Technical Appendix 14.1: Desk-Based Television and Radio Interference Assessment

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Urban & Renewables

Desk-Based Television and Radio Interference Assessment

SSE Plc

Glentarken Wind Farm

November 2024

PLANNING SOLUTIONS FOR:

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the potential effects on terrestrial television and radio reception due to a proposed wind turbine located north of St Fillans, Crieff, Scotland. The development consists of 12 turbines with a maximum tip height of 180m above ground level (agl), a hub height of 99m agl, and rotor diameter of 162m.

Conclusions

Terrestrial television are theoretically provided in the surrounding residential areas by Angus main transmitter and Killin, Lochearnhead, St Fillans and Crieff relay transmitters. Radio services are expected to be also provided by additional radio transmitters.

The area immediately surrounding the proposed wind turbine development is rural and relatively sparsely populated. The towns of Killin, Lochearnhead, St Fillans and Dunira are located further from the development. Terrestrial television services provided to these towns are predicted to come from their own respective relay transmitters[1].

The desk-based modelling to identify areas of interference for each transmitter showed that interference is possible in the area behind the turbines relative to each transmitter (forward scatter regions) and some surrounding areas. Interference outside the forward scatter region is not predicted to be attributable to the wind farm and is expected be caused by other factors, such as intervening terrain.

The towns which each transmitter is predicted to serve are outside the interference areas and forward scatter regions. Interference caused by the proposed development is therefore not anticipated.

Noticeable impacts upon radio signals in the surrounding area are not predicted. This is because the assessment area is outside radio coverage.

Mitigation and Recommendations

No requirement for pre-emptive mitigation has been identified. Any reported effects following construction of the development should be investigated with reference to this report, specifically in the context of whether they occur in an area that is in the forward scatter region for the transmitter providing coverage (see Section 3.4 for a technical description).

If interference is experienced following construction of the proposed development, it is recommended that the aerial is directed toward one of the other potential transmitters serving the area. If this does not eliminate the interference, further mitigation solutions are presented in Section 5.

[1] Crieff relay transmitter provides services to Dunira

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 59 countries within Europe, Africa, America, Asia, and Oceania.

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 BACKGROUND

1.1 Introduction

Pager Power has been retained to assess the possible effects on terrestrial television and radio reception due to a proposed wind turbine located north of St Fillans, Crieff, Scotland. The development consists of 12 turbines with a maximum tip height of 180m above ground level, a hub height of 99m agl, and rotor diameter of 162m.

1.2 Development Location and Details

The proposed development location is shown in Figure 1 below – Turbine locations are indicated by light blue markers.

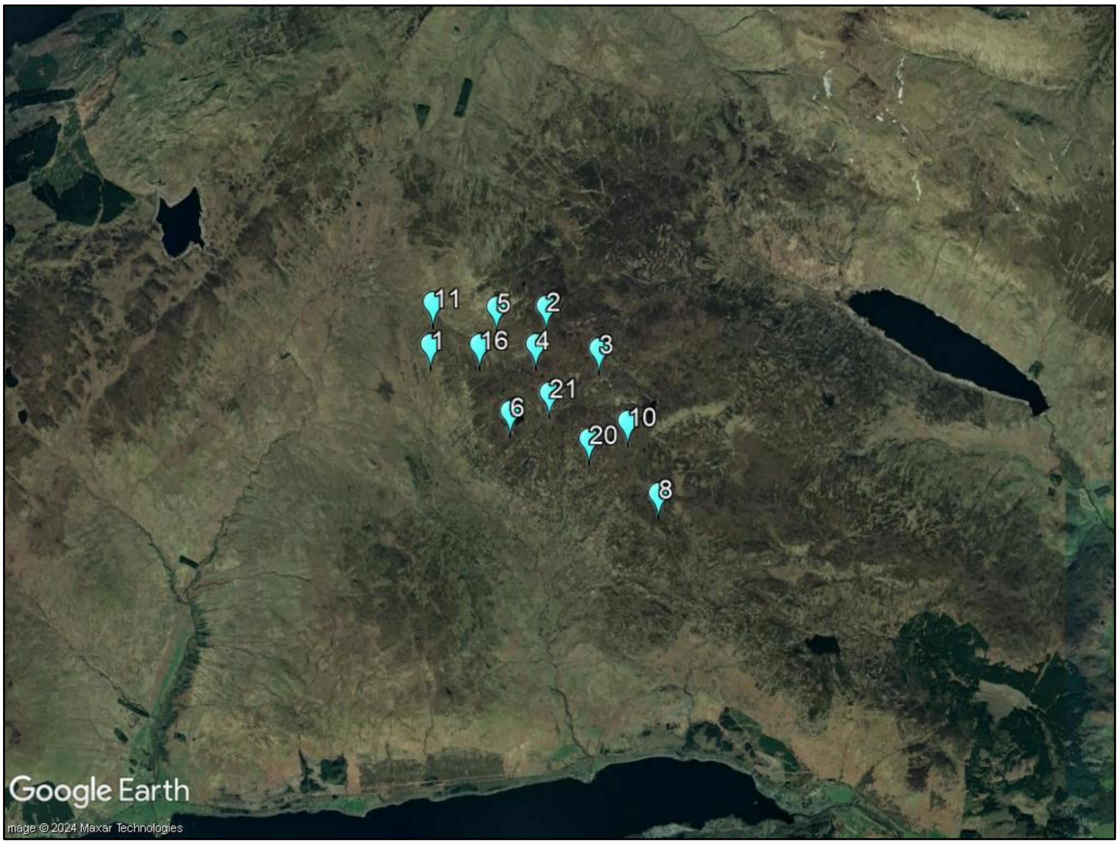

Figure 1 *Proposed turbine location*

Table 1 below shows the proposed turbine coordinates and dimensions.

Turbine	Latitude (°)	Longitude (°)	Tip Height AGL (m)	Hub height AGL (m)
1	56.43952	-4.18762	180	99
2	56.44376	-4.16458		
3	56.43909	-4.15404		
4	56.43954	-4.16666		
5	56.44364	-4.17448		
6	56.43217	-4.17174		
8	56.42314	-4.14221		
10	56.43110	-4.14834		
11	56.44414	-4.18712		
16	56.43953	-4.17784		
20	56.42913	-4.15604		
21	56.43422	-4.16394		

Table 1 *Turbine details*

2 TELEVISION TRANSMITTER DETAILS

2.1 Terrestrial Coverage

Television coverage was investigated via publicly available coverage maps and coverage by postcode via UK Free TV[2] online coverage checker service.

Five transmitters have been identified surrounding the turbine that provide coverage. Angus is the main transmitter for the area. Killin, Lochearnhead, St Fillans and Crieff are smaller relay transmitters that receive signals from Angus and broadcast to the small surrounding towns. The locations of these transmitters are shown in Figure 2.

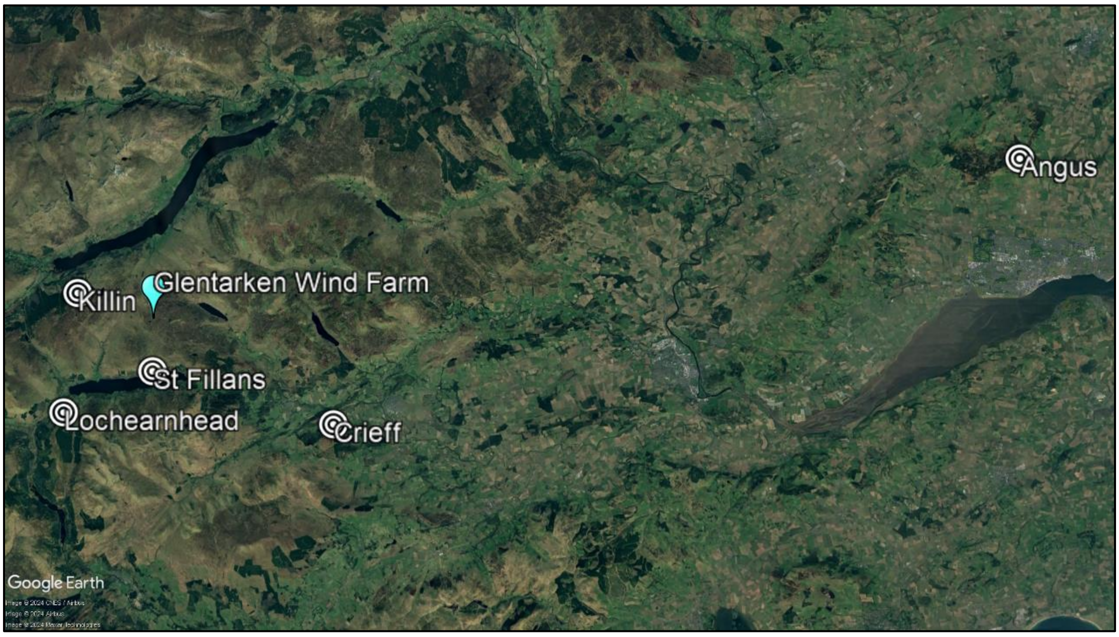

Figure 2 *Relative location of TV transmitters*

The coordinates and heights of each transmitter are presented in Table 2 below.

Transmitter	Easting	Northing	Terrain Height (m)	Mast height (m) (agl)
Angus	339,492	740,800	311.6	234.4
Killin	260,244	731,471	406.7	38.3
Lochearnhead	258,945	722,585	142.7	7.3
St Fillans	266,383	724,782	183.9	31.1
Crieff	281,446	719,991	217.6	49.4

Table 2 *Transmitter coordinates*

[2] Britain's free-to-air national digital television service

Coverage maps[3] of each transmitter, are presented in Figures 3 to 7 below, areas of green indicate strong coverage while areas of grey indicate no coverage. The approximate location of the wind farm is circled in blue. The transmitters do not cover the area of the development. However, they cover some of the assessment area.

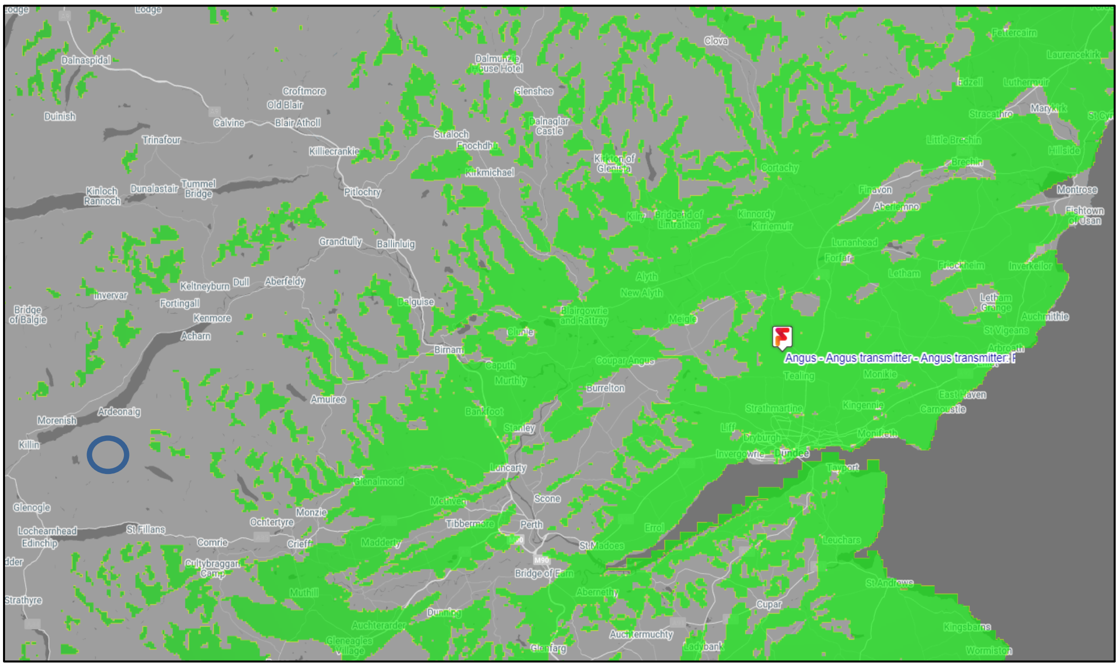

Figure 3 *Coverage from Angus Transmitter*

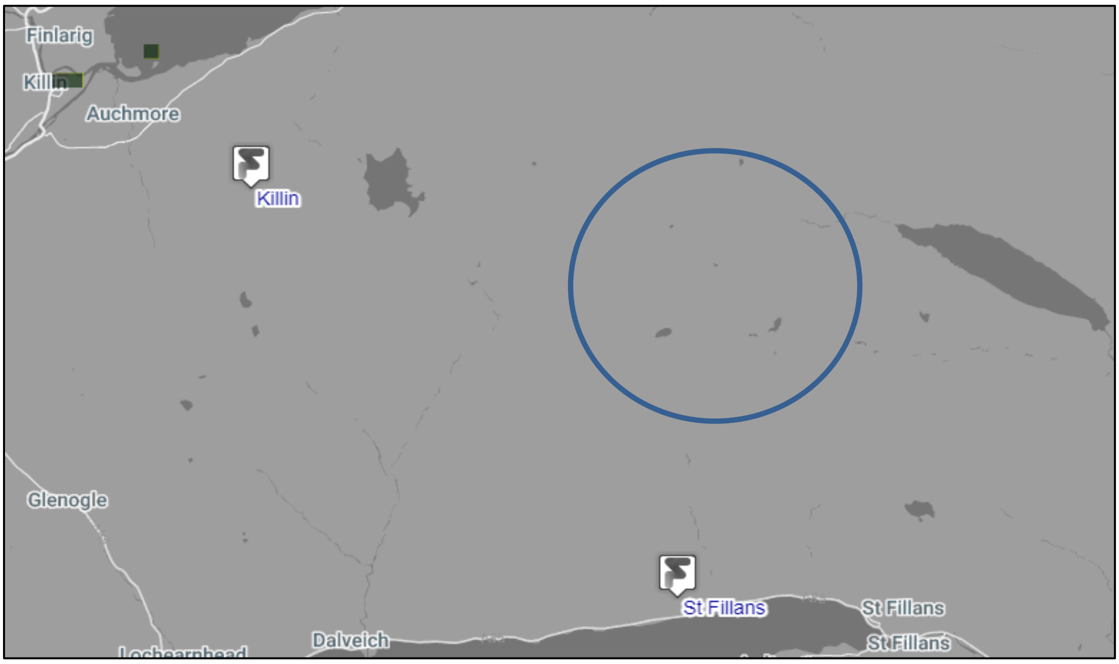

Figure 4 *Coverage from Killin Relay Transmitter*

[3] https://ukfree.tv/maps/freeview

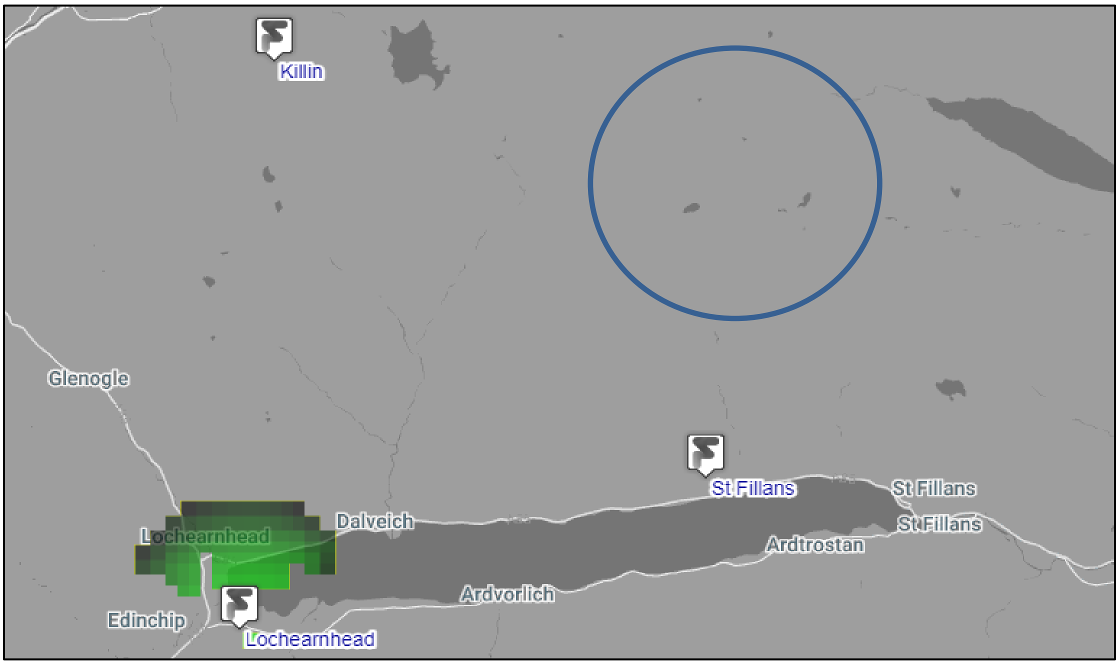

Figure 5 *Coverage from Lochearnhead Relay Transmitter*

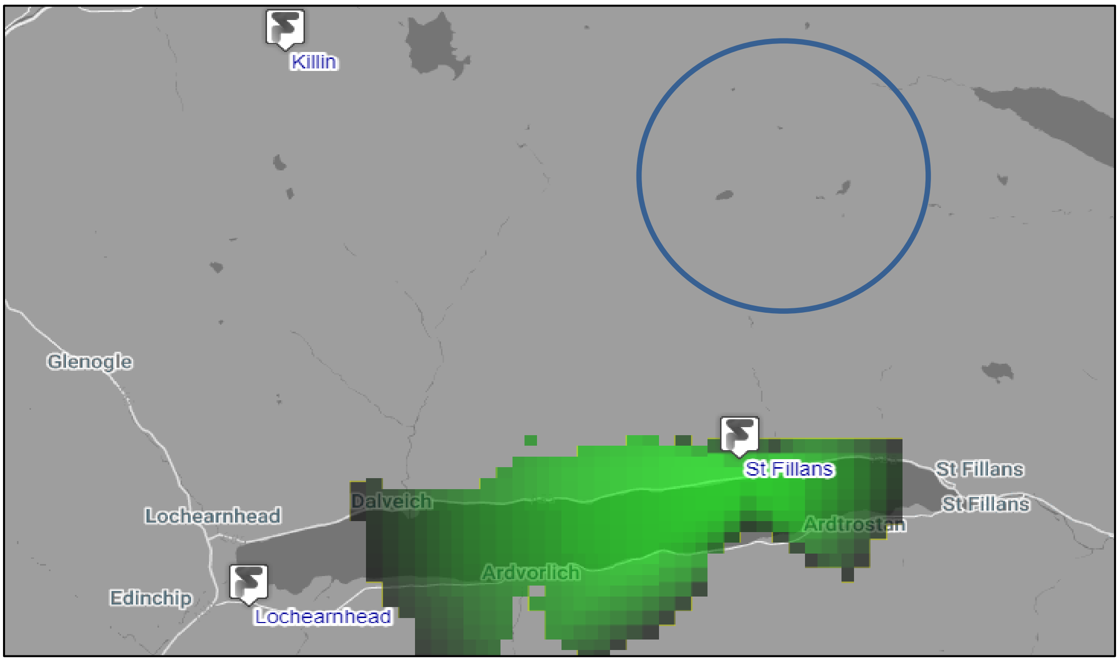

Figure 6 *Coverage from St Fillans Transmitter*

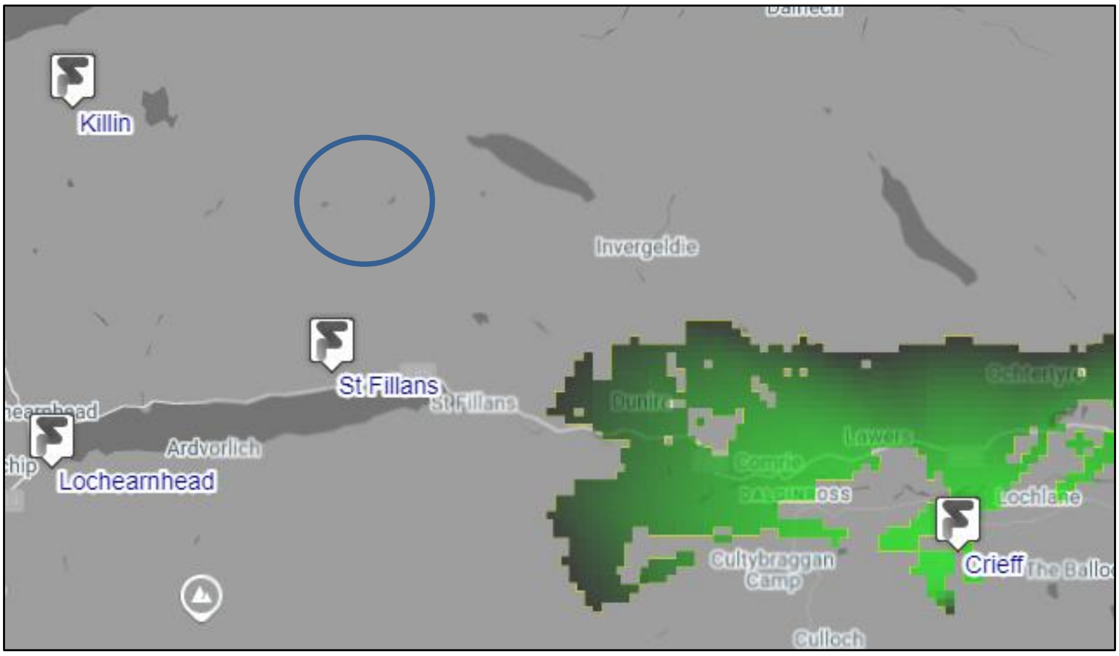

Figure 7 *Coverage from Crieff Relay Transmitter*

Carrier to Interference Ratio (CIR[4]) modelling has been undertaken for all transmitters. The results must be interpreted in the context of available coverage, see Section 4.

In reality, it is likely that a variety of sources provide television services to the wider area including:

- The Angus terrestrial transmitters (modelled in detail).
- The Killin, Lochearnhead, St Fillans and Crieff local relay transmitters.
- Satellites (e.g. Sky).
- The internet (e.g. streaming services).

[4] An industry-standard measure of the likelihood of interference for a broadcast radio signal such as terrestrial television.

3 RADIO TRANSMISSIONS

3.1 Sources

Radio services are provided by numerous transmitters within the UK, including the main television transmitters mentioned in the previous sections.

Radio services are broadcast digitally (DAB services) and as analogue services (such as FM).

3.2 Receivers

Receivers for radio services include mobile users, including within vehicles and dwelling locations. It is possible for dwellings to have external receiving aerials for radio services, although this is relatively uncommon.

It is expected that radio services in the surrounding area will predominantly be provided by the Angus transmitter; however, this is not guaranteed as it is not always straightforward to identify which radio transmitters/sources are serving a particular area. The availability of radio services is primarily established via survey measurements (see Section 6).

4 GUIDANCE

4.1 Guidance used for Modelling

There is little in the way of official guidance with regard to managing television interference issues associated with wind developments. However, there are some publications that warrant consideration when evaluating potential impacts.

Appendix A of this report lists an overview of published works that have informed the modelling approach used within this report.

4.2 Guidance for Evaluating Potential Interference

Further to the publications shown in Appendix A, the most relevant advice for considering potential interference for digital television signals can be found in ITU-R BT.2142-1[5]. Key points within this publication are:

- Small interference signals can be dealt with by a standard antenna whilst larger ones can typically be mitigated by a more directional antenna.
- In the backscatter region[6] there is little effect from scattering from wind turbines on the performance of digital television, but in the forward scattering region, if there is significant blockage of the direct signal, significant interference to the reception of the digital television signal is possible.

The above is not an extensive review of the ITU publication; however, these two points are particularly relevant with regard to quantifying potential interference.

4.3 Susceptibility of Radio Transmissions to Wind Turbine Interference

In principle, radio transmissions are subject to the same interference mechanisms as television transmissions.

Radio services are, in general, more robust to interference than television signals are. This is partly due to the fact that radio services are audio only and partly due to the fact that radio systems are generally designed to operate in a dynamic environment.

Broadly speaking, the interference zones for television services from the identified transmitters will be applicable for radio services from the same transmitter, although the risk of radio interference is judged to be lower.

4.4 Practical Experience

The results of Pager Power's model also compare well with real-world cases. Cases of interference that have been reported post-construction are almost always in areas where potential impacts have been predicted by the model.

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[5] Published in 2010 by the International Telecommunications Union.

[6] In between the transmitter and the wind turbine(s).

In Pager Power's experience, effects from wind turbines on television and radio signals are unlikely beyond distances of 10km.

4.5 Forward Scatter Region

The relevant literature and practical experience both suggest that interference is most likely within the forward scatter region. Figure 8 below, taken from ITU-BT.805, illustrates the forward scatter region.

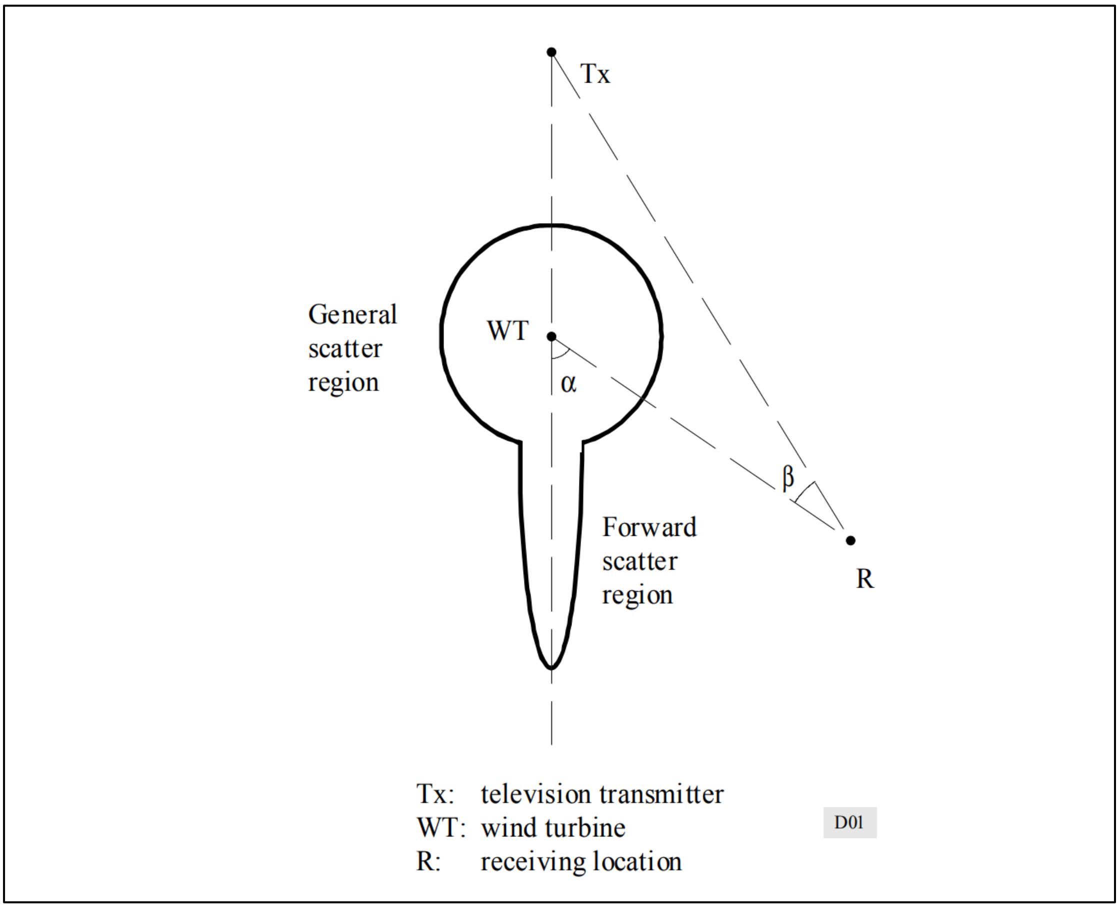

Figure 8 *Plan view of forward scatter region*

As this assessment pertains to multiple transmitters, further details on the forward scatter regions in the context of multiple transmitters is presented below. Figures 9 and 10 on the following page demonstrate the forward scatter regions for two transmitters with respect to a wind turbine development. The blue and orange areas show the forward scatter regions for transmitters 1 and 2 with respect to a notional wind turbine development, respectively.

In this example, the dwelling is in the forward scatter region of transmitter 1; however, it is not in the forward scatter region of transmitter 2. If there is no television reception for the dwelling with respect to transmitter 1, then it is not possible for interference effects to exist for the dwelling with respect to transmitter 1. If the dwelling receives services from transmitter 2, then interference is not predicted from the wind development because it is not in the forward scatter region for that transmitter.

If no television services are currently available from any transmitter for a particular dwelling, then interference effects are not predicted to occur due to the wind turbine development.

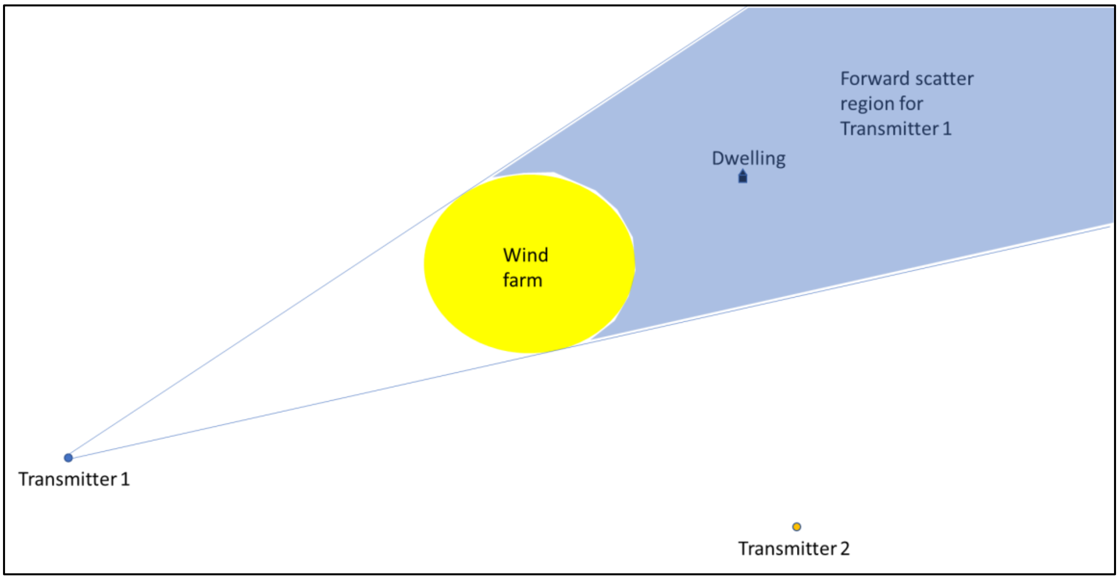

Figure 9 *Forward scatter region for 'Transmitter 1'*

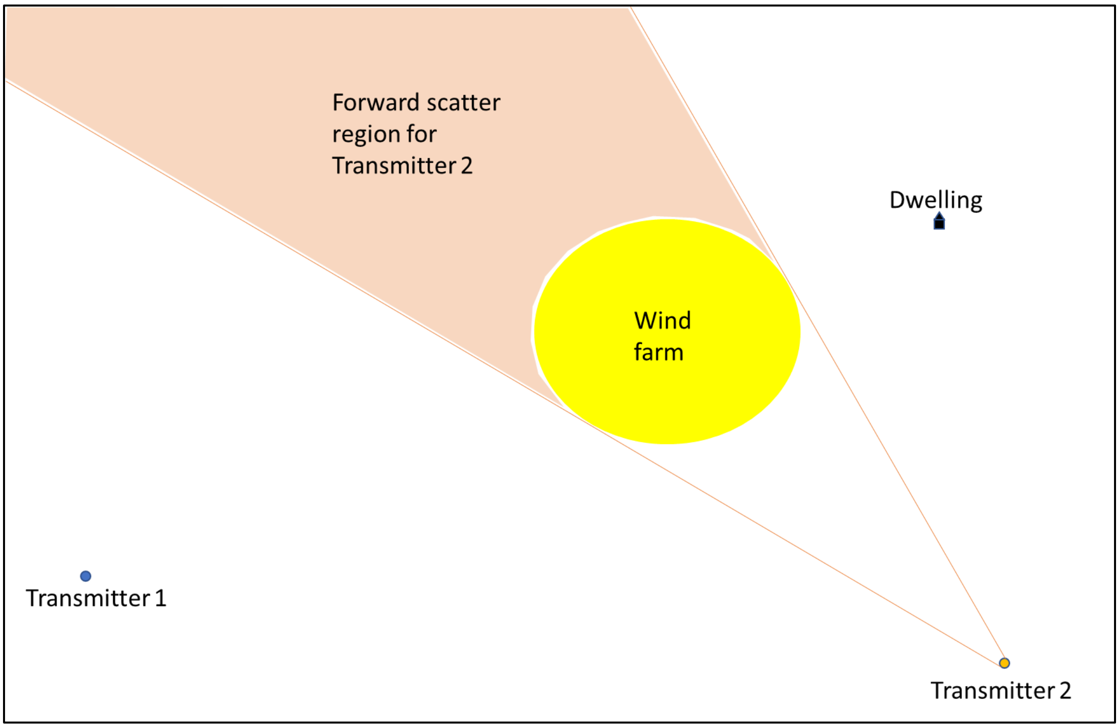

Figure 10 *Forward scatter region for 'Transmitter 2'*

5 ASSESSMENT METHODOLOGY

5.1 Sensitivity of Receptor

The framework for determining receptor sensitivity for the purpose of this assessment are presented in Table 3 below.

Sensitivity of receptor	Definition
Very High	The receptor has little or no ability to absorb change without fundamentally altering its present character, is of very high environmental value, or of international importance.
High	The receptor has low ability to absorb change without fundamentally altering its present character, is of high environmental value, or of national importance.
Medium	The receptor has moderate capacity to absorb change without significantly altering its present character, has some environmental value, or is of regional importance.
Low	The receptor is tolerant of change without detriment to its character, is low environmental value, or local importance. The receptor is resistant to change and is of little environmental value.

Table 3 *Framework for determining receptors sensitivity*

Given that television and radio services have a moderate capacity to absorb change with significantly altering its character (some reduction of signal strength is often not noticeable) and are of high importance, they are classified as having 'Medium' sensitivity level.

5.2 Magnitude of Impact

The framework for defining magnitude of impact for the purpose of television and radio interference assessment are presented in Table 4.

Magnitude criteria	Definition
Large	A fundamental change to the baseline condition of the asset, leading to total loss or major alteration of character.
Medium	A material, partial loss or alteration of character.
Low	A slight, detectable, alteration of the baseline condition of the asset.
Negligible	A barely distinguishable change from baseline conditions.

Table 4 *Framework for determining receptors sensitivity*

The potential effect of wind turbines on television and radio services is the partial or complete loss of information transferred electromagnetic waves which are interfered with by wind turbines, be it the static structure or rotating blade. The effect is dependent on numerous factors including the relative location of the receiving antenna to the wind turbines.

The resulting effect on individual receptors will vary and the magnitude of impact is assessed in Section 6.

5.3 Significance of Effect

The significance of potential effects has been evaluated using a systematic approach, based upon identification of the importance/value of receptors and their sensitivity to the project activity, together with the predicted magnitude of the impact, as shown in the following table.

The terms used to define receptor sensitivity and magnitude of impact are based on the results of the two-dimensional calculations. These criteria have been adopted in order to implement a specific methodology for telecommunications.

For the purposes of this assessment, potential effects identified to be of moderate significance or above are considered to be significant in EIA terms and additional mitigation will be required. Effects identified as less than moderate significance are generally considered to be not significant in EIA terms.

Magnitude of Impact	Sensitivity of receptor			
	Very high	High	Medium	Low
High	Major	Major	Moderate	Moderate
Medium	Major	Moderate	Moderate	Minor
Low	Moderate	Moderate	Minor	Negligible
Very Low	Minor	Minor	Negligible	Negligible

Table 5 *Matrix for determining significance of effect*

6 TELEVISION INTERFERENCE ANALYSIS

6.1 Technical Overview (Terrestrial TV)

Terrestrial television services are provided by means of Ultra-high frequency (UHF) radio waves which propagate from transmitters to receiving aerials which then relay the signal to a television set. The quality of the image and sound on a television set is dependent on the strength of the signal received directly from the transmitter (Carrier signal) and the strength of interference signals from other sources. Here, the interference signals are modelled as reflections of the Carrier signal by the turbine.

Pager Power's methodology for assessment of interference effects was developed based on evaluation of the predicted CIR. Whilst this parameter is related to analogue services, the interference mechanisms for digital transmissions are similar to those for analogue transmissions. The main difference is the manner in which the interference is manifested on the television screen. Analogue signals may suffer degradation that reduces the signal quality by causing various effects such as ghosting or flickering. Digital transmissions tend to be robust to small amounts of interference, but are drastically affected by more severe interference. The interference zones modelled here are equally applicable to digital transmissions as analogue transmissions. The CIR is interpreted as shown in Table 6 below.

Colour	CIR (dB)	Interference Level	Likelihood of Interference
Red	<5	High	Likely
Yellow	5 – 15	Medium	Possible
None	>15	Low	Unlikely

Table 6 *Interpreting the CIR*

The CIR is evaluated by taking the ratio of the predicted signal strength (provided directly from the transmitter) to the predicted interference signal strength (reflections from the turbine). More detail on the calculation method can be found in Appendix A. The television interference model used for the analysis is considered to be conservative.

6.2 Terrestrial Television Interference Modelling

Analysis of an approximately 400km^2 area centred on the proposed development has been undertaken. This area is defined by the coordinates shown in Table 7 below.

Boundary Point	Easting	Northing
Top Right	276,532	739,259
Bottom Left	256,532	719,259

Table 7 *Boundary coordinates*

Figure 11 below shows the modelled area (white outline). The turbine locations are shown for reference purposes.

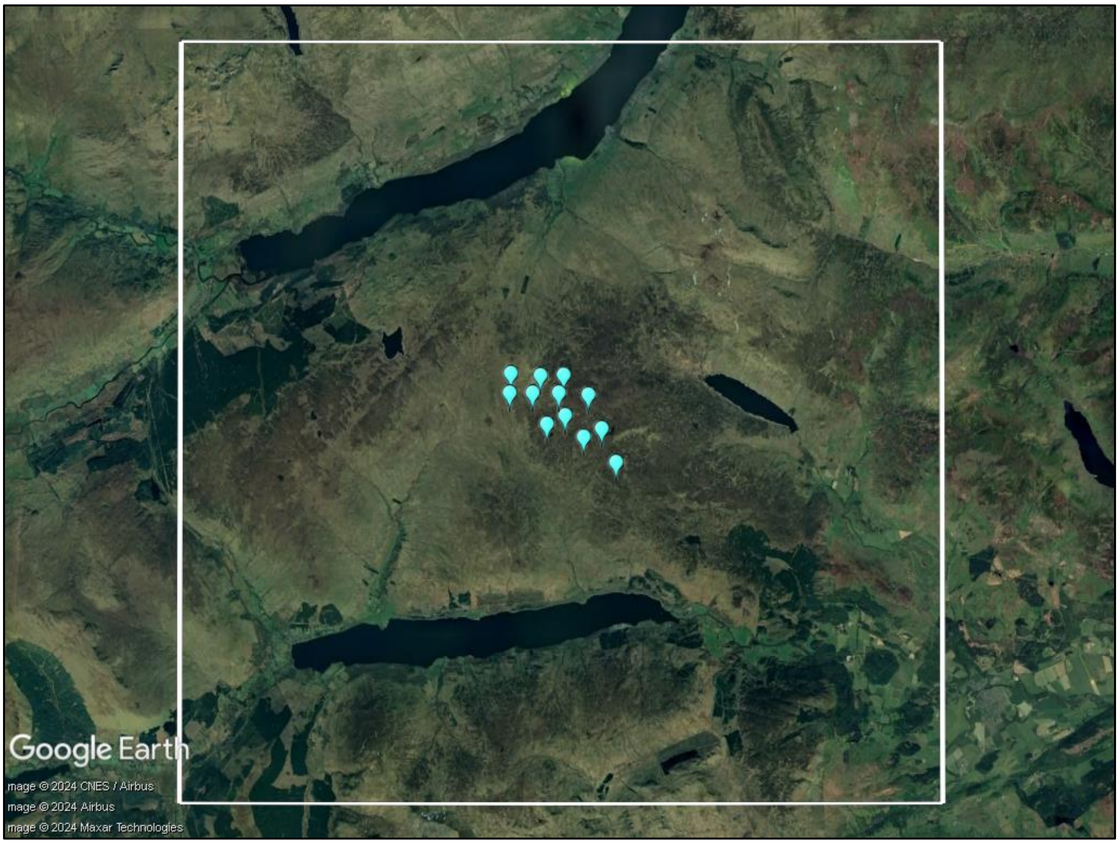

Figure 11 *Modelled area*

Figure 12 to 16 on following pages show the modelling output for the Angus, Killin, Lochearnhead, St Fillans and Crieff transmitters respectively. While figures 17 to 21 show the points where medium (yellow), or high (red) interference is predicted for each transmitter, overlaid onto imagery of the area. The green area represents the region covered by the relay transmitter. Figure 22 show the radio coverage of Angus transmitter. The blue area represents the region covered by Angus DAB.

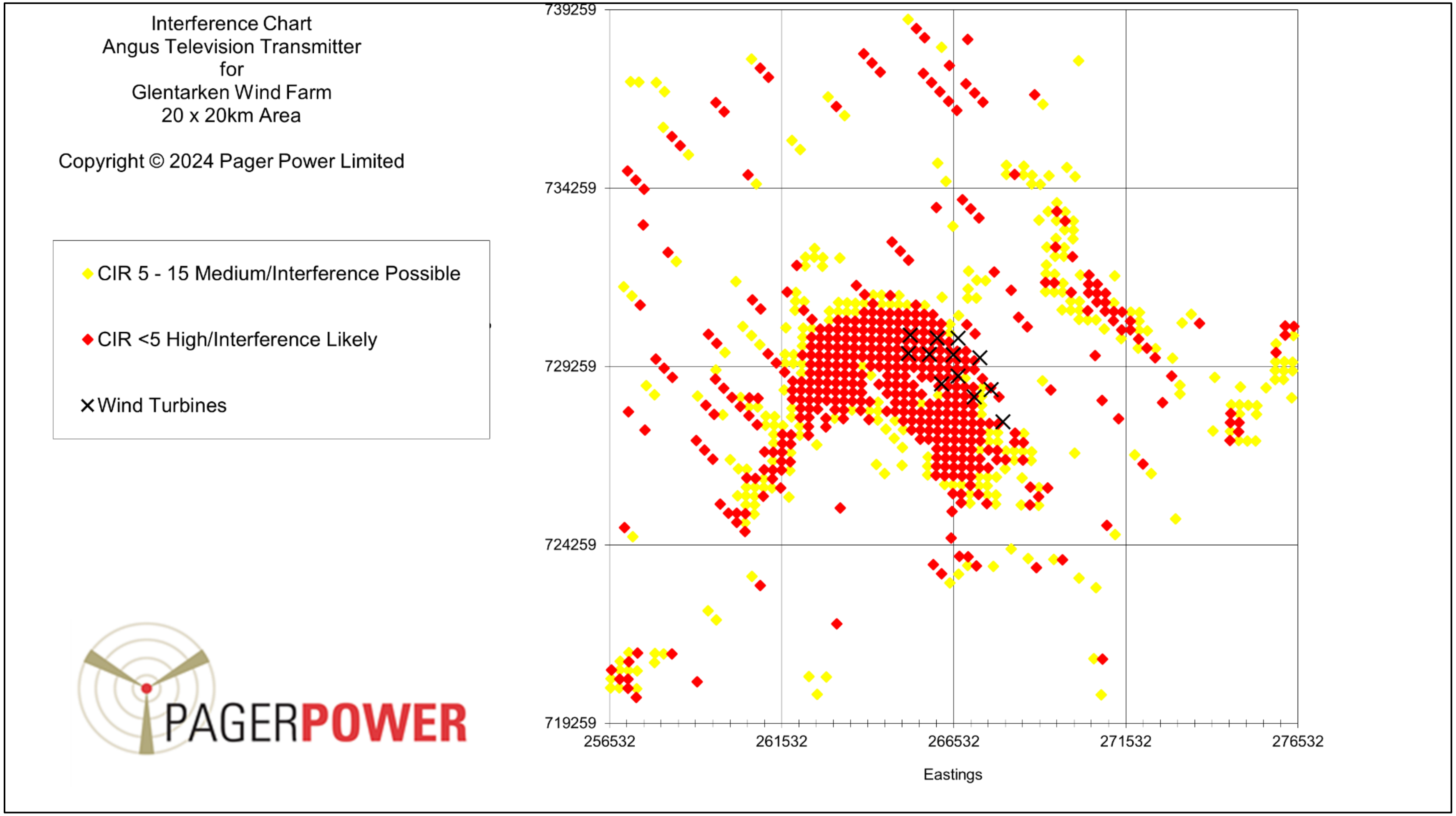

Figure 12 *Interference modelling (Angus)*

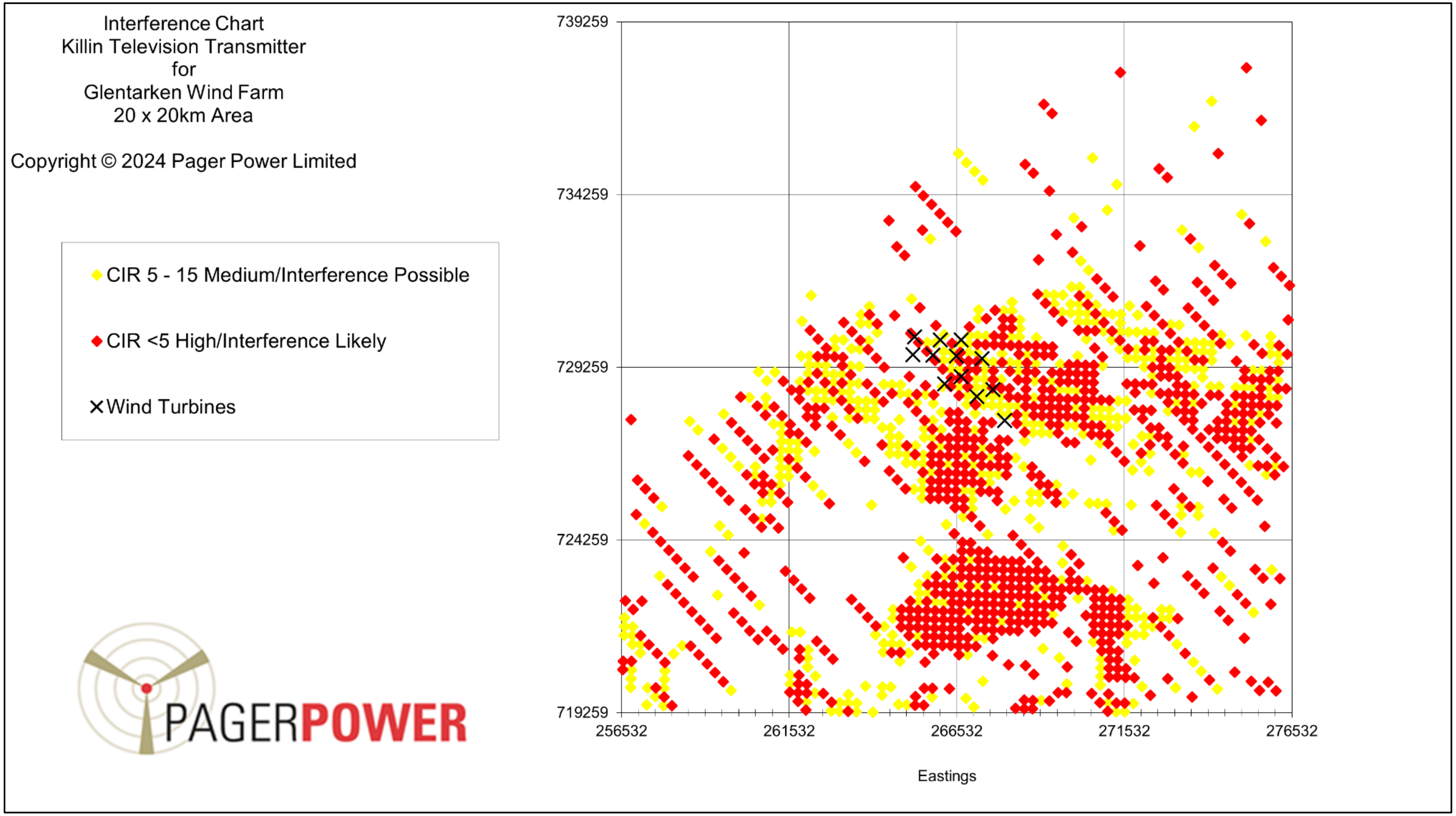

Figure 13 *Interference modelling (Killin)*

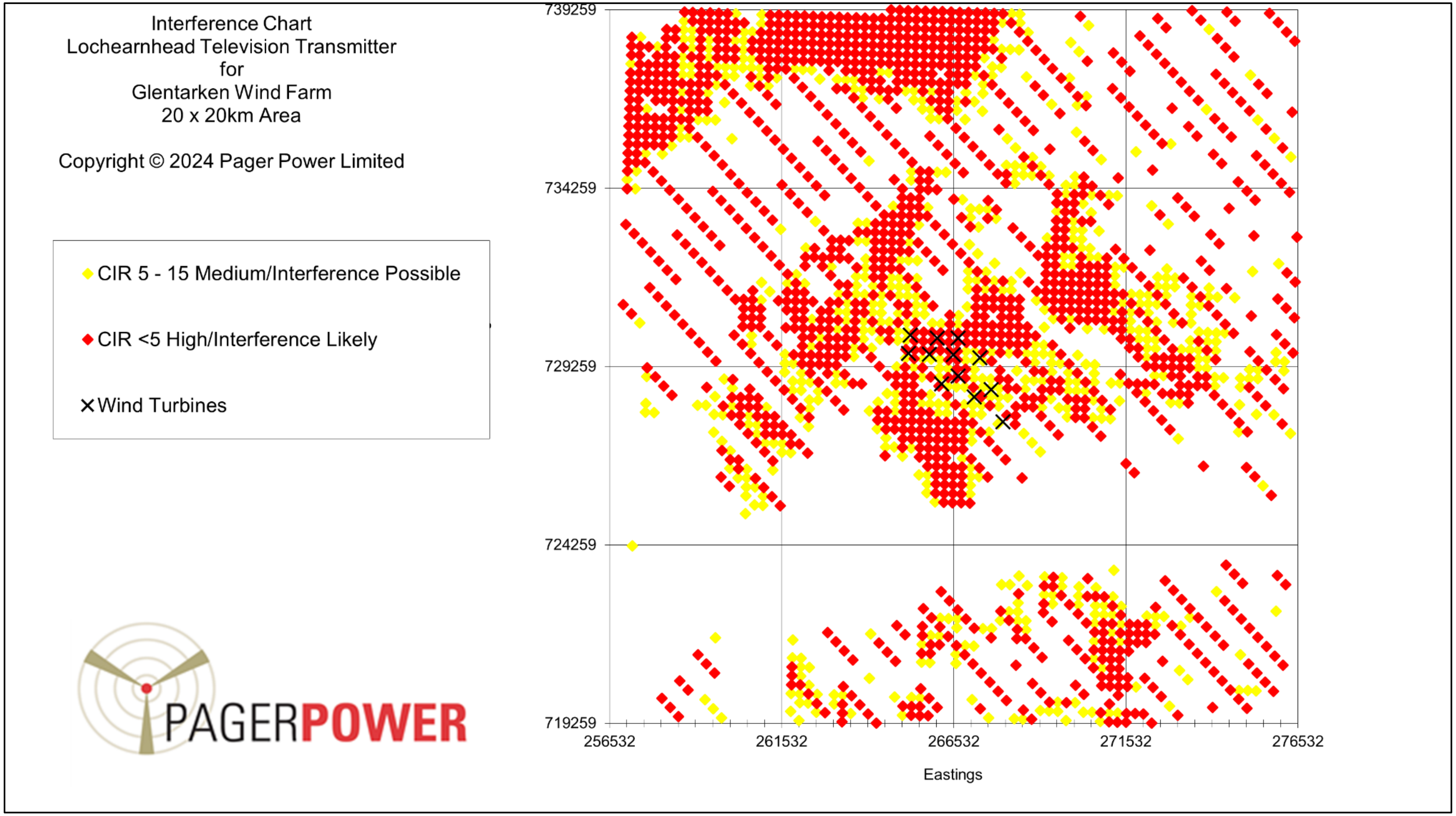

Figure 14 *Interference modelling (Lochearnh)*

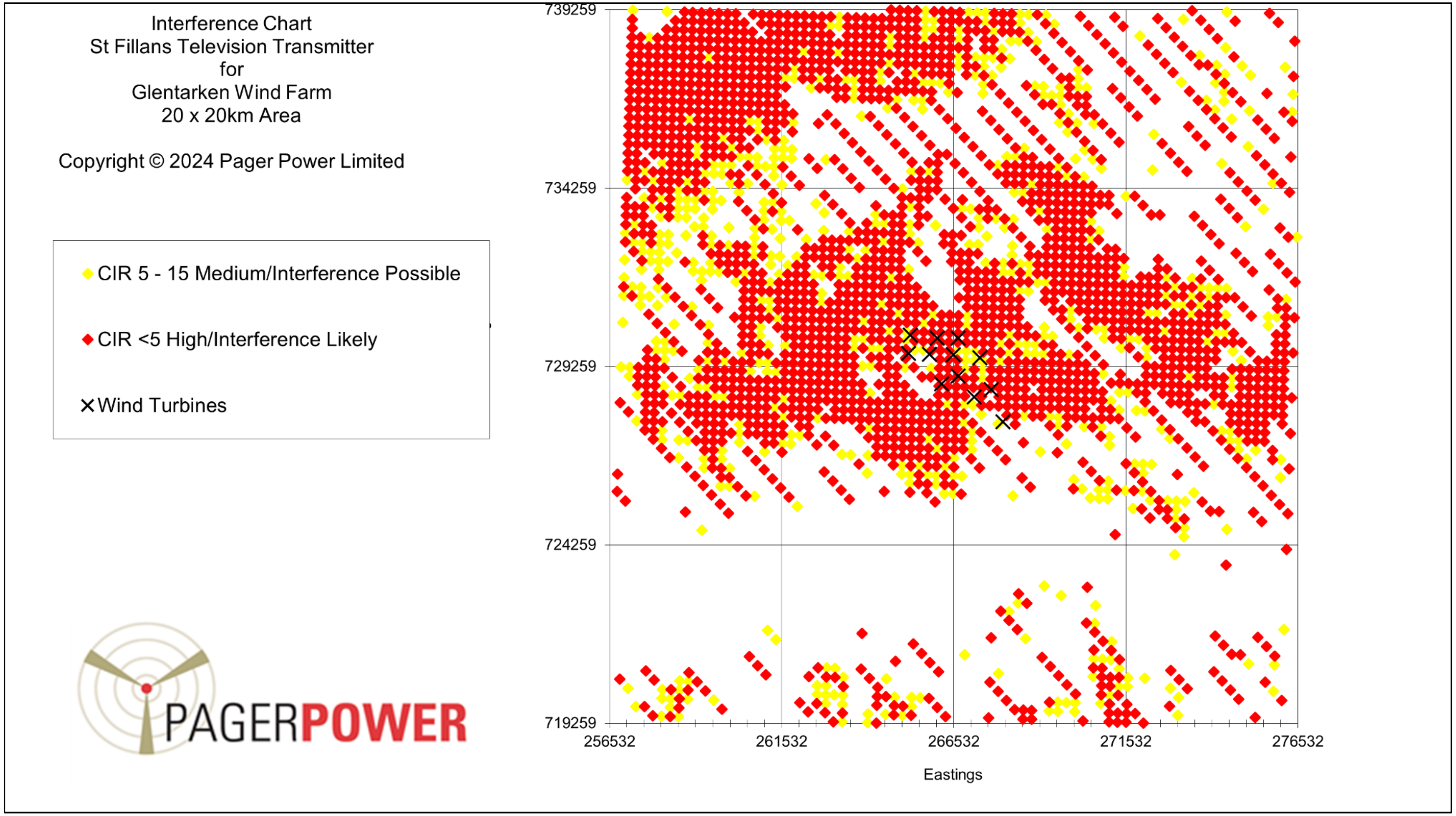

Figure 15 *Interference modelling (St Fillans)*

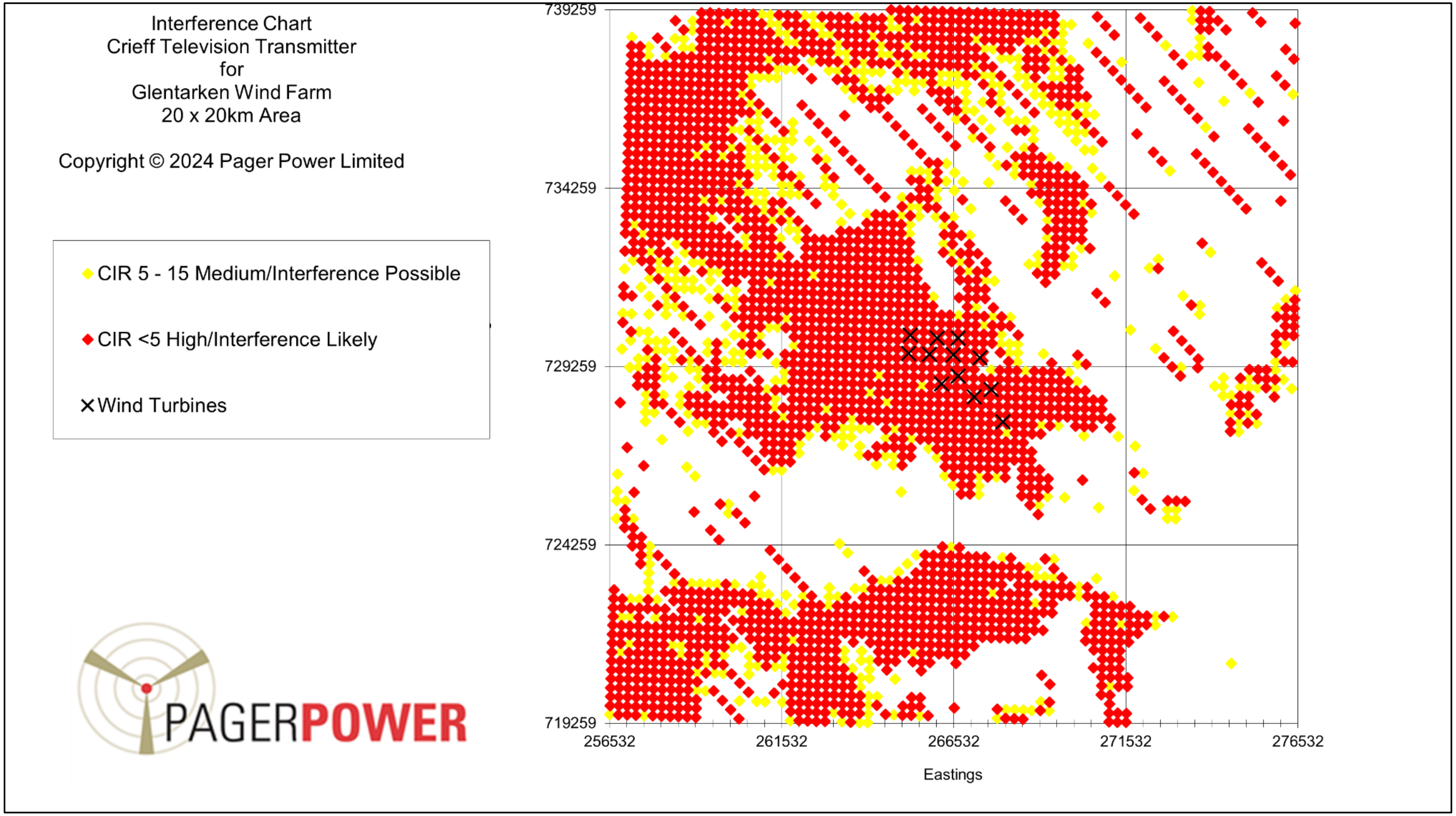

Figure 16 *Interference modelling (Crieff)*

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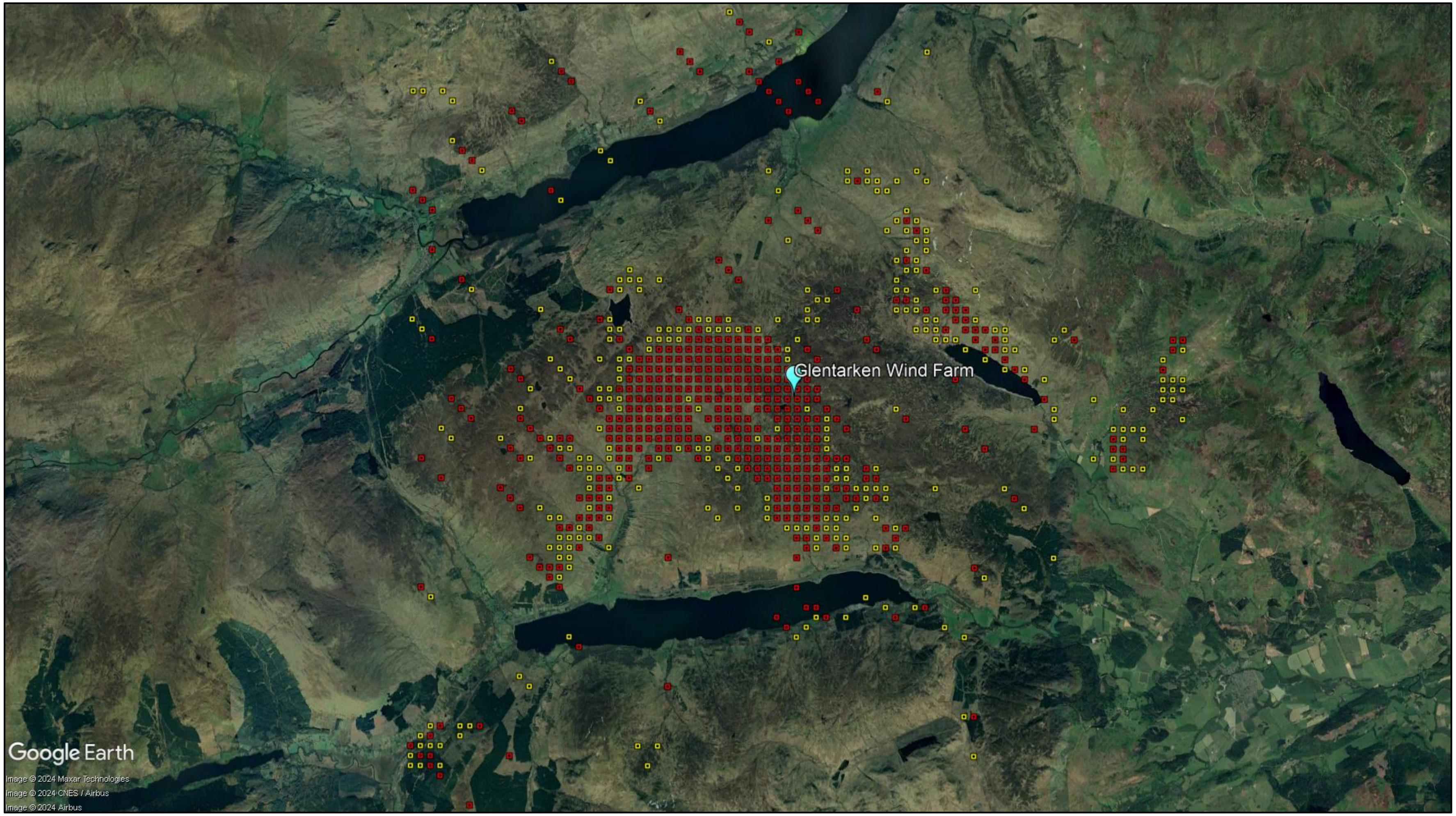

Figure 17 *Interference in context (Angus)*

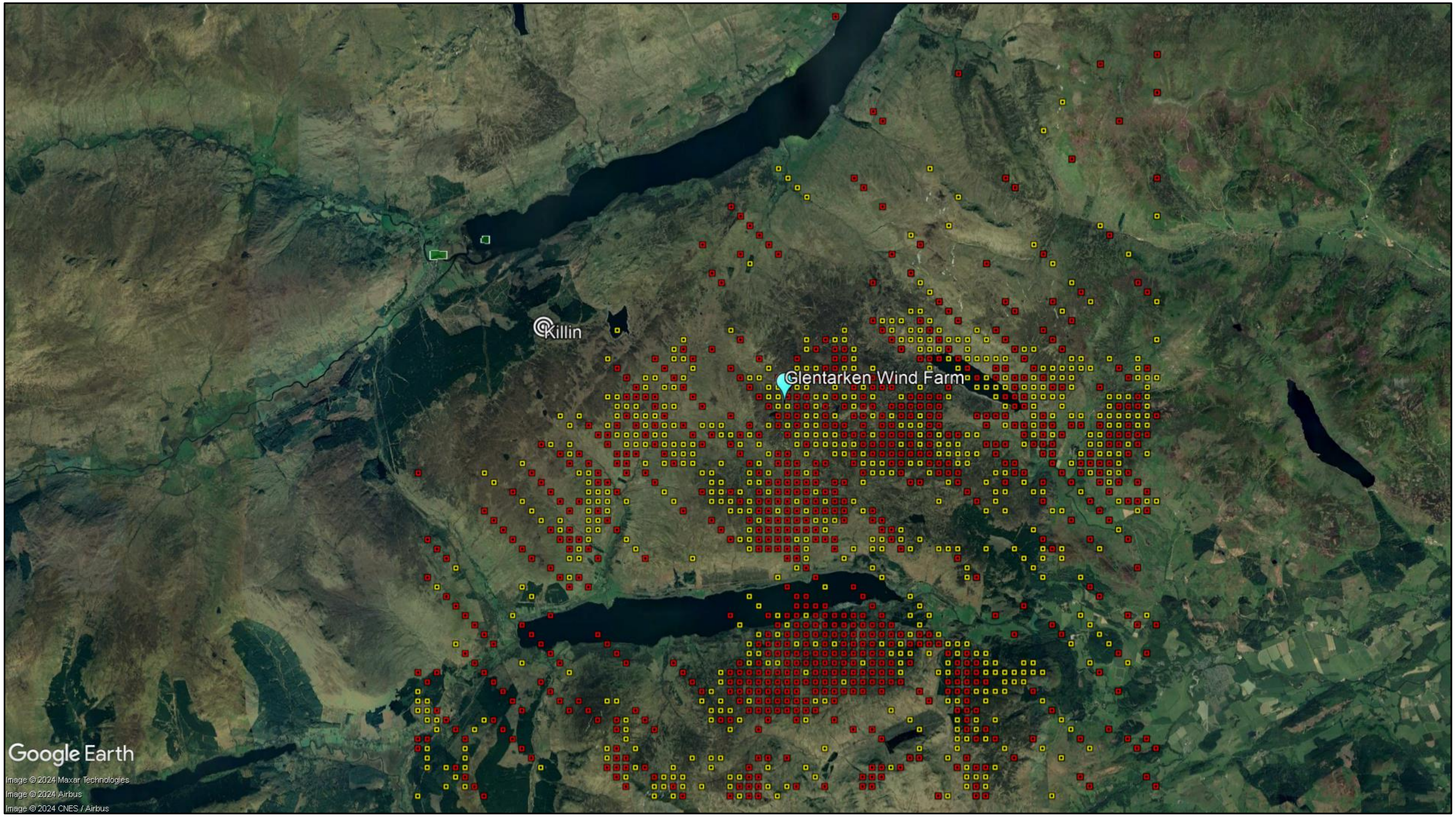

Figure 18 *Interference in context (Killin)*

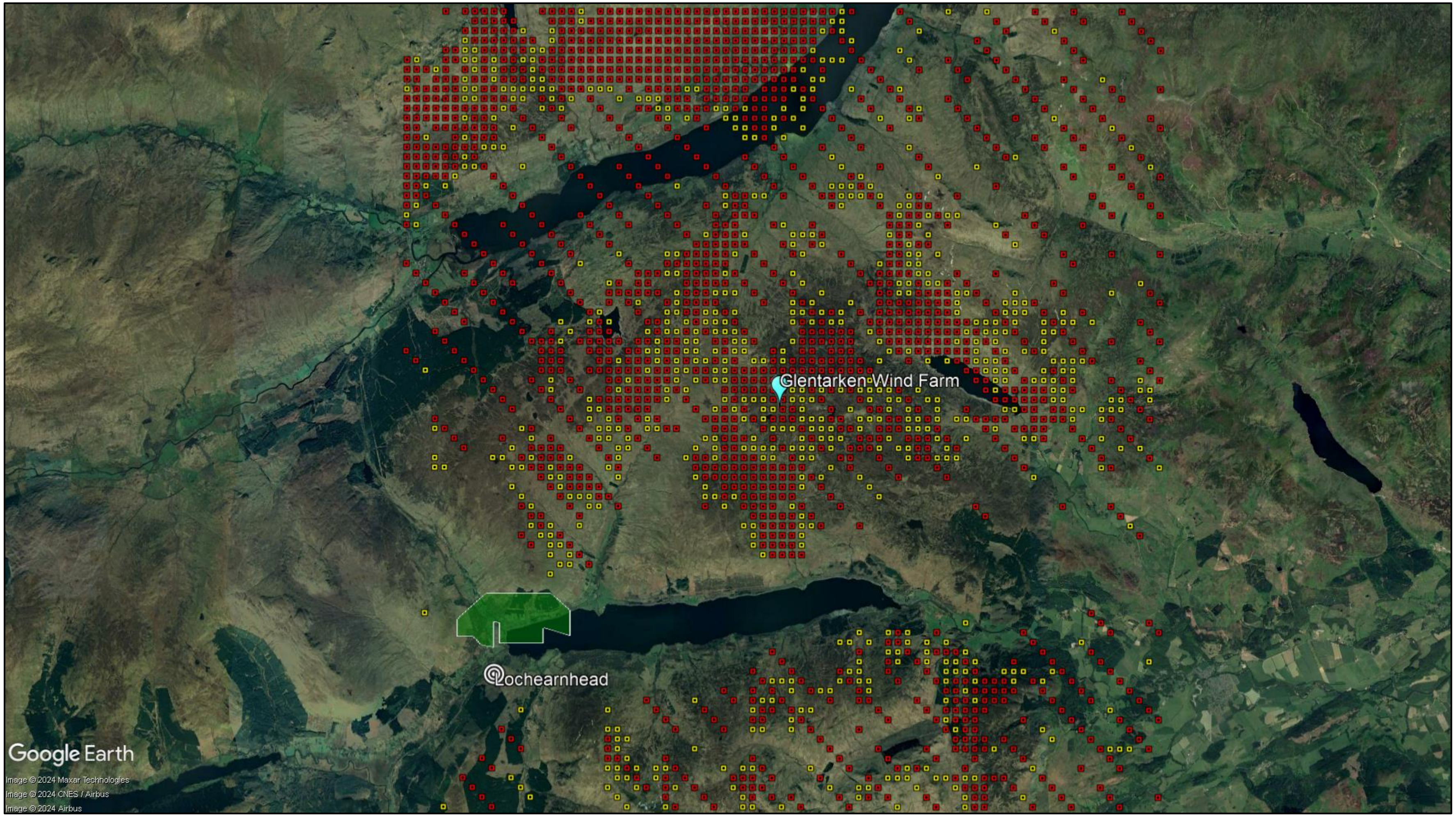

Figure 19 *Interference in context (Lochearnhead)*

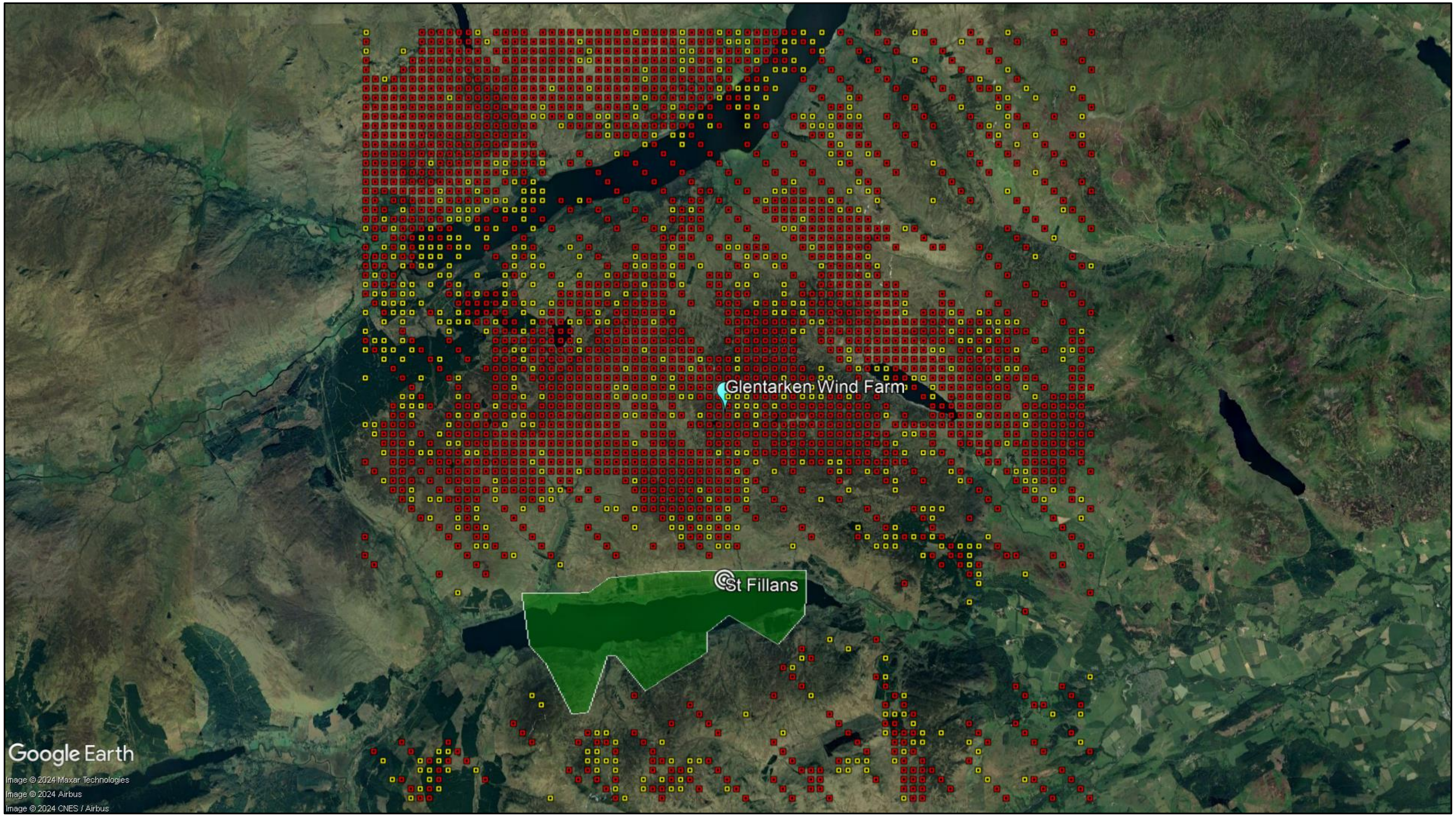

Figure 20 *Interference in context (St Fillans)*

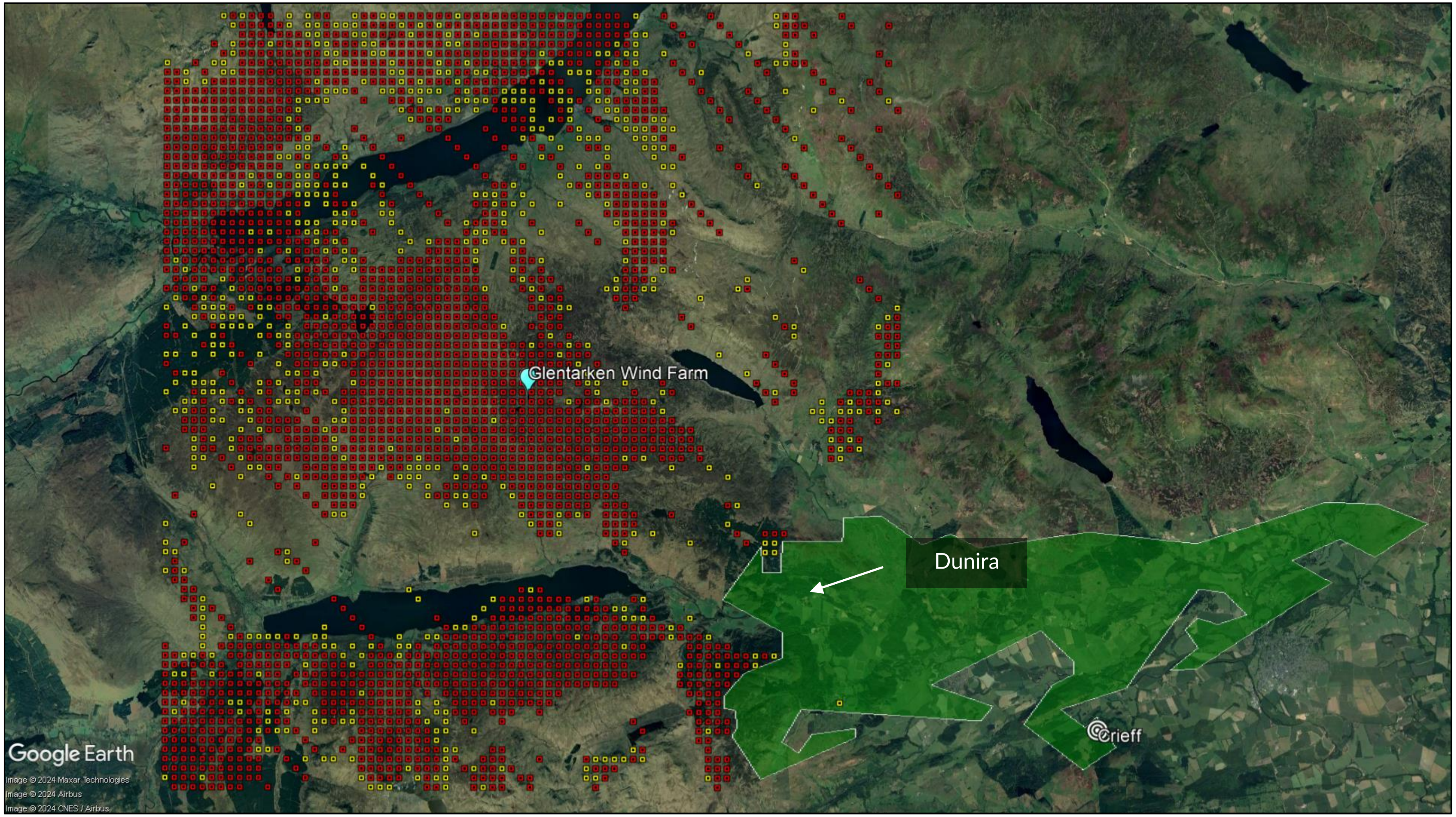

Figure 21 *Interference in context (Crieff)*

Figure 22 *Overall Radio signal coverage map*

6.3 Television Conclusions

The relevant literature and practical experience both indicate that interference is most likely within the forward scatter region. Within this region (behind each the turbines relative to the transmitter), there are some concentrated areas with a high or medium likelihood of interference predicted by the model. Interference is predicted in the forward scatter region of each transmitter. Within the forward scatter regions, no densely populated areas have been identified.

For the surrounding area, each town have their own TV relay transmitters. Terrestrial television services provided to Killin, Lochearnhead and St Fillans are predicted to come from their own respective relay transmitters. Terrestrial television services provided to Dunira are predicted to come from Crieff relay transmitter.

The interference area lies outside the transmitting range of the relay transmitters, as shown in Figure 18 to Figure 21. Since the interference area does not overlap with the transmitting area, the proposed development will not affect the TV signal.

The proposed development is predicted to have a 'Very Low' magnitude of impact upon surrounding terrestrial television and radio services. This would be 'Negligible' for medium sensitivity receptors.

6.4 Radio Conclusions

Noticeable impacts upon radio signals in the surrounding area are not predicted. This is because the assessment area is outside radio coverage. Additionally, alternate transmitters can provide coverage as radio transmission are more robust and receivers are designed to accept transmissions in dynamic environments.

The proposed development is predicted to have a 'Very Low' magnitude of impact upon surrounding terrestrial television and radio services. This would be 'Negligible' for medium sensitivity receptors.

7 MITIGATION OPTIONS

7.1 Requirement

No requirement for pre-emptive mitigation has been identified. Widespread effects on heavily populated areas are not predicted and there may be no mitigation requirement at all.

7.2 Mitigation Options

7.2.1 Television

Common mitigation options for television interference include:

1. Directing the receiving aerial to an alternative transmitter that covers the area and re-tuning the television accordingly;
2. Replacement of receiving aerial with a more directional, or higher gain, aerial;
3. Repositioning the receiving aerial so that the received signal is strongest;
4. Upgrading antenna cabling and connections;
5. Installation of signal amplifiers;
6. Replacing terrestrial reception equipment with satellite or cable reception equipment;
7. Provision of television services via the internet;
8. Development of a bespoke local solution using a receiving aerial some distance from the dwelling.

7.2.2 Radio

Common mitigation options for radio interference include:

1. Re-tuning the radio;
2. Relocation of the radio;
3. Upgrading the aerial or the radio itself;
4. Provision of an external aerial for receiving radio services;
5. Provision of radio services via the internet;
6. Development of a bespoke local solution using a receiving aerial some distance from the dwelling.

7.3 Process

Mitigation would only be applied following reported interference that was subsequently determined to be due to the development. Interference may be reduced or eliminated by redirecting the aerial toward one of the other potential transmitters serving the area. Specifics regarding a further mitigation process to be followed and the associated timescale may be further defined as conditions of the planning permission.

8 OVERALL CONCLUSIONS

8.1 Conclusions

Terrestrial television are theoretically provided in the surrounding residential areas by Angus main transmitter and Killin, Lochearnhead, St Fillans and Crieff relay transmitters. Radio services are expected to be also provided by additional radio transmitters.

The area immediately surrounding the proposed wind turbine development is rural and relatively sparsely populated. The towns of Killin, Lochearnhead, St Fillans and Dunira are located further from the development. Terrestrial television services provided to these towns are predicted to come from their own respective relay transmitters[7].

The desk-based modelling to identify areas of interference for each transmitter showed that interference is possible in the area behind the turbines relative to each transmitter (forward scatter regions) and some surrounding areas. Interference outside the forward scatter region is not predicted to be attributable to the wind farm and is expected be caused by other factors, such as intervening terrain.

The towns which each transmitter is predicted to serve are outside the interference areas and forward scatter regions. Interference caused by the proposed development is therefore not anticipated.

Noticeable impacts upon radio signals in the surrounding area are not predicted. This is because the assessment area is outside radio coverage.

8.2 Next Steps

The prospect of interference cannot be ruled out entirely due to the variable coverage and the possibility that services from a given transmitter could be receivable at isolated locations outside of its nominal coverage zone.

There is no requirement to undertake pre-emptive mitigation because it is unlikely there will be widespread significant effects in highly populated areas, however impacts on rural areas cannot be ruled out. Mitigation options are presented in Section 5. Specifics regarding a further mitigation process to be followed and the associated timescale may be further defined as conditions of the planning permission.

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[7] Crieff relay transmitter provides services to Dunira

APPENDIX A – TELEVISION INTERFERENCE

Television Interference

Introduction

Terrestrial television signals propagate from transmitters to receiving aerials which in turn are connected to television receiving equipment. Transmissions are in the UHF frequency range and may be either analogue or digital.

When considering interference from buildings or wind farms it is usual to consider direct signals – those that pass from transmitter to receiver in a straight line and reflected, or indirect, signals. The reflected signal goes from transmitter to turbine (or building) to receiver.

Standard receiving aerials are directional meaning that signals from the transmitter direction are amplified and signals from the sides and rear of the aerial are attenuated.

Carrier to Interference Ratio

The likelihood of television interference is determined by considering the strength of the direct, or carrier, signal in comparison to the reflected, or interfering, signal. The Carrier to Interference Ratio (CI Ratio) quantifies the relative strength of the direct and reflected signals.

A high Carrier to Interference ratio means interference is less likely. A low Carrier to Interference ratio means that interference is more likely. The CI Ratio is normally expressed in decibels (dB).

Free Space Path Loss

Television signals weaken over distance. The closer a receiver is to a transmitter the stronger its received signal will be. This reduction in signal strength due to separation distance is referred to a Free Space Path Loss (FSPL).

Electromagnetic Propagation by Diffraction

An electromagnetic signal may travel between two points, even when no direct line of sight exists between those two points. This is because transmission travels as a series of waves rather than as a direct ray. When no direct line of sight exists between the two points the signal is considerably weakened. This weakening is known as a diffraction loss.

International Telecommunications Union (ITU) Recommendation ITU-R P526-7 describes a method for calculating diffraction losses over regular terrain.

Total path loss for a specific path is determined by adding Free Space Path Loss to Diffraction Loss.

Radar Cross Section

The size of the interfering signal is dependent on the amount of energy that is reflected from the wind turbine. This reflective quality is known as the Radar Cross Section (RCS) and can be expressed in metres squared or in dBm^2.

A lot of work has been carried out to help determine wind turbine RCS by various parties although little work has been carried out at UHF frequencies. Values cited typically vary between 25 and 300 m^2 with instantaneous peaks reaching 3000 m^2 for a single wind turbine.

The moving and static parts of the turbine are often considered separately.

Nature of Television Interference from Wind Turbines

Determining whether a television picture is impaired by wind turbines or whether the impairment is significant enough to cause picture quality to become unacceptable is considered a subjective matter. The level of effect is determined by looking at the picture when the turbine is operating. There is a subjective system for grading television picture impairment with grades from 5 down to 1 described in ITU-R 500. The impairments are shown in the table below.

Impairment Grade	Likelihood of Interference
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very Annoying

Grading Table

Where interference is marked it is generally clear that it is being caused by wind turbines. The picture regularly distorts with a time base matching the passing of turbine blades. This means that it is fairly easy to determine whether a viewer's interference problem is related to a wind turbine.

Conditions for Wind Turbine Interference

Simplistically the television picture is likely to be unacceptably affected by wind turbine interference when the CI Ratio is low. In practice interference is most noticeable when some or all of the following conditions are satisfied:

1. The received signal strength is weak.
2. The direct signal path between transmitter and receiver is physically obscured.
3. There is a clear signal path between transmitter and wind turbine.
4. There is a clear signal path between wind turbine and receiver.
5. The wind turbine lies directly between the transmitter and receiver.

Pager Power Approach

Having reviewed many relevant published works, a synopsis of which is included at the end of this text, Pager Power has arrived at a compound methodology including some additional factors such as:

- Triplicate calculations accounting for tip, hub and rotor bottom.
- Accounting for actual field strength
- Calculating interference in accordance with the Dabis Method
- Calculating interference in accordance with the ITU method

Following assessment by these various methods the following conclusions have been drawn:

- Although it is true that wind farm interference appears more likely when the received signal is weak there is no direct relationship between direct signal strength and observed picture interference.
- Observed picture interference is directly related to the CI Ratio.
- The ITU-R BT805 method appears to be significantly more accurate than the Dabis method for assessing observed interference.
- Summing of unwanted signals from each turbine to determine a total unwanted signal level appears to be reasonably accurate.
- The CIR threshold of 10dB cited by RES appears to be reasonable – it is certainly true that the threshold of 28-34 cited by BT805 is too high when using this method. Observations on a 32 wind turbine development suggest that a threshold of 15dB may be more reasonable in this case.
- Carrying out an assessment based on the hub height appears to be fairly representative – however there can be significant variation in CI Ratio over the blade span. In an example with no direct line of sight between transmitter and receiver the CI Ratio varies by 31dB between the top and bottom of the rotor. This is a large variation and should be considered or accounted for.

It was concluded therefore that triplicate calculations at tip, hub and rotor base should be considered. The principals of this calculation are as follows:

- The interference signal calculation should be carried out three times for each turbine – at tip, hub and rotor base.
- A weighted average of the three unwanted interference signal levels should be made (of absolute levels not decibel levels).
- A signal passing through the turbine at hub height is clearly going to be affected much more than one passing through the tip or rotor base so an increased weighting should be applied to the hub signal.
- The weighting applied to rotor tip and rotor base should be identical as the proportion of the signal passing through the rotor is identical at both heights.
- A geometric calculation suggested that following weightings be used for averaging:

Turbine Part	Weighting (%)
Tip	19.55
Hub	60.9
Rotor Bottom	19.55

Weighting

- The following rounded values have therefore been used for calculation purposes.

Turbine Part	Weighting (%)
Tip	20
Hub	60
Rotor Bottom	20

Weighting for calculation

Pager Power Assessment Methodology

Having considered the various published works, exploring knowledge of real interference caused by wind farms, and modelling interference in various ways Pager Power has developed an effective modelling method for mapping likely television interference from wind farms. The process involves the following stages:

1. Acquire terrain data in digital format.
2. Determine the following for modelling:
    a. Transmitter location and height.
    b. Turbine locations and hub heights.
    c. Single Blade Area.
    d. Blade Width for modelling purposes.
    e. Television signal wavelength for modelling purposes.
3. Area of interest for interference modelling – this will be a rectangular area defined by top-right and bottom-left coordinate pair.
4. Determine the sample point spacing for modelling purposes – this is currently a fixed value for the entire area.
5. Determine the receiver aerial height for modelling purposes.
6. Calculate coordinates of each Receiver Sample Point in the area of interest.
7. Calculate Free Space Path Losses for the following paths:
    a. Transmitter to each Wind Turbine FSPL_TW.
    b. Transmitter to each Receiver Sample Point FSPL_TR.
    c. Each Wind Turbine to each Receiver Sample Point FSPL_WR.

8. Build electronic terrain profile for each of the above paths. The number of points in the profile is determined dynamically based on the source terrain data resolution and the particular path length.
9. Determine additional diffraction losses for each of the above paths using ITU-R 526 method. These losses are DL_TW, DL_TR and DL_WR respectively. These calculations are carried out for the turbine tip, turbine hub and turbine rotor.
10. Calculate a Wind Turbine Reflection Factor (RF) in accordance with ITU-R BT805.
11. Calculate an adjustment factor (ADJ) to compensate for the 1km free space path loss built into the Relative Amplitude (RA) calculation defined in ITU-R BT805. This is 88.662dB.
12. Determine the following for each wind turbine – sample point pair:
    a. Horizontal Angle (alpha) at the turbine between extended path from transmitter and path to sample point.
    b. Horizontal Angle (beta) at sample point between turbine and transmitter.
    c. Calculate Relative Amplitude (RA) based in accordance with ITU-R BT805. If RA is calculated to be smaller than -10 it is changed to -10 (as described in BT805).
    d. Calculate Loss due to Antenna Directivity (AL) based on angle beta and the curves in ITU-R BT419.
13. Calculate Interference Signal Magnitude for each Turbine Receiver Sample Point Pair at turbine tip, hub and rotor base by summing the following:
    a. - FSPL_TW
    b. - DL_TW
    c. - FSPL_WR
    d. - DL_WR
    e. RF
    f. RA
    g. ADJ
    h. –AL
14. The above absolute values are summed for each turbine sample point and converted back into decibel values and saved as Summed Interference Values (I). Summing occurs with a 20/60/20 respective weighting split for tip, hub and rotor base.
15. Carrier Signal Magnitude (C) is then determined for each Receiver Sample Point by summing:
    a. – FSPL_TR
    b. – DL_TR
16. CI Ratio is then calculated for each point by subtracting I from C.
17. CI Ratio for each sample point is then recorded on an interference map.

Formulae

Term	Unit	Description
A	m^2	Blade Area
AL	dB	Antenna Loss due to angle between signal source and antenna direction
Ave aC	dB	Carrier signal strength (based on inverse of losses)
CIR	dB	Carrier to Interference Ratio
d	m	Length of signal path
dkm	km	Length of signal path
DL	dB	Diffraction Loss
FSPL	dB	Free Space Path Loss
FSWT	dBV/m	Field Strength at Wind Turbine
I	dB	Interference signal strength
Iabs	-	Interference signal strength (absolute)
Ih	dB	Interference signal strength due to a single turbine calculated at hub height
Ir	dB	Interference signal strength due to a single turbine calculated at bottom of rotor
It	dB	Interference signal strength due to a single turbine calculated at tip height
Iw	dB	Interference due to a single wind turbine
Iwf	dB	Interference due to a wind farm
RA	dB	Relative Amplitude in forward scatter region
RF	dB	Reflection factor for a wind turbine including free space path loss for 1km
TW	suffix	Denotes path from transmitter to Wind Turbine
TR	suffix	Denotes path from transmitter to receiver

Term	Unit	Description
TXFIELD	dBV/m	Transmitter field strength at 1 metre
v	-	Diffraction Parameter
W	m	Width of blade
WR	suffix	Denotes path from wind turbine to receiver
α	Radians	Horizontal angle at turbine between extended path from transmitter and path to receiver
β	Degrees	Horizontal angle between path to signal source and direction receiving antenna is pointing
λ	m	Wavelength

Glossary of terms

1 Antenna Loss

AL = 0 when $\beta<20$

AL = (β-20) x 0.4 when β between 20 and 60

AL = 16 when $\beta>60$

From Figure 1 of ITU-R BT419 Bands IV and V (UHF)

2 Reflection Factor

RF = 20log(A/λ)-60 (From Annex 1 of ITU-R BT805).

3 Relative Amplitude

RA=20log sin(π×W/λ×sinα)/(π×W/λ×sinα) (From Annex 1 of ITU-R BT805).

4 Carrier to Interference Ratio

CIR = C – I (From first principles by definition when values expressed in dB)

5 Free Space Path Loss

FSPL = 20log(4πd/λ) (From Dabis paper and by definition)

6 Interference – Single Turbine – Hub Height

Formulae for a single path at hub height:

Ih = FSWT + RF + max(-10,RA) - 20log(dkm) [**a**]

From ITU-R BT805 for an unobscured path from Wind Turbine to transmitter

FSWT = TXFIELD - FSPL_TW - DL_TW [**b**]

From first principles

Ih = TXFIELD - FSPL_TW - DL_TW + RF + max(-10,RA) - 20log(dkm) [**c**]

Combining [**b**] and [**a**]

Ih = TXFIELD-FSPL_TW-DL_TW+RF+max(-10,RA)-20log(dkm)-DL_WR [**d**]

Accounts for additional diffraction losses between Wind Turbine and receiver

20log(dkm) = 20log(d/1000) = 20log(d) - 60 [**e**]

From first principles

FSPL = 20log(4π/λ) + 20log(d)

20log(d) = FSPL - 20log(4π/λ) [**f**]

From [**e**] and first principles

20log(dkm) = FSPL - 20log(4π/λ) - 60 [**g**]

Combining [**f**] and [**e**]

Ih = TXFIELD - FSPL_TW - DL_TW + RF + max(-10,RA) - FSPL_WR + 60 + 20log(4π/λ) - DL_WR [**h**]

Combining [**d**] and [**g**]

7 Interference Single Turbine

Interference for a single turbine is calculated by taking a weighted average of interferences at tip, hub and rotor base.

It, Ih and Ir are all calculated as detailed in 6 above. These values will differ due to diffraction loss differences.

Iw = 20log((0.2*10^(It/20))+(0.6*10^(Ih/20))+(0.2*10^(Ir/20)))

Absolute averaging of signals with a 20/60/20 weighting – Pager Power Methodology

8 Interference Multiple Turbines

Multiple Turbines based on calculations at hub height.

Interference signals from multiple sources are calculated by summing absolute values. The following formulae apply:

Iw = 20log(Iabs)

Iabs =10^(Iw/20)

By definition Iwf=20log(Σ(10^(Iw/20)))

Direct summing of absolute values – Pager Power and RES methodologies

9 Diffraction – Single Knife Edge

DL = 6.9 + 20log(sqrt(((v-0.1)^2)+1)+v-0.1) when v > -0.7

DL = 0 when v <= -0.7

Equation 17 of ITU-R P526 (DL ≈ 0 when v<= -0.7 from the graph at Figure 7)

10 Diffraction – Path over Irregular Terrain

The general method is described in Section 4.5 of ITU-R P526.

Up to three peaks are considered as specified by the method.

An effective Earth Radius (to account for atmospheric refraction) of 8,494,678 metres is used for calculation purposes.

Review of Published Works

A number of documents relate to the interference effects of wind turbines on television and radio systems. These include:

1. BBC, The impact of large buildings and structures (including wind farms) on terrestrial televisions reception
2. International Telecommunications Union, Assessment of impairment caused to television reception by a wind turbine, Recommendation ITU-R BT805*, 1992
3. Bacon, DF, A proposed method for establishing an exclusion zone around a terrestrial fixed radio link outside of which a wind turbine will cause negligible degradation of the radio link performance, Radio Communications Agency, 2002
4. Hall, SH, The assessment and avoidance of electromagnetic interference due to wind farms, Wind Engineering Vol 16 No 6, 1992
5. Dabis, HS, The provision of guidelines for the installation of wind turbines near aeronautical radio stations, Civil Aviation Authority, CAA Paper 99002, 1999
6. ETSU, Feasibility of mitigating the effects of wind farms on primary radar, ETSU W/14/00623/REP, 2003
7. Dabis, HS, The establishment of guidelines for the installation of wind turbines near radio systems, Proceedings of the eighteenth BWEA Wind Energy Conference, 1996
8. FES, Wind farms impact on aviation interests – final report, FES W/16/00614/00/REP, 2003
9. S Vila-Moreno, A Methodology to Assess Interference to TV Reception due to Wind Farms, RES, 2005

The two Dabis papers describe a method for determining the likely interference from a wind turbine based on it behaving like a reflector. This methodology is generally used for interference predictions. The methodology in these papers does not address the significant increase in the level of interference observed when the wind turbine is on the direct path between transmitter and receiver and in addition a method for accounting for multiple wind turbines is not provided.

The ITU-R BT805 paper is quite useful and applies to a single wind turbine. It suggests:

- A CIR in excess of 28-34 dB is required to attain a good analogue picture quality having impairment grade 4 or above.
- Interference levels directly behind the turbine are 10dB higher than interference levels to the side of the turbine.
- Interference levels in flat terrain are unlikely at distances of more than 500m from the wind turbine site.
- Investigation of interference levels is not required at distances of more than 5km from the site.
- The paper refers to the ratio of the wanted signal to the unwanted signal which the Dabis papers refer to as CI Ratio. This document uses the term CI Ratio or CIR.

Radar studies have shown that reflected or scattered signals are much stronger immediately beyond the turbine. This is normally accounted for in interference calculations by using a higher RCS for scenarios where the turbine lies between transmitter and receiver.

The RES document describes a similar approach but includes a method for accounting for the effects of multiple wind turbines by summing the unwanted reflected signals (absolute not decibel). The RES document also suggests:

- a study area of 20km x 20km centred on the wind farm
- allowing for a standard receiving antenna characteristic
- summing unwanted signals directly
- a CIR threshold of 10db – Interference being likely when CIR is less than 10dB.

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