development and the other windfarms considered and the cumulative total.

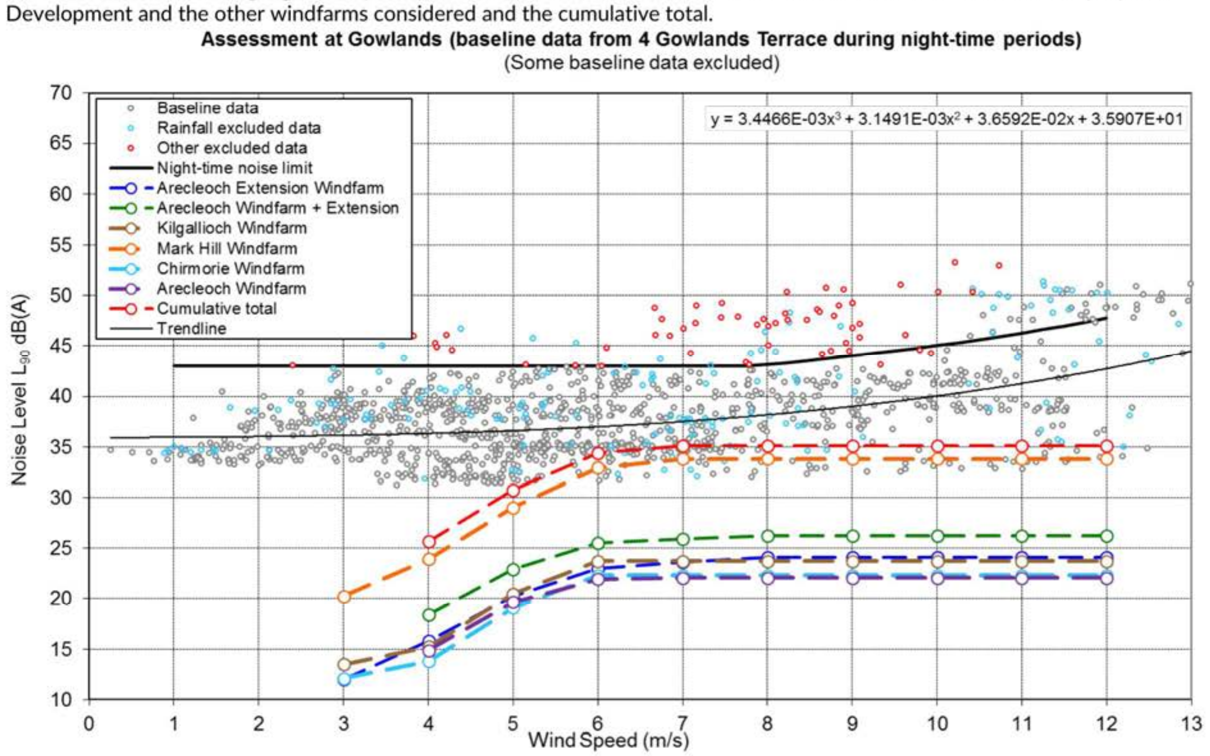


Figure E7 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Queensland Caravan Park during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

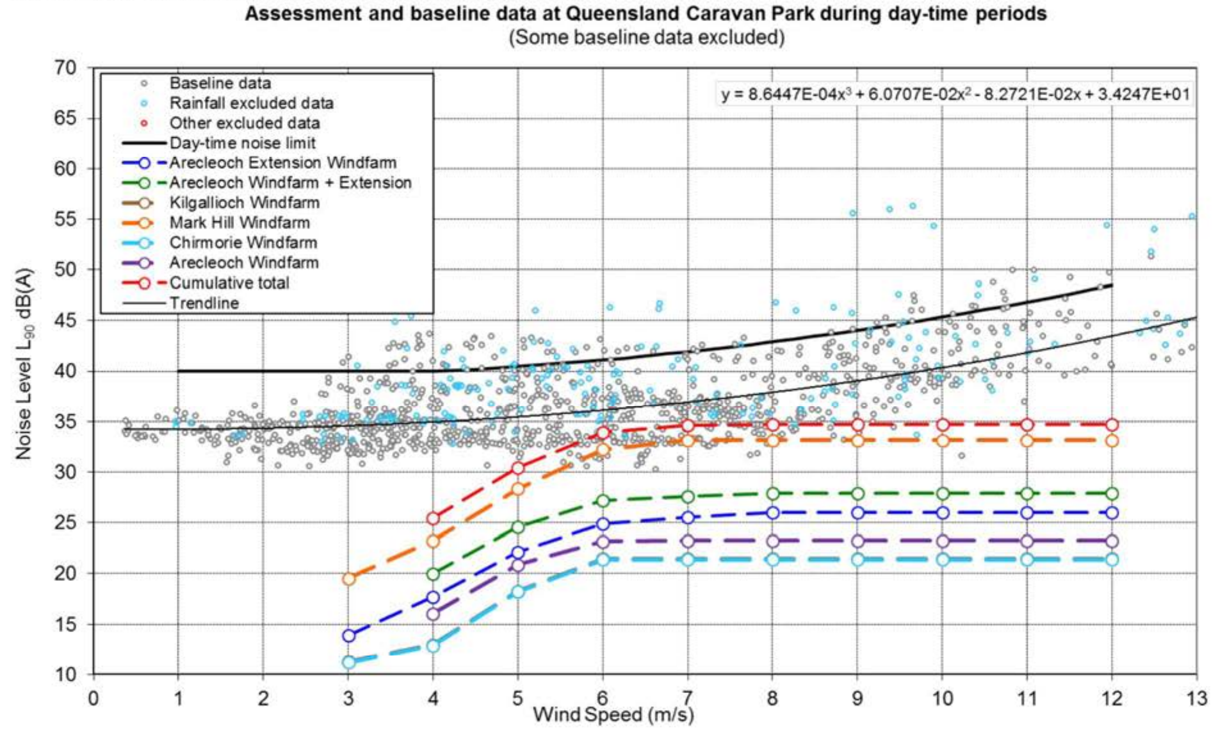


Figure E8 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Queensland Caravan Park during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

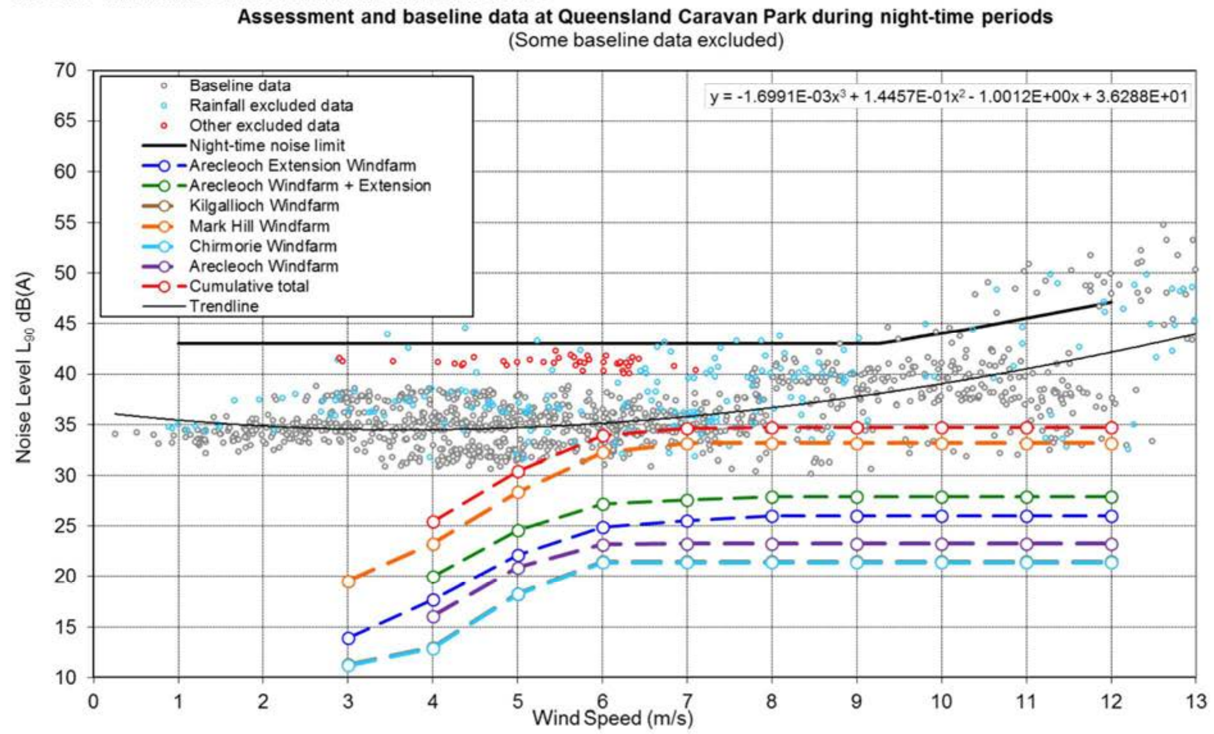


Figure E9 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for White Cairn during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

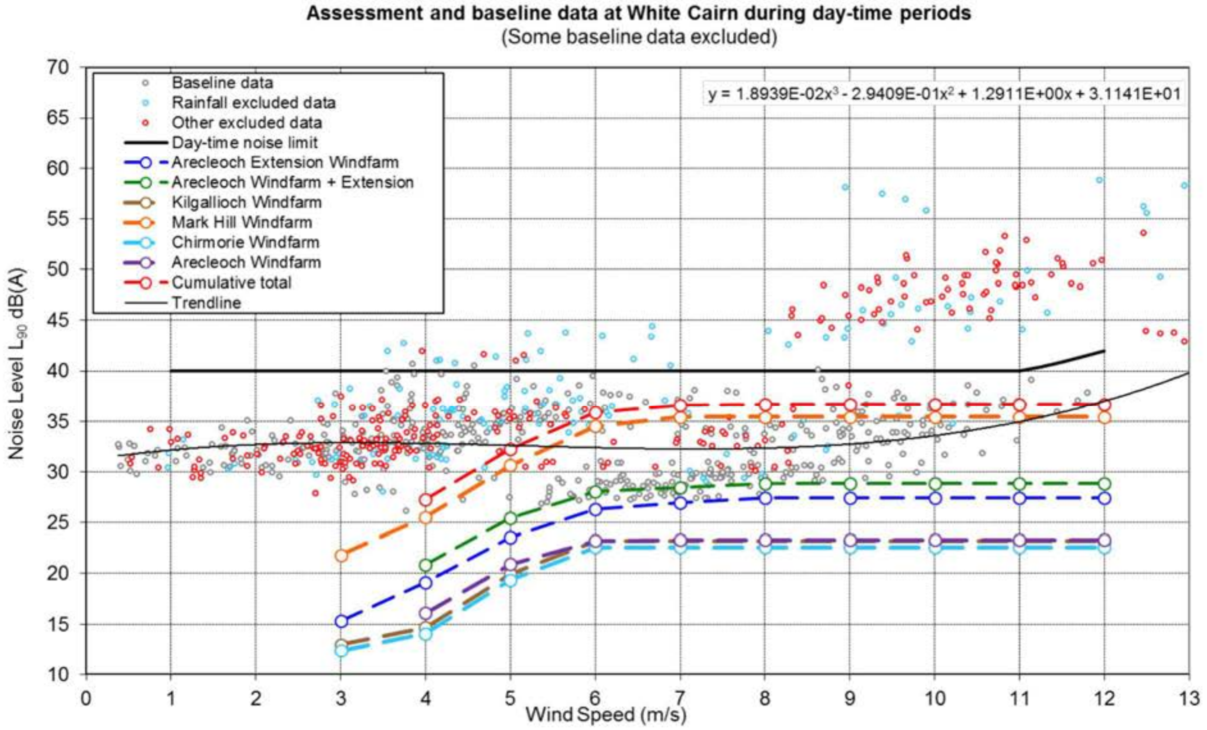


Figure E10 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for White Cairn during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

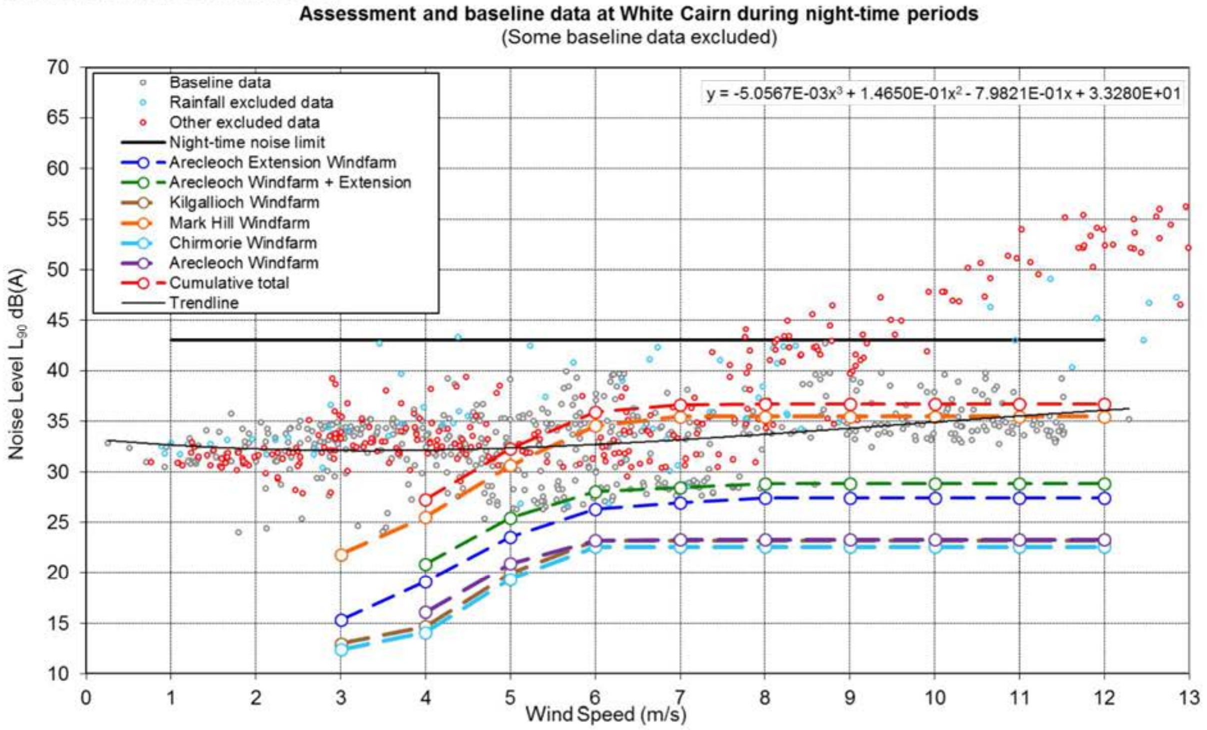


Figure E11 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Chirmorrie during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total (predictions do not include the Chirmorie Windfarm as the property would become unoccupied if this windfarm is built).

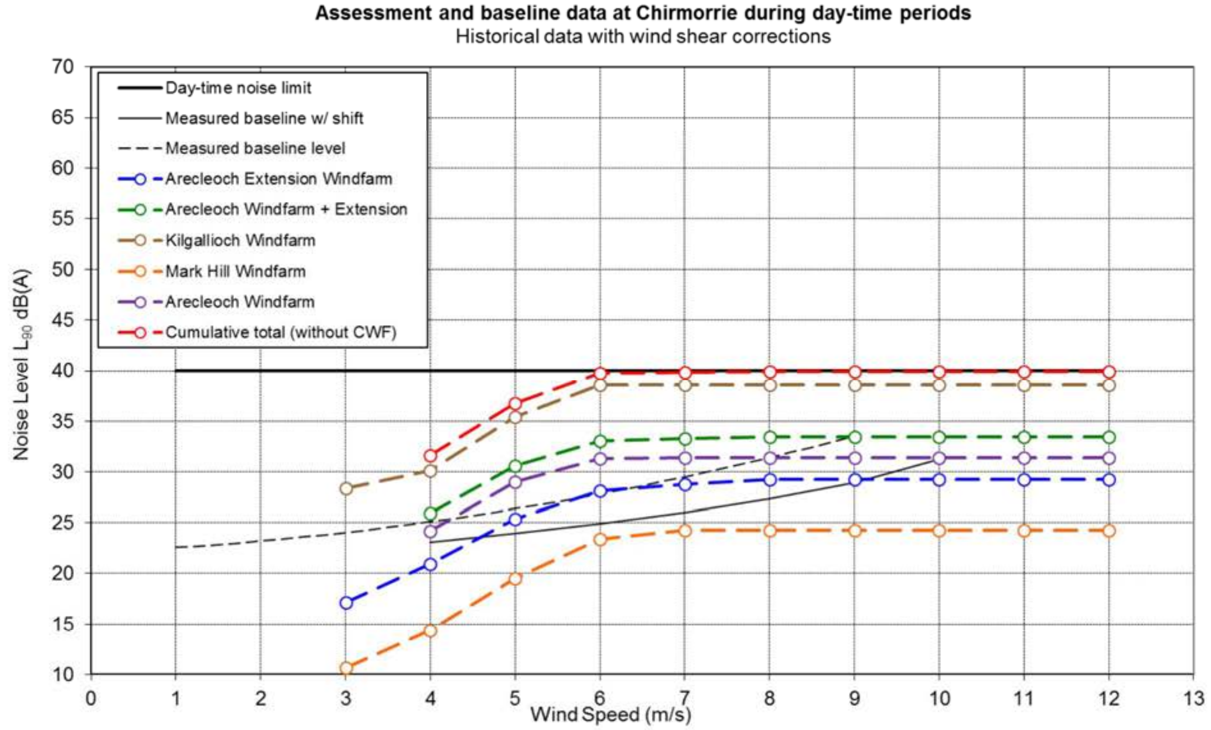


Figure E12 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Chirmorrie during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total (predictions do not include the Chirmorie Windfarm as the property would become unoccupied if this windfarm is built).

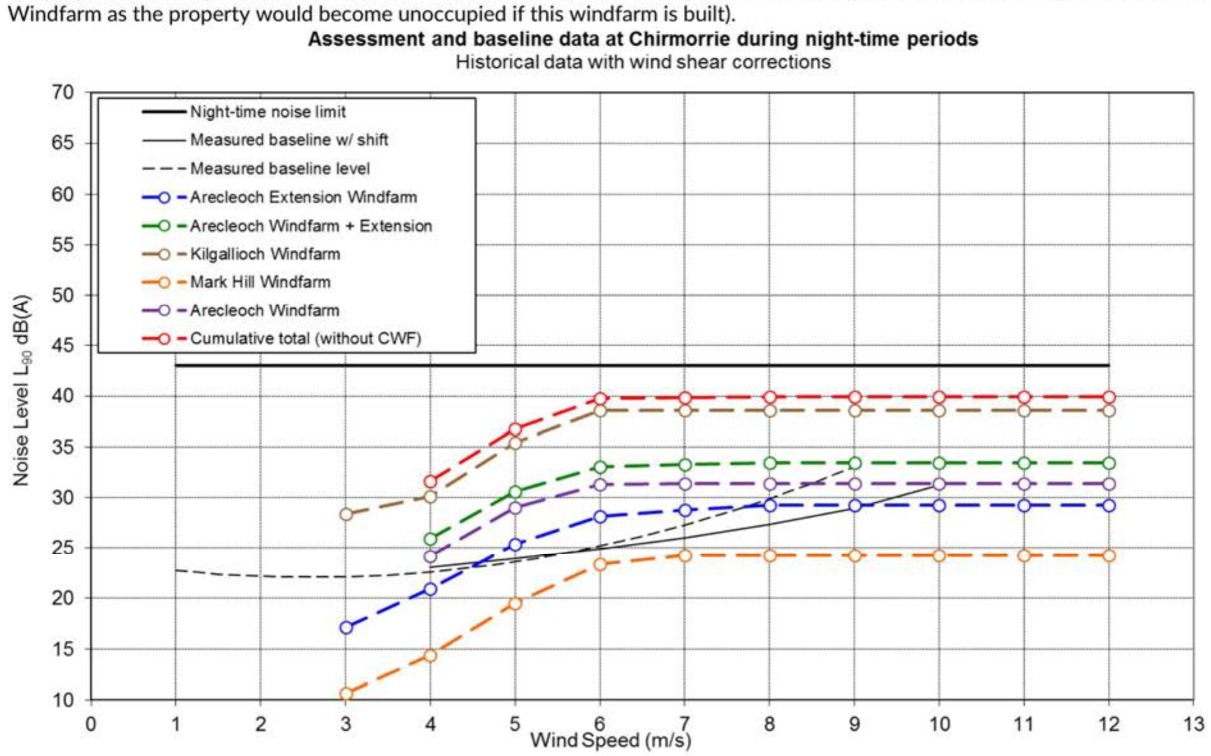


Figure E13 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Laggish during quiet day time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

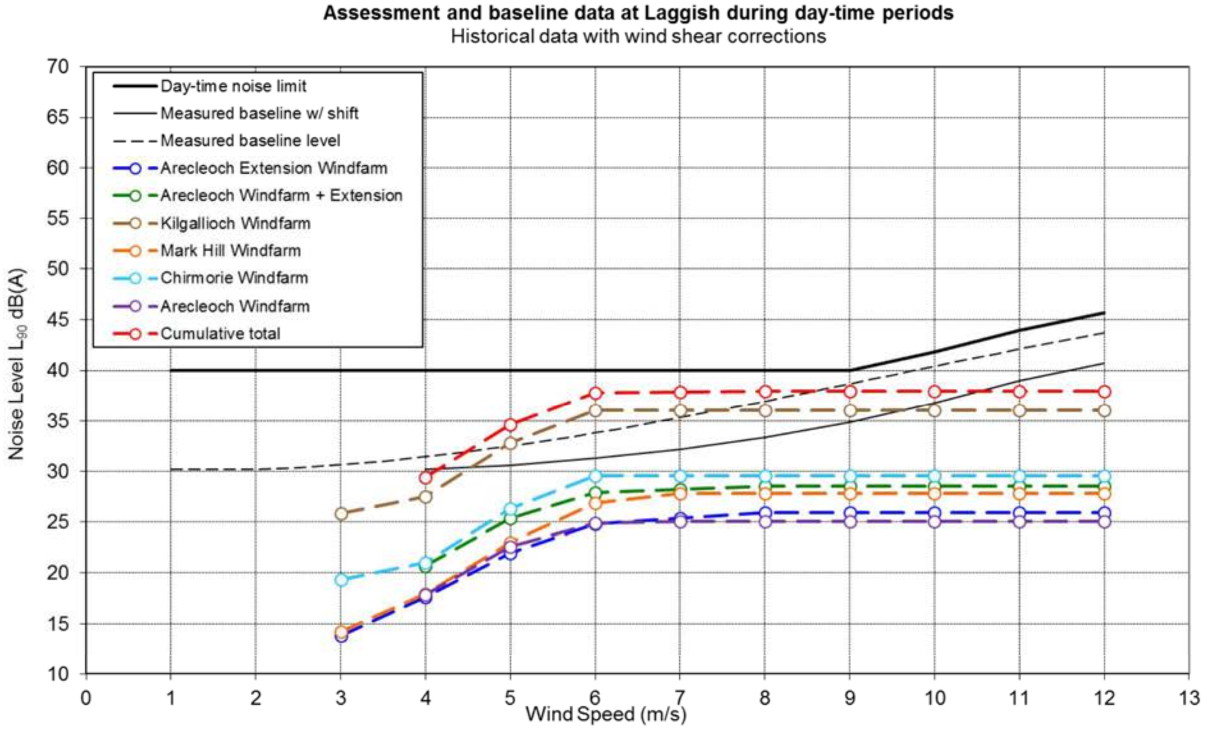


Figure E14 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Laggish during night time periods. Predicted immission noise levels are also shown for the proposed Development and the other windfarms considered and the cumulative total.

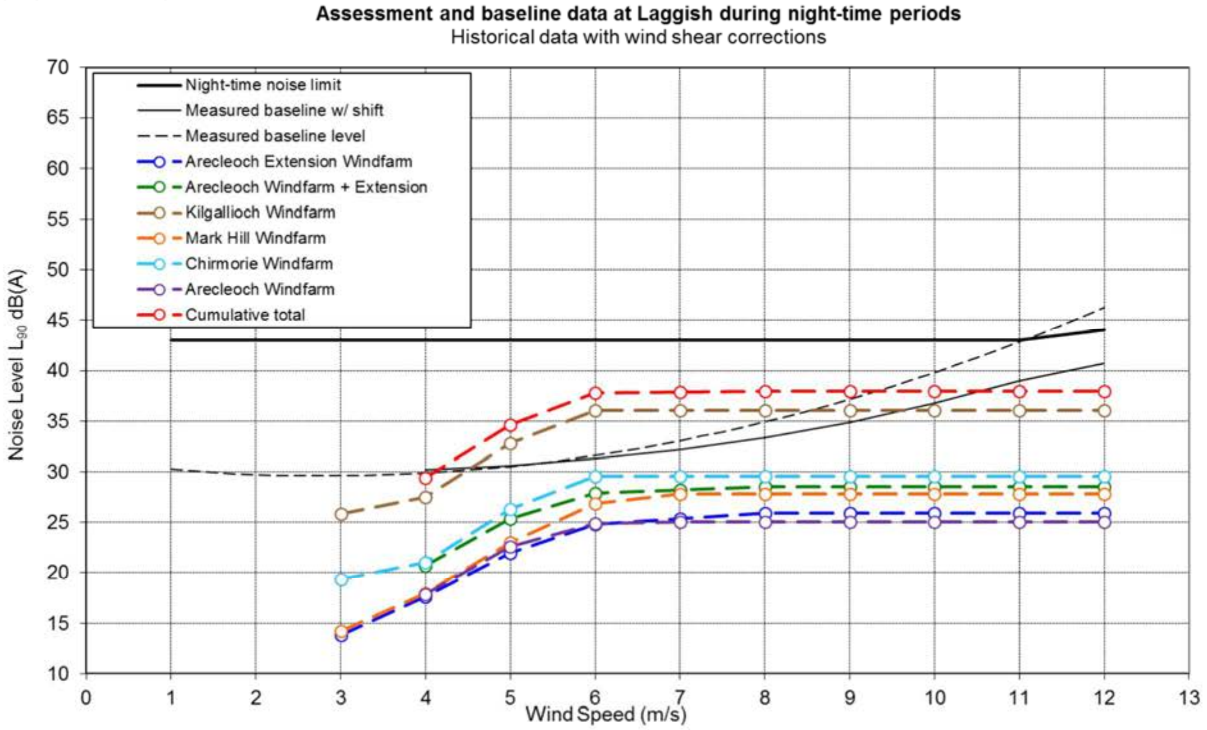


Figure E15 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Kilrenzie during quiet day time periods. Predicted immission noise levels at Glenour are also shown for the proposed Development and the other windfarms considered and the cumulative total.

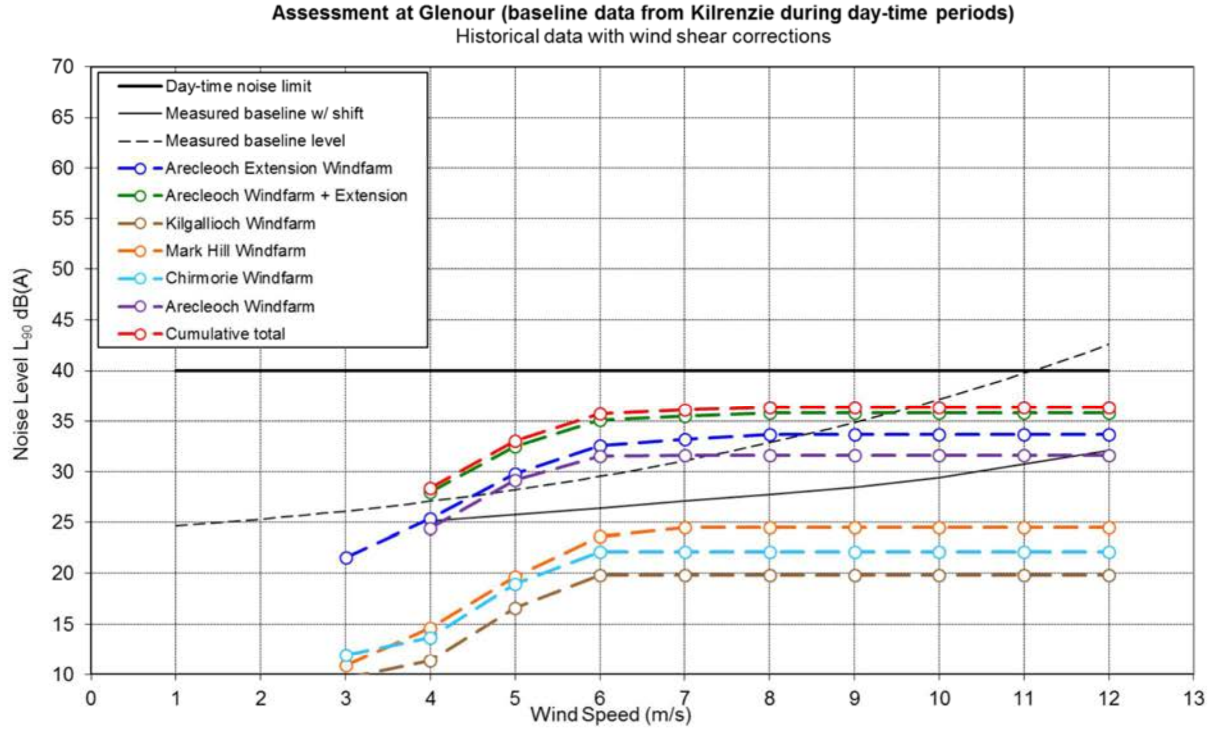


Figure E16 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Kilrenzie during night time periods. Predicted immission noise levels at Glenour are also shown for the proposed Development and the other windfarms considered and the cumulative total.

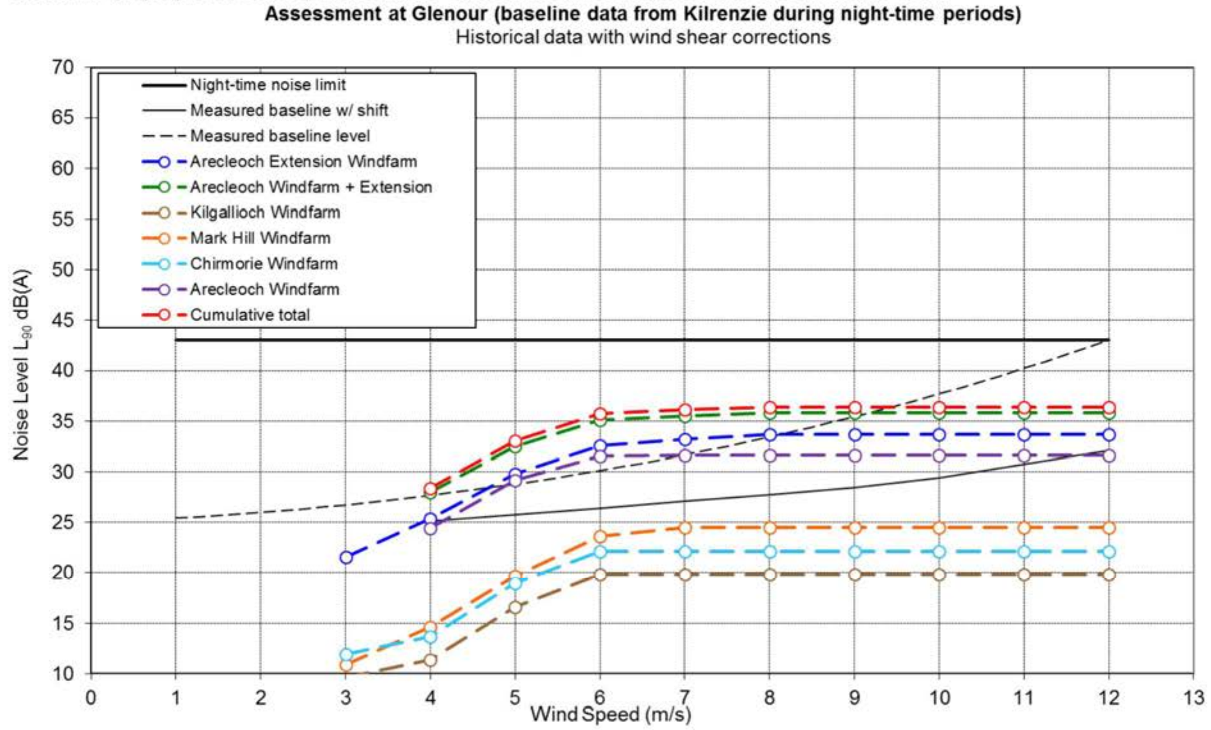


Figure E17 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Ward of Cairnlea during quiet day time periods. Predicted immission noise levels Ferngate Cottage are also shown for the proposed Development and the other windfarms considered and the cumulative total.

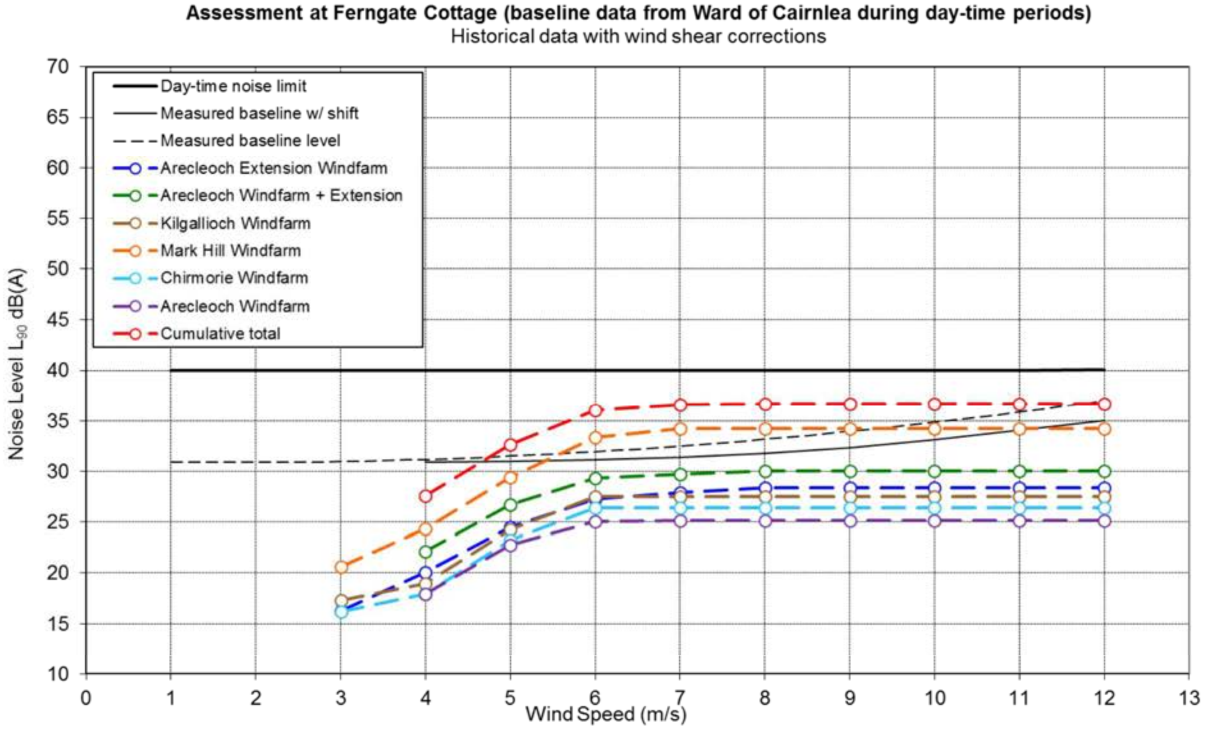
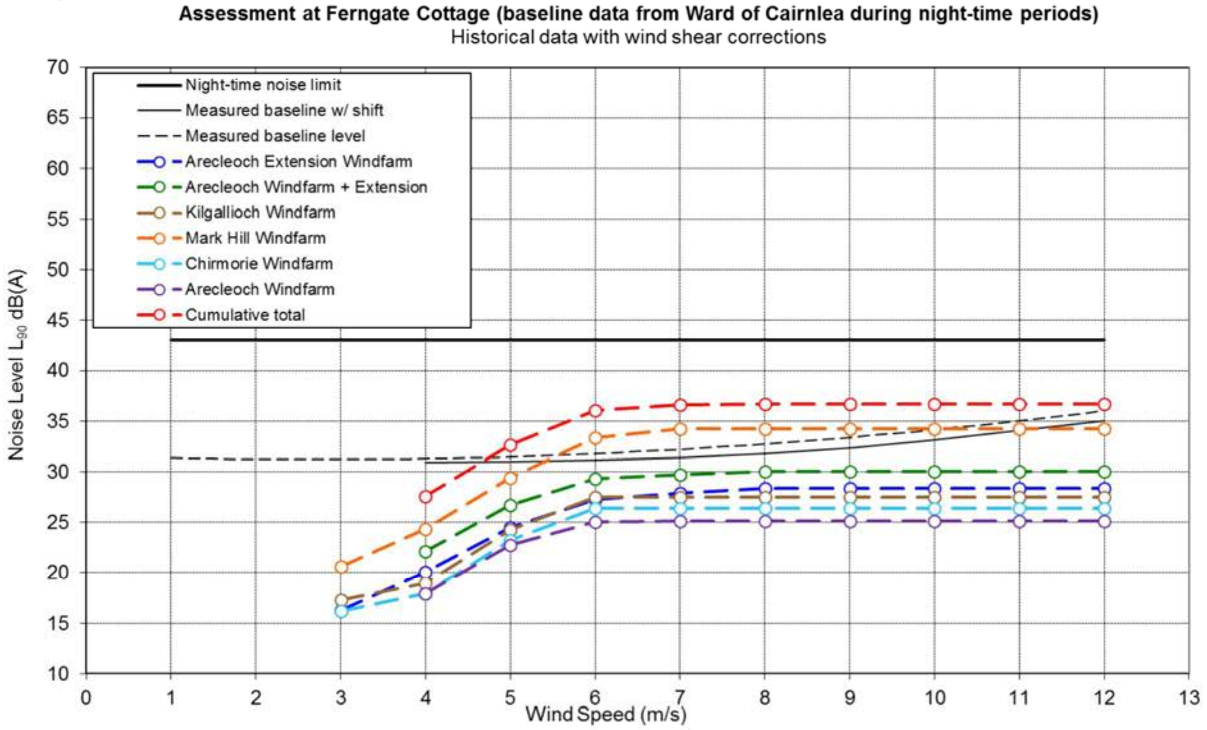


Figure E18 Chart of derived background noise levels curve against wind speeds, both as originally derived and with wind shear shift applied, and the derived noise limit curve for Ward of Cairnlea during night time periods. Predicted immission noise levels at Ferngate Cottage are also shown for the proposed Development and the other windfarms considered and the cumulative total.



Annex F – Wind Speed Calculations

F.1 An important consideration when specifying the sound power outputs of wind turbines is the fact that wind speed varies with height above the ground. This effect is commonly termed 'wind shear'. Therefore, if the wind speed on a site is characterised in terms of, say, the wind speed measured at ten metres above ground level, then some means must be available for converting this ten-metre height wind speed to whatever the hub height of the proposed turbine will be. This is important because it is this hub height wind speed (i.e. the wind speed seen by the rotor of the wind turbine) that determines the actual sound power radiated by that turbine.

F.2 The example of a ten-metre height wind speed is selected here because this height is frequently adopted as a 'reference'. For example, in ETSU-R-97 [1] the wind speed dependent background noise levels are specified as a function of ten metre height site wind speeds. Likewise, the declared sound power data measured in accordance with the internationally adopted standard for the measurement of wind turbine sound power output, IEC61400-11 [2], is also referenced to a ten-metre height wind speed.

F.3 The ground roughness length, z, indicates the degree to which wind is slowed down by friction as it passes close to the ground: the rougher the ground, the more the wind is slowed down and the larger the roughness length. Table 11 of ETSU-R-97 gives examples of roughness lengths, as repeated here in Table F.1. Figure F.1 shows the wind speed profiles corresponding to the four ground roughness lengths given in Table F1.

F.4 However, it has been found from measurements that the influence of the ground may not be the only factor affecting the variation of wind speed as a function of height above the ground. Another key factor can be the amount of turbulence in the atmosphere itself.

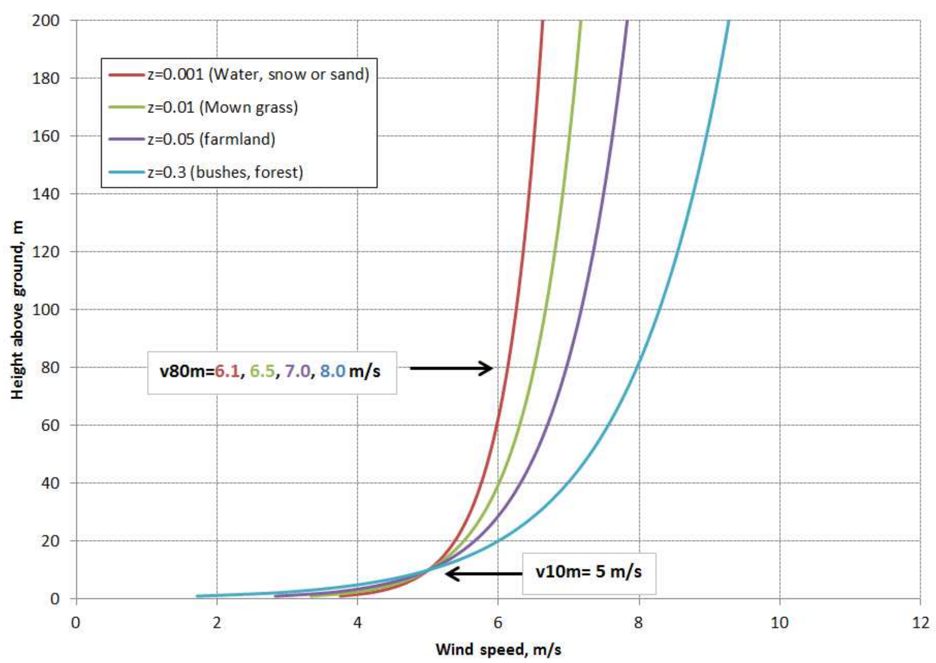
F.5 Generally speaking, under a typical day time meteorological scenario, the atmosphere lying above the ground will exhibit what is termed 'neutral' characteristics. In such cases the atmosphere itself has little effect on the wind speed profile which is then controlled primarily by ground roughness. However, under certain conditions, typically on a summer's evening following a warm day, the radiative effects of the ground can cool the air lying close to the earth at a rate faster than the convective cooling of the air lying above. This can result in a highly stable atmosphere, one of the characteristics of which is a pronounced wind shear effect. This means that the relative difference between the wind speed at ten metres height and that at hub height during affected evening/night time periods may be significantly greater than the difference which typically exists during day time periods or other 'neutral' conditions.

Table F1 Table 11 of ETSU-R-97 showing the typical roughness lengths associated with different terrain types

Type of Terrain	Roughness Length, z (metres)
Water, snow or sand surfaces	0.0001
Open, flat land, mown grass, bare soil	0.01
Farmland with some vegetation (reference)	0.05
Suburbs, towns, forests, many trees and bushes	0.3

F.6 When undertaking noise certification measurements of wind turbine sound power outputs, the relevant procedure applies a standard means of converting between hub height and ten metres height wind speeds. This involves using a 'standard' roughness length of 0.05 metres in Equation F1, regardless of what the actual roughness length seen on the test site may have been. This 'normalisation' procedure is adopted to ensure direct comparability between test results for different turbines. However, when this standardised data is subsequently used to calculate the sound power radiated from an installed turbine on an actual windfarm site, it is important to convert between ten metres height wind speeds and hub height wind speeds using the actual wind speed differences experienced on the Site itself. These hub height wind speeds may well be different from those calculated by assuming the standard 0.05 metres ground roughness length.

Figure F1 Wind speed profiles calculated for the four different ground roughness lengths listed in Table F.1. The figure adopts a fixed wind speed at ten metres height of v10=5 ms-1 then presents the calculated wind speeds at other heights as the curved lines. The calculated wind speeds at 80 metres height corresponding to the assumed U10=5 ms-1 are also presented as numerical values, ranging from U80=6.1 ms-1 for a ground roughness length of z=0.001 metres to U80=8.0 ms-1 for ground roughness length of z=0.3 metres.



F.7 The relevance of this conversion between wind speeds at ten metres height and wind speeds at hub height has come under increasing scrutiny with the acknowledgement that, on some sites, the wind shear (i.e. the increase in wind speed with increasing height above ground level) can vary significantly between day time and evening/night time periods. This difference occurs for the reasons discussed above concerning the radiative cooling effects of the earth on the lower levels of air. When this effect occurs, the wind speed seen by the turbine blades at night can be significantly higher than that derived using either a 'standard' assumed roughness length based on the characteristics of the general terrain, or from using on a roughness length or shear factor based on longer term averaged measurements of the difference in wind speeds measured at two different heights.

Approach

F.8 The Site of the proposed Development had two temporary meteorological (met) masts installed which measured wind conditions at various heights as follows:

- Mast 1: Shiel Hill (easting / northing 219548 / 581607)
  - 81 metre — Wind speed (2 anemometers)
  - 78 metre — Wind direction
  - 71.5 metre — Wind speed
  - 50.5 metre — Wind speed
  - 28 metre — Wind direction
  - 30 metre — Wind speed
- Mast 2: Railway Bridge (easting / northing 220546 / 580539)
  - 70 metre — Wind speed (2 anemometers)
  - 68 metre — Wind direction

  - 60 metre — Wind speed
  - 50 metre — Wind speed
  - 28 metre — Wind direction
  - 30 metre — Wind speed

F.9 Both met masts were operating during the new baseline survey measurements undertaken in 2019. Furthermore, as both masts were installed in 2017, historical wind data was also available.

F.10 Wind speeds are needed at a height of ten metres for correlation with measured noise data as specified in ETSU-R-97. ETSU-R-97 also requires the noise assessment be performed with a wind speed maximum of no more than 12 m/s at ten metres height. Whilst it would be possible to use the direct measurement of wind speeds at a height of ten metres, this approach has been questioned due to potential differences in the wind shear profile during the evenings and night times when compared to the day time. In accordance with the preferred methodology set out in the Institute of Acoustic Bulletin Good Practice Guide [3], all ten metre wind speed data is calculated from those which will be directly experienced by the wind turbines. Wind speeds are therefore related directly to those at hub height and calculated to be at ten metres height assuming reference conditions. Reference conditions are those used when reporting the measured and/or warranted sound power levels of the wind turbines and assume a ground roughness length of 0.05 metre. The process used to calculate the ten metres height wind speeds is therefore described below.

Methodology

F.11 ETSU-R-97 specifies that where measurements are not made using a ten-metre met mast, measurements at other heights may be used to provide ten metre height wind speeds by calculation. Equation F1 is given in ETSU-R-97 for this purpose.

$$U_1 = U_2 \cdot \frac{\ln\left(H_1/z\right)}{\ln\left(H_2/z\right)}$$ [F1]

Where:

H_1	The height of the wind speed to be calculated (10 metres)
H_2	The height of the measured wind speed
U_1	The wind speed to be calculated
U_2	The measured wind speed
z	The roughness length (0.05 metres in the case of reference conditions)

F.12 Equation F1 is of the same form as that given in BS EN 61400 11:2003 [2] for calculating ten metre wind speeds related to hub height wind speeds when providing source noise emission data for wind turbines. ETSU-R-97 suggests that the roughness length may be calculated from wind speed measurements at two heights, by inverting equation F1. Alternatively, wind shear can be described by the wind shear exponent according to equation F2 as follows:

$$U = U_{ref} \cdot \left[\frac{H}{H_{ref}}\right]^m$$ [F2]

Where:

U	calculated wind speed.
U_{ref}	measured wind speed

H height at which the wind speed will be calculated

H_{ref} height at which the wind speed is measured

m shear exponent

F.13 In this case as well, the wind shear exponent may be calculated from wind speed measurements at two heights, by inverting equation F2.

F.14 Data from the met. masts were available for the duration of the 2018-2019 survey. These data were used to perform a calculation of the shear exponent found between the highest two wind speed measurements on each mast for every ten-minute period. Where wind speeds were the same at both heights or lower at greater height, the shear exponent was assumed to be zero. The shear exponent so calculated for every ten-minute period were then used to calculate the hub height (125 m) wind speed from that measured at the tallest height measured on the mast using equation F2. Equation F1 was then used to calculate a ten-metre height wind speed from the hub height wind speed every ten minutes assuming the reference roughness length of 0.05 metres. General guidance in the IOA GPG advises that the mast height should 60 % or more of the turbine hub height considered: this is achieved by the Shiel Hill mast; although the Railway Bridge mast is just marginally under this guidance height, this is not considered significant.

F.15 By using this method, measured background noise levels were correlated to ten metre wind speeds calculated from wind speeds at hub height. Any likely difference in the shear profile during the 24 hours of the day will be accounted for within the method and be reflected in the resulting ten metre wind speed data.

F.16 The method used to calculate ten metre wind speeds from those at hub height is the same as that used when deriving noise emission data for the turbines. Because the same method has been used, direct comparison of background noise levels, noise limits and predicted turbine noise immission levels may be undertaken. This method is consistent with guidance published in the Institute of Acoustic Bulletin Good Practice Guide [3].

Historical analysis

F.17 The baseline noise surveys for the Arecleoch Windfarm, which are considered in the present assessment, were referenced to wind speeds were measured directly at 10 m height from a meteorological mast located near the Chirmorrie property. As stated in the IOA GPG, when background levels are related to wind speeds directly measured at 10 m, a correction should be applied to account for wind shear effects. In the present assessment, this correction has been derived from the study of the long-term anemometry data obtained at both the masts referenced above. These correction values obtained are then applied to the derived levels presented in the Arecleoch Environmental Statement (Technical Appendix 5.5, Background Noise and Limits). Detailed guidance specified in an IOA GPG Supplementary Guidance Note [4] was also referenced.

F.18 The historic wind speeds were divided into contiguous 10-minute averaging periods across the entire data set, representing almost two years of data for both the Shiel Hill and the Railway Bridge masts. Using equation F2, the actual wind shear exponent between the lowest two and highest two measurement heights has been calculated for each of these 10 minute periods. It is normal when performing this kind of analysis to filter the data to remove that which is erroneous or unrepresentative. Measuring the wind speed at a height lower than the top of the met mast will result in the anemometer being downwind of the structure of the met mast in some wind directions. These conditions were excluded as the anemometer is not truly representing the wind speed. Data was also excluded where the wind speed at the higher height is not greater than measured at the lower height.

F.19 As above, the wind shear exponent calculated for the two upper heights has been used to calculate the wind speed at hub height (125 m), which is then standardised at 10 m height using equation F1 and the reference roughness length of 0.05 metres. The wind shear exponent calculated for the two lower heights is then used to extrapolate down to 10 m height above the ground from the lowest measured

height (30 m in this case). This procedure yields the best representation (in the absence of actual measurements at 10 m height) of the 'real' wind speed closer to the ground at 10 m.

F.20 The next part of the process involves calculating the difference between the derived actual 10 m height wind speed and the 'standardised' 10m height wind speed for every 10-minute period. The calculated differences for each measured 10-minute period are then sorted into bins, each bin corresponding to a given hour of the day and a given 1 m/s wide wind-speed bin. Wind speed differences are then calculated for each bin based on the mean and standard deviation of all the individual differences in that bin.

F.21 Calculated differences between the 'real' and the 'standardised' ten metre height wind speeds in each bin are then averaged for evening and night-time periods: see results in Table F2. These results can then be used to correct the previously derived curves of prevailing background noise levels. The effect is to shift the measured levels to higher wind speeds, resulting in lower (and therefore more conservative) noise limits, as illustrated in the relevant charts of Annex E.

Table F2 Wind shear correction values (m/s) derived from historical analysis for both met masts

Wind speed (10 m height)	4	5	6	7	8	9	10	11	12
Railway Bridge									
Evenings (quiet day-time)	2.2	2.3	2.3	2.3	2.1	1.8	1.8	1.9	1.7
Night-time	2.4	2.4	2.3	2.2	2.2	2.3	2.3	2.1	2.1
Shiel Hill									
Evenings (quiet day-time)	3.0	3.7	4.1	4.3	4.5	4.7	4.8	4.3	n/a
Night-time	3.2	3.7	4.1	4.3	4.8	5.0	4.8	4.5	n/a

References for Wind Speed Calculations

[1] ETSU-R-97, The Assessment and Rating of Noise from Wind Farms, Final Report for the Department of Trade & Industry, September 1996. The Working Group on Noise from Wind Turbines.

[2] IEC 61400 11:2003 Wind turbine generator systems - Part 11: Acoustic noise measurement techniques.

[3] A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise, M. Cand, R. Davis, C. Jordan, M. Hayes, R. Perkins, Institute of Acoustics, May 2013.

[4] IOA GPG Supplementary Guidance Note 4: Wind Shear, July 2014.

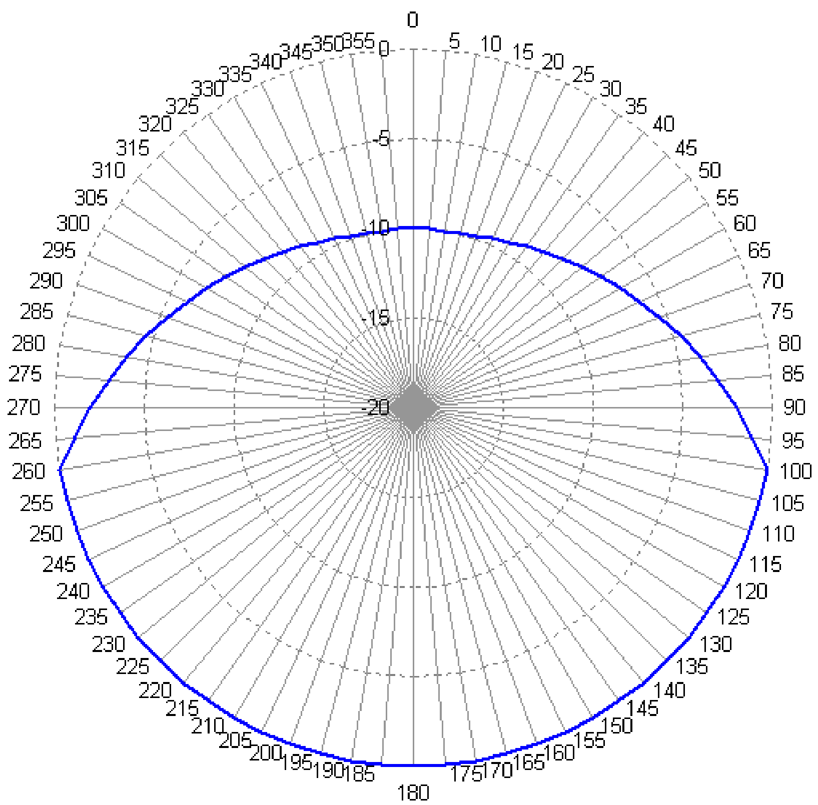
Annex G – Directional analysis

Figure G1 illustrates the relationship assumed between the reduction in turbine noise levels and wind heading that may occur, because of propagation effects, as described in the main report. This relationship is based on the conservative assumption that for a range of headings directly downwind (0°) to crosswind (90°) there may be no reduction in noise levels, once in cross wind directions (90°) then the reduction may be 2 dB(A) and when upwind the reduction would be 10 dB(A). This is consistent with guidance set out in section 4.4.2 of the IOA GPG, based on research and advice set out in the JOULE project (Bass et. al., 1998), BS8233 and ISO 9613-2.

The present analysis is made on the conservative assumption that downwind conditions occur for angles of up to 10 degrees from crosswind conditions (corresponding to a 2 m/s positive downwind component for wind speeds of 12 m/s). Furthermore, this does not account for potential turbine radiation directivity characteristics.

The attenuation factors have been normalised zero for favourable downwind propagation and are therefore applied as a correction to the values predicted using the model given in ISO 9613-2. As noted in the IOA GPG, such reductions (due to "shadow zone" refraction effects) will in practice only progressively come into play at distances of between 5 and 10 turbine tip heights and this was accounted for in the calculations.

Figure G1 – Relationship of the change of noise levels with wind direction, 180° is where the receptor is directly downwind of the turbine and 0° where the receptor is directly upwind of the turbine.



Direction	Attenuation
0	-10.0
15	-9.9
30	-9.3
45	-8.3
60	-6.7
75	-4.6
90	-2.0
105	0.0
120	0.0
135	0.0
150	0.0
165	0.0
180	0.0
195	0.0
210	0.0
225	0.0
240	0.0
255	0.0
270	-2.0
285	-4.6
300	-6.7
315	-8.3
330	-9.3
345	-9.9
360	-10.0

Figure G2 - Relationship of the change of noise levels with wind direction at Chirmorrie for a wind speed of 8 m/s. Predicted noise levels including directional effects have been provided for the Arecleoch Windfarm (AWF), the proposed Development (AWF Extension) and combination with AWF, the Kilgallioch Windfarm (KWF), Mark Hill Windfarm (MHWF) (see legend) and the cumulative total (red).

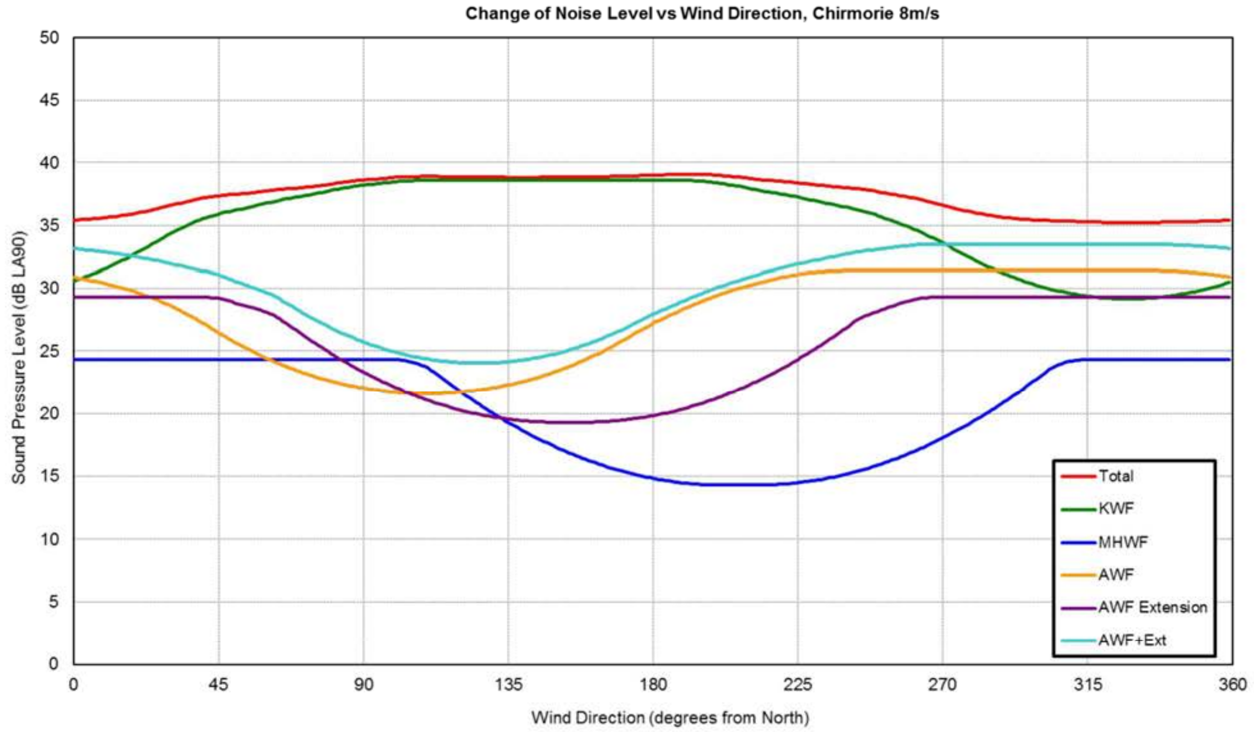


Figure G2 sets out the results of the directional analysis at a representative wind speed of 8 m/s. It is apparent that the conditions for which the noise levels from the combination of the Arecleoch Windfarm and the proposed Development reach their maximum (broadly, 235 to 45 degrees from North) are those in which noise from the Kilgallioch Windfarm is strongly reduced, and *vice-versa*. Over this range, the noise from the combination of windfarms other than the Arecleoch Windfarm and the proposed Development does not exceed 36.7 dB L_{A90}. The specific limits of Table 20 and 21 above were therefore determined on this basis. In other wind directions, complying with the defined specific noise limits means that the reductions due to propagation effects would lead to cumulative levels which would also remain compliant with the derived ETSU-R-97 noise limits.

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