Cush Wind Farm

Environmental Impact Assessment Report

Annex 13.3: Radio Telescope Impact Assessment

Cush Wind Limited

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PAGERPOWER
Urban & Renewables

Radio Telescope Impact Assessment

Cush Wind Limited

Cush Wind Farm

August 2023





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ADMINISTRATION PAGE

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Issue	Date	Detail of Changes
1	14 April 2022	Initial issue (11117A)
2	06 June 2023	Updated turbine details (11117B)
3	07 June 2023	Minor updates
4	02 August 2023	Finalised layout

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EXECUTIVE SUMMARY

Background

Pager Power has been commissioned to investigate the potential impact of a proposed wind development, located approximately 3.1km north northeast of Birr, County Offaly, upon the Irish Low Frequency Array (I-LOFAR).

The proposed wind development comprises eight wind turbines with a maximum tip height of 200 metres above ground level, a hub height of 114 metres agl, and a rotor diameter of 172 metres.

LOFAR System Overview

The Low Frequency Array (LOFAR) is an international network of telescopes used to observe the Universe at low radio frequencies. LOFAR consists of 12 international stations spread across Germany, Poland, France, UK, Sweden and Ireland, with additional stations and a central hub in The Netherlands, operated by the Netherlands Institute for Radio Astronomy.

I-LOFAR is the Irish addition to this network and is located west of Birr, County Offaly.

Overall Conclusion

The potential impacts of the wind turbines on LOFAR arise primarily due to the following three mechanisms:

1. Obstruction of signals from space by the turbines as physical structures;
2. Reflections of existing terrestrial sources of noise (such as television transmissions); and
3. Radio Frequency emissions from the turbines themselves.

Based on assessment of these primary mechanisms, the proposed development is not predicted to have a significant impact on I-LOFAR.

The assessment is based on first principles and typical safeguarding processes for radio equipment. The operational considerations around astronomy using such telescopes is complex, high specialised and evolutionary. It is recommended that the operator of the I-LOFAR is consulted to understand their position regarding the project and this assessment.

Technical Findings

The proposed wind turbines as obstructions will reduce the minimum horizon of the LOFAR antennae. The elevation angle from the antennae to the turbine tip ranges from approximately 1.6 degrees to 2.3 degrees, an increase of approximately 0.3 degrees compared to the current maximum obscuration from the terrain. The presence of the turbine will therefore have a technical impact on the lowest unobscured angles; however, the change is small and likely to be insignificant because the elevation angles required for actual astronomical data are likely to be larger than the angle to the turbine blade tips.

A sample calculation has been undertaken to establish the loss in field strength due to a turbine tower as an obstruction for a radio source at 120 MHz. This has indicated an average value of 2.9 dB. This will result in a slight weakening of signals at low levels, directly beyond the turbines.

Sample reflection calculations to quantify the potential increase in existing terrestrial noise sources have indicated cumulative Carrier to Interference Ratio (CIR) of 39.8 dB. In this context, the carrier signal is the existing noise source and the interference signal is the reflection of this noise from the turbines. The increase in existing noise sources will be of the order of 0.01%.

Based on the typical emissions emitted from the turbines, field calculations of extrapolated field values for the nearest turbine indicated values of up to 20.0 dBµV/m[1]. Emissions from the turbines are therefore not predicted to be significant because the emissions are small, due to their compliance with International Electrotechnical Commission standards, and because they reduce significantly with distance. Any emissions from the turbines will therefore be significantly smaller than emissions from closer sources, such as vehicles, mobile phones, buildings, machinery, home appliances, etc. in and around Birr.

[1] Less than a fifth of the average field strength of a mobile phone using 3G at a distance of 5cm.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 58 countries within Europe, Africa, America, Asia and Australasia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially the company focus was on modelling the impact of wind turbines on radar systems. Over the years, the company has expanded into numerous fields including:

- Renewable energy projects.
- Building developments.
- Aviation and telecommunication systems.

Pager Power prides itself on providing comprehensive, understandable and accurate assessments of complex issues in line with national and international standards. This is underpinned by its custom software, longstanding relationships with stakeholders and active role in conferences and research efforts around the world.

Pager Power's assessments withstand legal scrutiny and the company can provide support for a project at any stage.

1 INTRODUCTION

1.1 Overview

Pager Power has been commissioned to investigate the potential impact of a proposed wind development located approximately 3.1km north northeast of Birr, County Offaly, upon the Irish Low Frequency Array (I-LOFAR).

The proposed wind development comprises eight wind turbines with a maximum tip height of 200 metres above ground level, a hub height of 114 metres agl, and a rotor diameter of 172 metres.

In detail the report includes:

- Proposed wind development details.
- I-LOFAR system details.
- Overview of LOFAR interference principles
- Overview of assessment methodology.
- I-LOFAR interference assessment.
- Overview of potential mitigation solutions.
- Conclusions and recommendations.

2 PROPOSED DEVELOPMENT INFORMATION

2.1 Proposed Development Layout

The proposed development layout overlaid onto aerial imagery is shown in Figure 1 below.

Figure 1 *Proposed development layout*

Wind turbine coordinates and assessed altitudes amsl can be found in Appendix A.

3 LOFAR SYSTEM DETAILS

3.1 LOFAR System Overview

The Low Frequency Array (LOFAR) is an international network of telescopes used to observe the Universe at low radio frequencies. LOFAR consists of 12 international stations spread across Germany, Poland, France, UK, Sweden and Ireland, with additional stations and a central hub in The Netherlands, operated by the Netherlands Institute for Radio Astronomy (ASTRON).

I-LOFAR is the Irish addition to this network and is located west of Birr, County Offaly.

3.2 I-LOFAR Location

The location of the I-LOFAR relative to the proposed wind development is shown in Figure 2 below.

Figure 2 *I-LOFAR location*

3.3 I-LOFAR Antennae

LOFAR makes observations in the 10 MHz to 240 MHz frequency range with two types of antennas: Low Band Antenna (LBA) and High Band Antenna (HBA), optimized for 10 – 80 MHz and 120 – 240 MHz, respectively. These are not tabulated within this report as there are 94 LBA and 97 HBA locations. The I-LOFAR antennae locations are shown in Figure 3 below.

Figure 3 *I-LOFAR anntenae*

The centre location of each cluster is shown in the previous figure. The LBA centre location has been used for the purposes of assessment as it is the closest cluster to the proposed development. Its details are presented in the following sub-section.

3.4 I-LOFAR System Details

Table 1 below provides the details for the assessed I-LOFAR. The coordinates heights have been extrapolated.

Antenna altitude above mean sea level (amsl)[2]	46m
Co-ordinate location (Longitude, Latitude - Degrees)	-7.922184, 53.095254
Average distance between the proposed development and I-LOFAR	5.8km
Average grid bearing from I-LOFAR to proposed development	20.5°

Table 1 *I-LOFAR system details*

3.5 Antenna Pattern

A reliable antenna pattern was not available for this analysis. It is understood that this is difficult to define meaningfully, particularly for angles below 20°.

Therefore, no consideration has been given to the directionality of the antenna, i.e. noise which is radiated onto the array from an angle of 10° is not considered to be better or worse than noise from 1°.

Further analysis could be undertaken with regard to such issues if an antenna pattern can be agreed for this purpose.

[2] Extrapolated from SRTM terrain data and an antenna height of 1m agl.

4 RADIO INTERFERENCE MECHANISMS

4.1 Overview

The following subsections describe some of the principles which are relevant to the analysis conducted within this report.

4.2 Reciprocity Theorem

The reciprocity theorem states If a voltage is applied to the terminals of an antenna A and the current measured at the terminals of an antenna B then an equal current will be obtained at the terminals of antenna A if the same voltage is applied to the terminals of antenna B.

This means that anything affecting radio signals travelling from antenna A to antenna B will affect returning radio signals in the same way. This means that analysis carried out for signals travelling in one direction will apply to signals travelling in the other.

4.3 Shadowing

Signal strength drops when the receiver is shadowed by trees, large buildings or terrain. The received signal is made up of signals reflected from other objects or terrain and signals which are diffracted around the shadowing terrain.

Diffraction loss calculations are used to calculate the impact of shadowing effects.

4.4 Reflections

Signals arriving at a receiver may come directly from the transmitter, or be reflected from the ground, trees, vehicles, buildings and structures[3].

At the receiving antenna these direct and reflected waves are summed, with some components adding to the received signal strength and some detracting.

4.5 Atmospheric effects

Radio signal strength may vary with time due to atmospheric changes. These can include signal absorption by water vapour, variations in refractivity and changes in ionisation levels.

4.6 Emissions

All electrical equipment and devices emit weak radio signals. Electrical equipment must be designed so that (a) their own emissions are weak (b) they are not unduly affected by emissions from other sources.

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[3] Scattering is a term that describes a general amalgamation of reflection and shadowing effects.

5 LOFAR INTERFERENCE ISSUES

5.1 Overview

The potential impacts of the wind turbines on LOFAR arise primarily due to the following three mechanisms:

1. Obstruction[4] of signals by the turbines as physical structures;
2. Reflections of existing sources of noise (such as television transmissions); and
3. Radio Frequency (RF) emissions from the turbines themselves.

These three areas are dealt with in turn in the following three chapters of this report. There are some technical considerations which are unique to LOFAR and are not encountered when assessing other telecommunication systems. These are described below.

5.2 Unknown Radio Sources

The nature of LOFAR as a tool for investigating astronomical objects and phenomena means that it is not known what radio sources will be analysed. It should be noted that the frequencies of interest are known (10 – 250 MHz). Furthermore, the power and temporal nature of the signals being investigated can be accurately modelled.

5.3 Sensitivity

LOFAR has the potential to detect very distant and very faint radio sources from space. Therefore, any impact on the sensitivity of the array could be of significance.

Therefore, there are not a fixed set of criteria that must be met in order to ensure that the telescope functions adequately. This is in contrast to other radio systems where an 'acceptable' level of interference may be more readily defined.

5.4 Approach

The approach employed within this study is to quantify the impacts of the turbines in terms of changes to the RF environment. Whilst it is acknowledged that the process of determining whether these impacts are acceptable is complex, consideration of the magnitude of any changes introduced is considered the most logical starting point.

[4] Also described as shadowing or diffraction effects.

6 ANALYSIS – OBSTRUCTION OF SIGNALS

6.1 Technical Analysis Methodology

Technical analysis has been undertaken based on a radar Line-of-Sight (LOS) analysis, which determines how much of a turbine is illuminated by the radio signal considering:

- The I-LOFAR position.
- The turbine position.
- The intervening terrain profile.
- Radio signal refraction.
- Earth curvature.

It has been assumed that the low band antennae have a height above ground of 1m and the high band antennae have a height above ground of 0.5m. The actual height of the top of the low band antennae is understood to be 1.7m; however, the antenna itself is not located at a single point. Therefore, the height of 1m is considered more appropriate for the analysis.

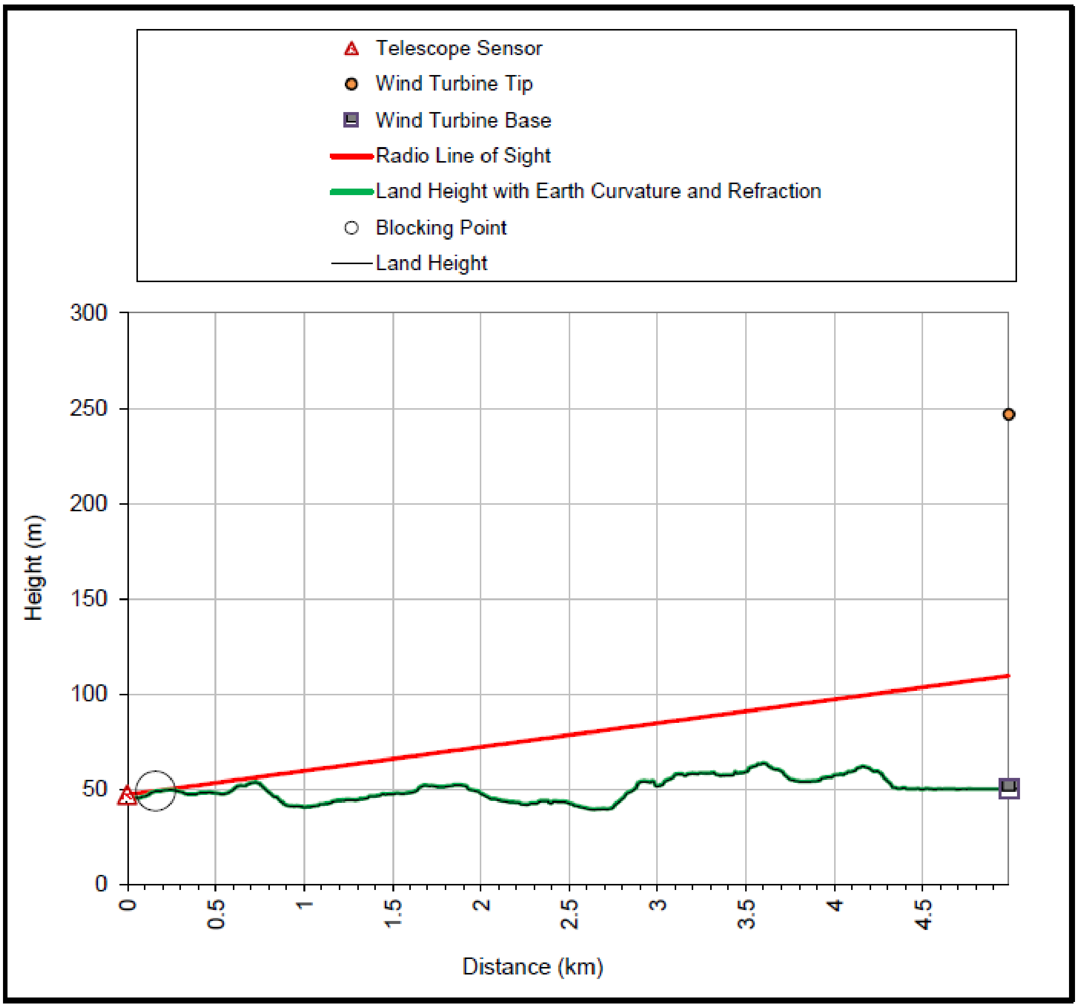
6.2 Radar Line of Sight Analysis

Figure 4 on the following page shows the LOS chart for wind turbine T02 (the most visible turbine to the I-LOFAR). Additional LOS charts can be provided upon request.

The box labelled 'certainty' provides the distance (in metres) by which the wind turbine is or is not within LOS to the I-LOFAR.

Radio Line of Sight Calculation	
I-LOFAR	

11117 Birr, Co. Offaly	
Turbine	2
Result	VISIBLE
Certainty	140.6 metres



Turbine Height (m)	200
Hub Height (m)	115
Rotor Diameter (m)	172
Turbine Elevation (m)	46.7
Turbine Location	Ln:-7.9057 Lt:53.1389
Distance to telescope (km)	5.0
Blocking Point Location	Ln:-7.9217 Lt:53.0967
Distance to BP (km)	4.8

Additional Analysis	
Angle (Telescope to Tip)	2.317 degrees up

Figure 4 *Radio Line of Sight chart – Wind Turbine T02*

The overall LOS results are presented in Table 2 below. In all cases, the turbine is significantly within radar Line of Sight to the I-LOFAR. In addition, in all cases, the rotor is entirely visible. This is relevant because it is the rotating elements of the turbine that have the most potential[5] interact with radio signals towards the array.

Turbine	Visibility to I-LOFAR (m)	Elevation Angle from Antenna to Turbine Tip (°)
T01	133.3	1.98
T02	140.6	2.32
T03	124.8	1.83
T04	134.5	2.09
T05	121.2	1.85
T06	126.7	2.01
T07	121.6	2.04
T08	120.2	1.88

Table 2 *Radio line of sight results*

The table shows that the maximum elevation angle from the antennae to the turbine tips will be 2.32 degrees.

6.3 Polar Coverage Assessment

The effect on the unobstructed horizon due to the turbines has been assessed by assessing the increase in elevation angle to the turbine tips, compared to the terrain at the horizon. Figure 5 on the following page shows polar coverage chart visualising this.

The antenna location is the centre of the chart. The red icons represent the turbines shown at their horizontal bearing. The numbered concentric rings represent the vertical angle from the antenna. The blue line represents the current horizon due to the surrounding terrain.

[5] This is because radar are typically fitted with a filter that ensures static reflectors such as terrain are not displayed.

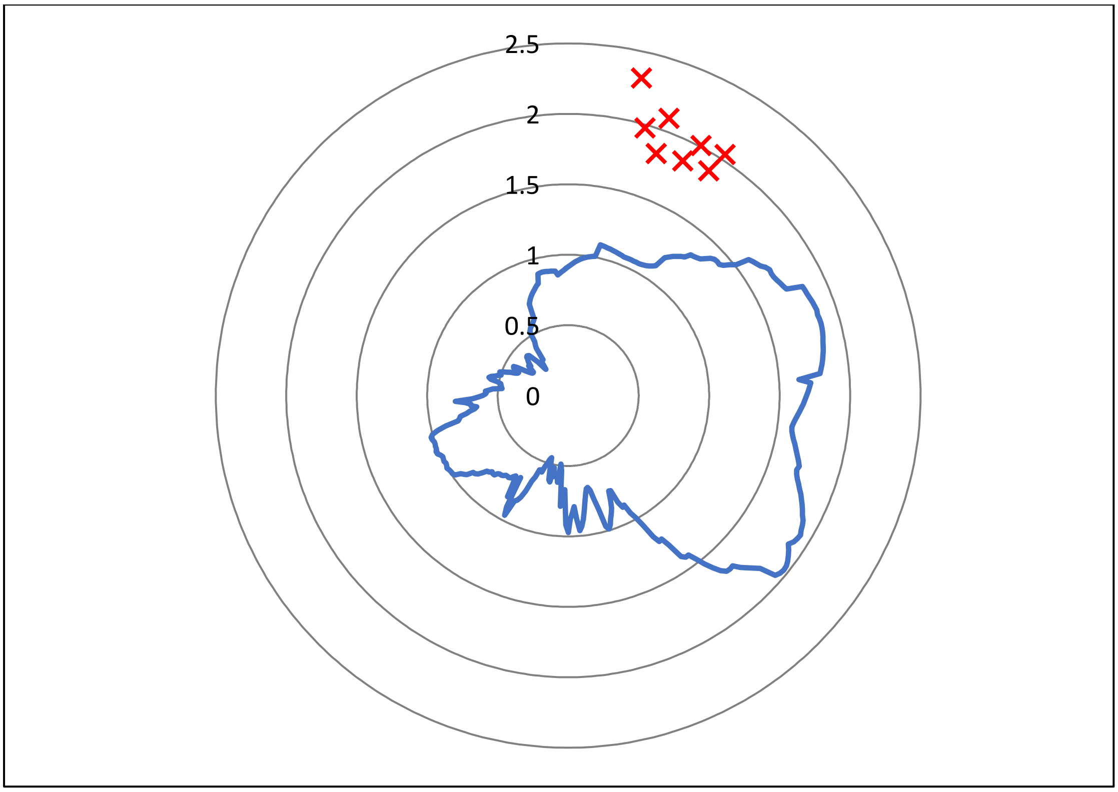


Figure 5 *Polar coverage chart*

It can be seen that the horizon due to the terrain is a maximum of almost 2 degrees to the east and southeast of the LOFAR. It can also be seen that the vertical angle to the turbine tips varies from approximately 1.8 degrees to 2.3 degrees.

6.4 Required Horizon

Pager Power cannot comment on the requirements of LOFAR. However, it is understood[6] that sensitivity data for the antennae is not available for angles of less than approximately 22 degrees[7]. One of the reasons for this appears to be this information is not required for astronomy.

Since the maximum vertical angle from the antennae to a turbine is approximately 2.3 degrees, the obscuration of the horizon due to the proposed development is not predicted to be an issue for LOFAR. This is especially the case given the presence of the turbines only results in an increase of 0.3 degrees compared to the maximum obscuration from the terrain.

[6] Correspondence between Pager Power and ASTRON, December 2011

[7] Whilst observations are not carried out at low elevations, radio information from low elevation reference sources can nevertheless be useful.

6.5 Signal Attenuation

The impact of the turbines on the visible horizon of the array is only an issue if a significant amount of signal attenuation occurs. The array is designed to detect frequencies in the range of 10-250 MHz. It is unlikely that frequencies this low will be attenuated a great deal by wind turbines. However, as discussed in the previous section, LOFAR has the potential to detect very faint radio sources.

6.6 Attenuation Calculation

Calculations have been carried out in order to quantify the attenuation effect due to the proposed development. The variation between each turbine is not predicted to be larger and therefore T05 has been assessed as it is the most central turbine.

The calculation has been carried out in accordance with the International Telecommunications Union document ITU-R P526[8] and the calculation sheet is shown in Appendix B. Section 4.2 of the aforementioned document describes a method for calculating diffraction[9] losses due to a finite width screen. A finite width screen is essentially a rectangle of blocking material standing across the radio path. Of the methods described in ITU-R P526 the finite width screen method is the most appropriate for modelling the diffraction effects caused by a wind turbine tower.

The attenuation calculation results are shown in Table 3 below. The calculation sheet is shown in Appendix B.

Turbine	Frequency (MHz)	Average Loss in Signal (dB)
T05	120	2.9

Table 3 *Attenuation calculations*

The calculation suggests an average loss of 2.9 dB for T05, and therefore all turbines. It should be noted that this is a loss associated with the scenario where the turbine is directly between the radiating source and the antennae. This scenario is highly unlikely given that signals are being received from space and the required horizon.

6.7 Blocking of Existing Noise Sources

If there are existing noise sources originating from beyond the wind farm, i.e. to the northeast of the centre of the array, the interfering signals may be partially blocked by the wind turbines. Therefore, the turbines could potentially reduce the magnitude of existing interference signals in this way. As shown in the previous subsection, such losses would be less than 3 dB and would therefore be unlikely to have significant effect in this way.

[8] The latest version is ITU-R P526-15
[9] Also referred to as Shadowing or Obstruction losses

6.8 Line of Sight Analysis Conclusions

The wind turbines will be considerably within line of sight to the LOFAR antennae.

The elevation angle to the turbine tip ranges from approximately 1.8 degrees to 2.3 degrees, an increase of approximately 0.3 compared to the current maximum obscuration from the terrain. Therefore, the obscuration of the horizon due to the proposed development is not predicted to be an issue for LOFAR.

The losses in field strength due to signal blocking is likely to be approximately 2.9 dB for a radio source which is completely obstructed by the turbine. Considering the low angle of the shadows and small losses in signal strength, no significant impacts from shadowing are predicted.

7 ANALYSIS – REFLECTION OF EXISTING NOISE SOURCES

7.1 Overview

Existing terrestrial sources of radio emissions produce interference, or 'noise', which in some cases is detected by LOFAR. These sources are understood to include electric power cables, pirate radio, passing traffic and lawnmowers. It should be noted that ASTRON has already developed methods for filtering out unwanted interference from local sources.

Radio emissions which cause such disturbances can be reflected by the wind turbine tower and blades. Therefore, it is possible that the amount of interference detected by LOFAR will increase as a consequence of the turbines due to reflections of these interfering signals.

7.2 Most Significant Noise Source

For the purposes of this analysis, radio signals from a transmitting location in Kilduff are considered to be the most significant noise source. This is because it is located approximately 29km south and within line-of-sight of the LOFAR[10]. The transmitter details used for this assessment are shown in Table 3 below.

Parameter	Value	Source
Location	206115E 175994N	Approximate location of transmitter extrapolated from Google Earth in Irish National Grid.
Height above ground	56.1m	https://ukfree.tv/transmitters/tv/Kilduff (Accessed April 2022) and SRTM terrain data.
Frequency	554 – 602 MHz	https://ukfree.tv/transmitters/tv/Kilduff

Table 4 *Kilduff transmitter data for calculation*

Diffraction losses due to terrain are considered insignificant between the transmitter and the turbines, as the transmitter will have clear line of sight to the turbine hub. However, losses due to terrain between the transmitter and the LOFAR antennae are potentially significant as these are low to the ground, meaning that signals may be attenuated by terrain. Therefore, the diffraction losses between the transmitter location and the LOFAR have been accounted for.

[10] Cairn Hill and Maghera transmitters were considered but are not in line-of-sight of the LOFAR and are therefore not considered to cause significant reflection issues.

7.3 Carrier to Interference Ratio (CIR)

When determining whether a turbine is likely to interfere with radio reception, the Carrier to Interference Ratio (CIR) is considered.

The receiver is considered to receive two signals, one directly from the transmitter and one that is reflected from the wind turbine. The CIR is expressed in decibels (dB). When assessing radio systems such as television transmitters, the CIR is a measure of how strong the wanted signal is compared to the unwanted signals. In this case, the carrier signal is not a wanted signal, but the CIR is still a measure of the increase in noise levels due to the turbines.

The carrier to interference ratio has therefore been calculated at the centre of the LBA. For the turbine the height of the reflecting point is taken as that of the base of the hub height.

7.4 Establishment of Radar Cross Section

There is not a generally accepted method available for modelling the effects of multiple turbines on CIR. This is because:

- RCS varies considerably and cannot be predicted at a specific time for a specific direction;
- Signals reflect from turbine to turbine.

RCS is dependent on a number of factors including shape, size, material and angle of incidence. For complex objects RCS can vary significantly, with very small changes in angle of incidence. Typical RCS values for some common objects are shown in Table 5 below.

Object	Radar Cross Section (m^2)
Small single engine aircraft	1
Jumbo Jet	100
Car	100
Man	1
Pickup Truck	200

Table 5 *Typical RCS Values*

There has been a lot of work carried out to determine the Radar Cross Section of a wind turbine, and there are a number of computer models available. Nevertheless, there is no generally accepted method for determining a conservative RCS value for general calculation purposes. Various values are used by various organisations. Some of these are shown in Table 6 on the following page.

Source	Radar Cross Section of a single wind turbine (m^2)
UK Radio Communications Agency Example	30
Wind Turbine tower where reflection is not perpendicular to tower – general values – ETSU Report	100 (S Band[11]) 1000 (L Band[12])
Wind Turbine Rotor – general values – ETSU Report	10 – 1000 (S Band) 1000 (L Band)
Measured values from single turbine at Swaffham – FES Report	50 (approximate average) – 2,800 (Worst Case)

Table 6 *Wind Turbine RCS Values*

It can be seen that there is a wide range of values. For modelling purposes, we will use a typical value of 1,000. This is considered to be a conservative figure, especially as the static reflective component is often of less interest.

7.5 Calculations – Reflection Issues

Table 7 below shows the results of the calculation and the proportion of the signal strength received at the antenna location being due to reflections from the turbine. The calculation sheets are shown in Appendix C.

Turbine	CIR (dB)	Proportion
T01	51.5	<0.001%
T02	50.2	0.001%
T03	52.3	<0.001%
T04	50.9	<0.001%
T05	52.1	<0.001%
T06	51.3	<0.001%
T07	51.3	<0.001%

[11] Band 1 – 2 GHz
[12] Band 2 – 4 GHz

Turbine	CIR (dB)	Proportion
T08	52.1	<0.001%

Table 7 *CIR Calculations for Kilduff transmitter*

The values in the table above indicate that the increase in noise from existing sources, based on a single turbine, will be 0.001% or less. However, it is necessary to consider the cumulative effect of the other turbines. Pager Power is unaware of any formal guidelines for assessment of cumulative effects on CIR due to reflections. One method advocated by the Joint Radio Company in the United Kingdom for analysis of telemetry links is using the formula:

$CIR_{cumulative} = CIR_{single\ turbine} - 10 \log_{10}$ (no. of turbines) dB

Based on the above calculation, the cumulative CIR for the proposed development is taken to be 41.2 dB. This means that the increase in noise from existing sources, based on all turbines, will be less than 0.01%.

7.6 Reflection of Wanted Radio Signals

Technically, the wind turbines have the potential to reflect the radio signals received from space. This could cause the same signal to arrive at different times at a receiver location (multi-path effect). However, it is considered highly unlikely that a measurable amount of energy would be reflected in this way. Furthermore, the difference in path length for the direct and indirect signals is negligible.

No issues are foreseen with regard to reflection of wanted signals.

7.7 Reflection Issue Conclusions

Based the calculations carried out for the Kilduff transmitter, a cumulative CIR of 41.2 dB has been calculated, which means that the increase in existing noise sources experienced by the LOFAR will be less than 0.01%. Therefore, the increase in noise due to reflections from the proposed development will be negligible.

No issues with regard to reflection of wanted signals are anticipated.

8 ANALYSIS – RADIO EMISSIONS FROM TURBINES

8.1 Overview

All commercial wind turbines which are installed in Ireland, and elsewhere in Europe, must meet emissions criteria in order to comply with legal requirements relating to health and spectrum licencing. It is understood that there are currently no formal guidelines with regard to emissions criteria in the vicinity of LOFAR.

IEC 61000-6-4[13] (2018) guidelines state that the industrial limit for frequencies in the range of 30 – 230 MHz is 40 dBµV/m at a distance of 10 m. It is anticipated that this limit will not be conservative enough for ASTRON's requirements with regard to LOFAR; however, it is appropriate to be used as a reference point.

8.2 Typical Turbine Emissions

Emissions from wind turbines are dependent on the specific manufacturer. However, in Pager Power's experience, indicative fluctuation fields across the 30 MHz – 300 MHz and 30 MHz – 1000 MHz frequency ranges are:

- 30 MHz – 300 MHz - Mostly between 5 dBµV and 50 dB dBµV with spikes up to approximately 75 dBµV, across the whole spectrum;
- 30 MHz – 1000 MHz - Spikes of up to approximately 78 dBµV, at the higher frequency end of the spectrum.

It is understood that some trials have found there is no difference between the emissions of a wind turbine generating electricity and the results with the turbine not generating electricity (reference measurement), implying that the levels measured represent the background spectrum only.

8.3 Calculation Process

In order to calculate the worst-case field strength at an antenna location it is important to sum the contributions from all turbines. The calculation process is therefore as follows:

1. Assume every turbine is producing a field strength of 35.6 dB at 30m from the turbine, accounting for the fact that this is a distance of approximately 119m from the nacelle;
2. Convert this to an absolute value (3.63 mVm^{-1});
3. Extrapolate the resulting field strength at the antenna location, for each turbine, based on distance and a field strength that falls away in proportion to the square of the distance;
4. Sum the contributions from all turbines;
5. Convert back to decibels.

[13] Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments.

8.4 Field Strength Calculations

Table 5 below shows the results from the centre of the LBA cluster.

Turbine	Horizontal Distance Turbine (km)	Field Strength due to Turbines (dBµV/m)
T1	5.72	19.4
T2	5.01	20.0
T3	6.18	19.1
T4	5.41	19.6
T5	6.14	19.1
T6	5.66	19.5
T7	5.67	19.4
T8	6.14	19.1

Table 8 *Turbine Field Strength Emissions*

The table shows T2 (the closest turbine to the antennae) produces a field strength of 20.0 dBµV/m. The calculation method is conservative, as described above. Furthermore, it is important to note that these high emissions are not present across the entire frequency spectrum, rather there are spikes at specific frequencies. Such spikes are present in the background spectrum also, and the typical deviation from the baseline environment is likely to be significantly less than the calculations show.

The calculations show values of up to 20.0 dBµV/m. This is less than a fifth of the average field strength of a mobile phone using 3G at a distance of 5cm (107 dBµV/m). Such levels are unlikely to make the development detectable to LOFAR.

8.5 Emissions from Cables and Grid Connection

Pager Power has not modelled the electric and magnetic fields associated with underground cables and a grid connection point. It is considered highly likely that fields associated with underground cables will be significantly less than the emissions associated with the turbines themselves.

8.6 Radio Emission Conclusions

Any electric and magnetic emissions from the turbines will be insignificant at the LOFAR site. This is because the emissions are small, due to their compliance with International Electrotechnical Commission standards, and because they reduce significantly with distance. Any emissions from the turbines will therefore be significantly smaller than emissions from closer sources, such as vehicles, mobile phones, buildings, machinery, home appliances, etc. in and around Birr.

Furthermore, the telescope site is a single remote node which is part of a large European telescope, with its main receiver site located in the east of the Netherlands. This means that any interference that affects just one node, without affecting the core telescope site, is likely to be filtered out when received signals from multiple sites are combined and processed.

9 OVERALL CONCLUSIONS

9.1 Technical Findings

The proposed wind turbines as obstructions will reduce the minimum horizon of the LOFAR antennae. The elevation angle from the antennae to the turbine tip ranges from approximately 1.8 degrees to 2.3 degrees, an increase of approximately 0.3 degrees compared to the current maximum obscuration from the terrain. The presence of the turbine will therefore have a technical impact on the lowest unobscured angles; however, the change is small and likely to be insignificant because the elevation angles required for actual astronomical data are likely to be larger than the angle to the turbine blade tips.

A sample calculation has been undertaken to establish the loss in field strength due to a turbine tower as an obstruction for a radio source at 120 MHz. This has indicated an average value of 2.9 dB. This will result in a slight weakening of signals at low levels, directly beyond the turbines.

Sample reflection calculations to quantify the potential increase in existing terrestrial noise sources have indicated cumulative CIR of 41.2 dB. In this context, the carrier signal is the existing noise source and the interference signal is the reflection of this noise from the turbines. The increase in existing noise sources will be of the order of 0.01%.

Based on the typical emissions emitted from the turbines, field calculations of extrapolated field values for the nearest turbine indicated values of up to 20.0 dBµV/m. Emissions from the turbines are therefore not predicted to be significant because the emissions are small, due to their compliance with International Electrotechnical Commission standards, and because they reduce significantly with distance. Any emissions from the turbines will therefore be significantly smaller than emissions from closer sources, such as vehicles, mobile phones, buildings, machinery, home appliances, etc. in and around Birr.

9.2 Overall Conclusion

Based on assessment of the three primary mechanisms for potential impacts of wind turbines on LOFAR, the proposed development is not predicted to have a significant impact on the I-LOFAR.

The assessment is based on first principles and typical safeguarding processes for radio equipment. The operational considerations around astronomy using such telescopes is complex, high specialised and evolutionary. It is recommended that the operator of the I-LOFAR is consulted to understand their position regarding the project and this assessment.

APPENDIX A – WIND TURBINE DETAILS

Turbine Details

The coordinates and max tip height altitudes of the proposed wind turbines are shown in the table below. Terrain heights were extrapolated from SRTM data.

Turbine	Easting (Irish National Grid)	Northing (Irish National Grid)	Tip Height (amsl m)
T1	206797	210446	246.9
T2	206312	209829	246.7
T3	207351	210753	248.3
T4	207060	210033	246.7
T5	207922	210465	246.7
T6	207844	209967	248.9
T7	208286	209735	251.9
T8	208427	210195	250.8

Wind turbine details

APPENDIX B – ATTENUATION CALCULATIONS

Diffraction Loss Calculation					
Birr, Co. Offaly					
Frequency (GHz)	**0.12**				
Wavelength (m)	**2.49827**				
			1	**2**	**3**
Distance from Antenna 1 to blocking point (m)			**100000**	**100000**	**100000**
Distance from Antenna 2 to blocking point (m)			**6134**	**6134**	**6134**
Height of blocking point (m)			**78.77**	**3**	**3**
		v	0.927068	0.035308	0.035308
		J dB	13.44625	6.338483	6.338483
		jv (Loss Factor)	4.702326	2.074551	2.074551
Shielding Loss		**Jmin(v)**	**-1.4135**		
		Jav(v)	**2.924858**		

APPENDIX C – CARRIER TO INTERFERENCE CALCULATIONS

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	1		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
206797	210446		544000000	0.551
Hub Height aod	246.90			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34460.2		
Antenna 2 - WT		5725.4		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.9
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-102.3
CIR (dB)				**51.5**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	2		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
206312.00	209829		544000000	0.551
Hub Height aod	246.70			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		33837.0		
Antenna 2 - WT		5010.6		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.8
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-101.2
CIR (dB)				**50.2**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	3		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
207351	210753		544000000	0.551
Hub Height aod	248.30			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34782.4		
Antenna 2 - WT		6186.0		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-118.0
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-103.0
CIR (dB)				**52.3**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	4		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
207060	210033		544000000	0.551
Hub Height aod	246.70			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34053.5		
Antenna 2 - WT		5410.5		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.8
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-101.8
CIR (dB)				**50.9**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	5		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
207922	210465		544000000	0.551
Hub Height aod	246.70			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34519.7		
Antenna 2 - WT		6140.6		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.9
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-102.9
CIR (dB)				**52.1**

Birr, Co. Offaly LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	6		Radio System	
Easting	Northing		Frequency (Hz)	Wavelength (m)
207844.00	209967		544000000	0.551
Hub Height aod	248.90			
Antenna 1			Antenna 2	
Kilduff Transmitter			LBA	
Easting	Northing		Easting	Northing
206115.18	175993.5		205263.26	204933.49
Height aod	499		Height aod	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34018.4		
Antenna 2 - WT		5660.2		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.8
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-102.2
CIR (dB)				**51.3**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	7		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
208286	209735		544000000	0.551
Hub Height aod	251.90			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		33812.2		
Antenna 2 - WT		5677.5		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.7
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-102.2
CIR (dB)				**51.3**

Birr, Co. Offaly				
LOFAR Radio Analysis				
Radar Cross Section		1000		
Turbine	8		**Radio System**	
Easting	**Northing**		**Frequency (Hz)**	**Wavelength (m)**
208427	210195		544000000	0.551
Hub Height aod	250.80			
Antenna 1			**Antenna 2**	
Kilduff Transmitter			**LBA**	
Easting	**Northing**		**Easting**	**Northing**
206115.18	175993.5		205263.26	204933.49
Height aod	499		**Height aod**	46
		Distance		
Antenna 1 - 2		28956.1		
Antenna 1 - WT		34280.4		
Antenna 2 - WT		6142.9		
Net Antenna Interference Rejection (dB)			0	
Amount by which forward gain exceeds interference path gain. Enter 0 for Isotropic				
RCS Factor				46.2
Main Signal (Path Loss, dB)				-116.4
Reflected Signal 1 (Path Loss, dB)				-117.9
Diffraction Loss to Carrier (dB)				-6.1
Diffraction Loss to Interference (dB)				0
Reflected Signal 2 (Path Loss, dB)				-102.9
CIR (dB)				**52.1**

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TECHNICAL MITIGATION MEASURES

Overview

No impacts requiring mitigation upon I-LOFAR have been identified in the Radio Telescope Impact Assessment. Nevertheless, the purpose of this document is to introduce potential mitigation options should an objection be raised by the operator of I-LOFAR.

Any solution would require discussion with the I-LOFAR operator prior to being progressed in order to establish;

1. The operator's amenability to the solution; and
2. The technical feasibility of such a solution.

Potential Mitigation Solutions

The options below should be regarding as starting points for further discussion with the operator:

- Moving turbines further away from the array.
- Reducing the turbine height/elevation.
- Keeping inverters on the side of the development furthest from the array.
- Ensuring the door to the turbine faces away from the array.
- Providing the operator with money to cover the costs of additional antennae to improve the overall performance.
- Provision of a screen that blocks some of the electromagnetic noise.
- Using a turbine manufacturer with the lowest emission data.

Other Considerations

It may be necessary to establish additional mitigation measures with regard to radio interference. Specifically, policies regarding Wi-Fi and mobile phone use on-site should be considered. This may also extend to the use of mobile radios during construction.

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