Impact of the Proposed Luumäki-Suurikangas Wind Farm on the Kouvola Kaipiainen Finnish Weather Radar

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1 Introduction

1.1 Background

Myrsky Energia Oy is planning to build the Luumäki-Suurikangas wind farm, located approximately 17 km east from the Kouvola Kaipiainen weather radar, safeguarded by the Finnish Meteorological Institute (FMI). An assessment is required to quantify the radar impacts and compare them with the four FMI criteria [1].

1.2 Scope of work

The assessment is carried out in accordance with the QinetiQ CLOUDSiS 1.0 method, which is the official method for assessing the impacts on Météo-France weather radars [2]. The assessment activities are described in the QinetiQ statement of work [3].

1.3 Luumäki-Suurikangas wind farm

Details of the Luumäki-Suurikangas wind farm were provided by Myrsky Energia Oy [4][5][6]. The proposed wind farm consists of fifteen Vestas V172 turbines, with a hub height of 161 metres (m) above ground level (AGL). Figure 1-1 shows the turbine layout, along with turbine identification (ID) numbers.

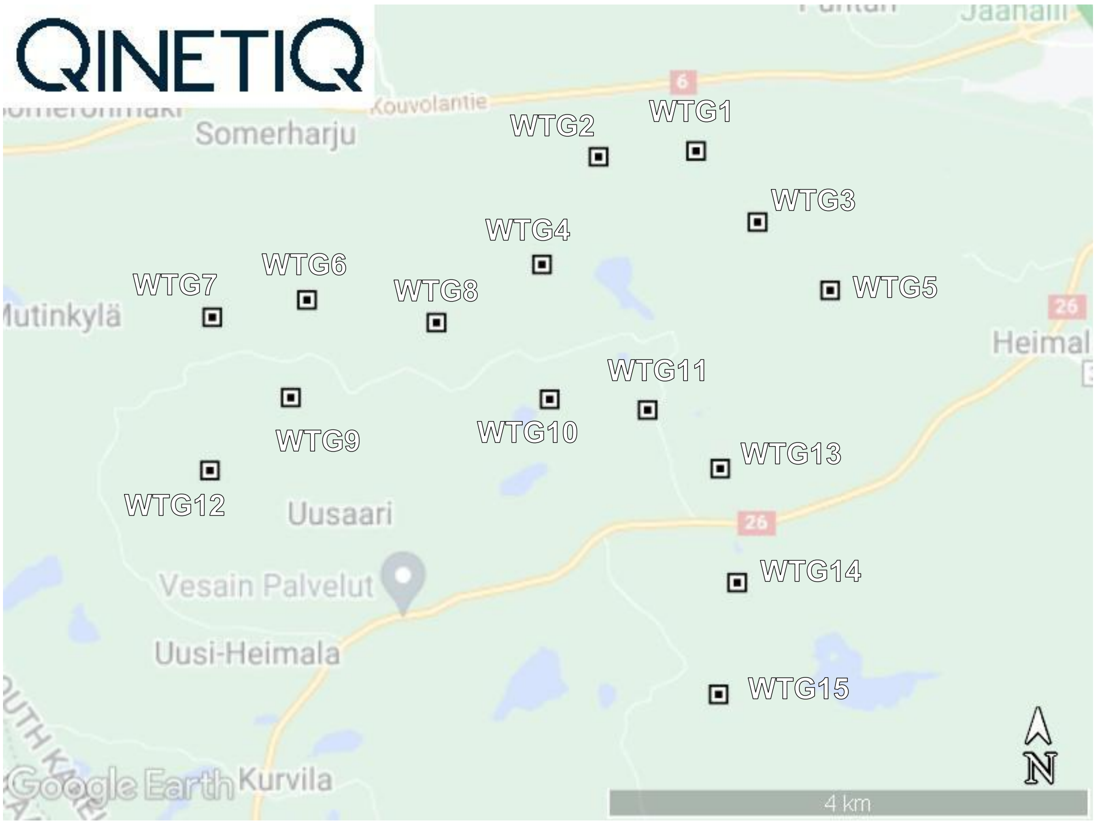

Figure 1-1: Proposed turbine layout (white squares) [4]

Table 1-1 shows the locations of the proposed turbines in World Geodetic System 1984 (WGS84) latitude and longitude format [4].

Turbine ID	WGS84 coordinates		Turbine ID	WGS84 coordinates	
	Latitude (°N)	*Longitude (°E)*		*Latitude (°N)*	*Longitude (°E)*
WTG1	60.913333	27.491621	WTG9	60.895031	27.429825
WTG2	60.912902	27.476753	WTG10	60.894909	27.469297
WTG3	60.908055	27.500998	WTG11	60.894115	27.484231
WTG4	60.904914	27.468117	WTG12	60.889620	27.417499
WTG5	60.902986	27.512075	WTG13	60.889761	27.495294
WTG6	60.902278	27.432282	WTG14	60.881303	27.497871
WTG7	60.900986	27.417851	WTG15	60.873008	27.495034
WTG8	60.900597	27.452036			

Table 1-1: Proposed turbine coordinates [4]

Table 1-2 shows the main parameters for the V172 turbine type [5]. The tower dimensions for the V172 turbine are not finalised, therefore, the tower diameters are only indicative. A representative tower shape was agreed with Myrsky Energia Oy [6], and is shown in Figure 1-2.

Parameter	Value
Hub height (m AGL)	161
Tower base diameter (metres)	6.0
Tower top diameter (metres)	3.7
Rotor diameter (metres)	172
Blade tip height (metres)	247

Table 1-2: V172 main turbine parameters [5]

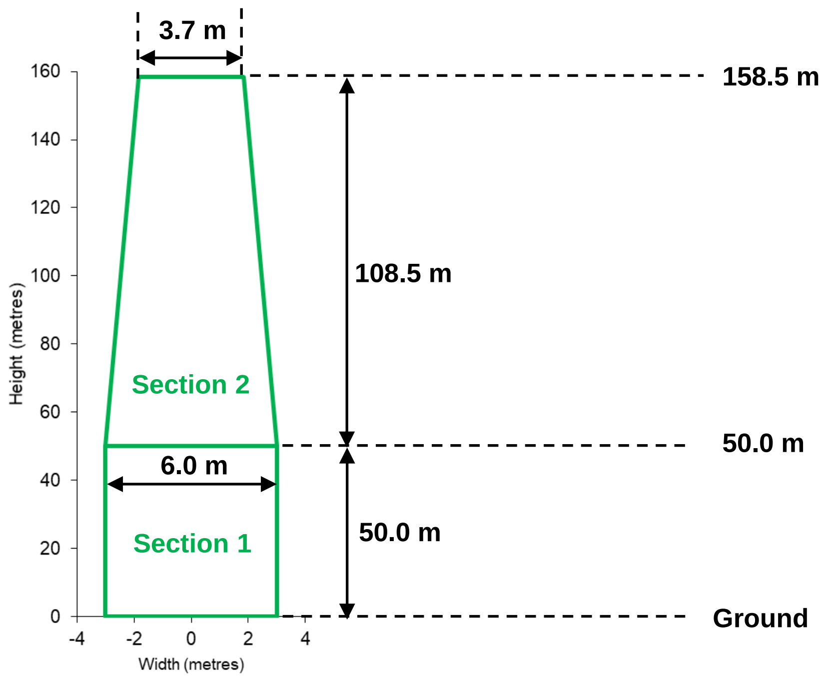

Figure 1-2: Representative V172 tower shape used in the modelling

1.4 FMI safeguarding rules

Wind turbines have the potential to impact the operation of weather radars. There are two main impacts:

- Occultation (blockage of radar signal, creating a weaker signal in the sector behind the turbines); and
- Reflections (unwanted reflections), creating an impact zone of 'fictitious' rainfall in the radar data.

The FMI guidelines set out the distances within which an assessment of the potential impact is required [1]. The distances are summarised in Table 1-3[A].

Distance of wind turbine from an FMI radar	Safeguarding requirement
Within 5 km	Turbines are not allowed.
5 km to 20 km	An assessment is required to quantify the impacts.
Farther than 20 km	Turbines farther than 20 km are considered to be acceptable by FMI, except in the case where they are directly next to other turbines within the 20 km limit. In this case, an assessment is required. If a development extends across the 20 km limit, all turbines need to be considered.

Table 1-3: FMI safeguarding distances [1]

If an assessment is required, the criteria summarised in Table 1-4 are used to judge a project's acceptability.

Criterion	Description	Acceptable condition
C1	Maximum percentage power loss, L, in any sector containing a proposed turbine.	$L < 10\%$
C2	Maximum dimension, D, of the impact zone created by the proposed wind farm.	$D < 10$ km
C3	Angular extent of the impact zone, A.	$A \leq 30$ km
C4	Minimum separation, S, between the proposed wind farm's impact zone, and other wind farm impact zones.	$S > 10$ km

Table 1-4: FMI acceptance criteria [1]

If a wind farm fails these criteria, it is likely to receive an objection from FMI. If a wind farm passes these criteria, FMI will still need to do a final operational assessment to take into account the impact on sensitive sites (geographical areas with high operational significance) [1].

[A] For the purpose of this assessment, the 5 km zone will be referred to as the protection zone (PZ); the 5 km to 20 km zone will be referred to as the coordination area (CA)

1.5 Kouvola Kaipiainen weather radar

The location of the Kouvola Kaipiainen weather radar is shown in Figure 1-3, along with the proposed turbines. There are no other turbines within the CA radius [7]. The main radar parameters were obtained from the FMI guidelines [1]. Additional parameters were provided by FMI [8].

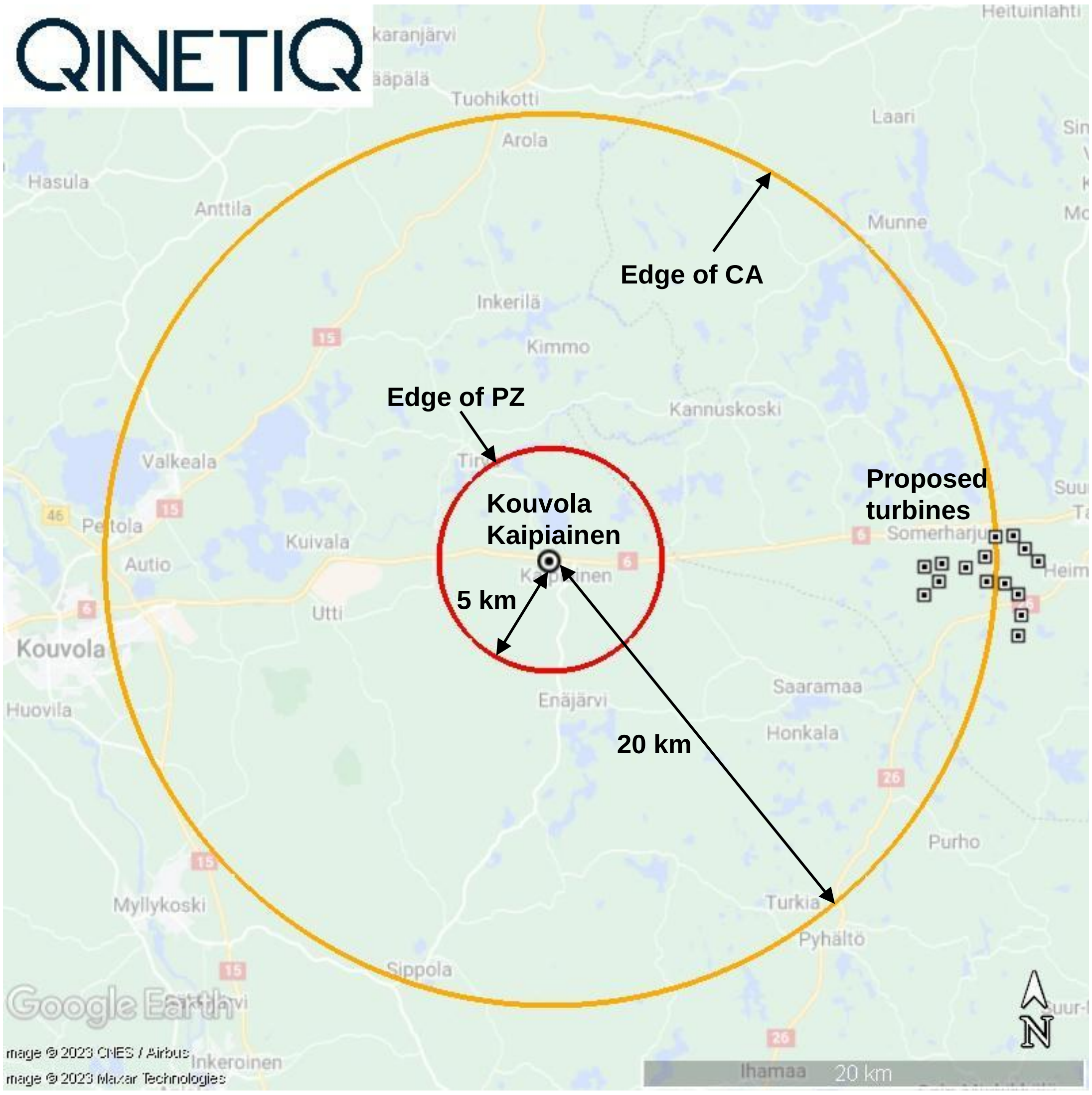

Figure 1-3: Kouvola Kaipiainen radar (white circle) and proposed turbines (white squares). Orange line (CA radius); red line (PZ radius)

2 LoS visibility

Radar line of sight (LoS) visibility can be used as an approximation of whether a radar will be able to detect an object. Radar waves curve downwards in the atmosphere and so a radar LoS region will cover a slightly wider area than a geometric (straight line) LoS region. When an object is in radar LoS it is likely that it will be detectable and may have an impact on the radar's operation. When an object is out of radar LoS it is likely the impact will be less or there may be no impact.

For LoS calculations, QinetiQ normally uses the Shuttle Radar Topography Mission 3 (SRTM3) terrain dataset, which is sampled on an approximately 90 m spaced grid. However, SRTM3 does not cover the geographical area of interest. Accordingly, the SRTM30 dataset (900 metre resolution) was used instead.

Figure 2-1 shows the height to LoS in the vicinity of the proposed wind farm, as viewed from the Kouvola Kaipiainen radar. The colours represent the minimum height (in m AGL) that an obstacle would need to be in order for it to be in radar LoS.

All proposed Luumäki-Suurikangas turbines are in blue areas of the map, where the radar has visibility down to or nearly down to the ground. At all proposed turbine locations the towers and blades are in radar LoS and are likely to have an impact on the radar data. Although there is partial shielding of the towers for some turbine locations, this is unlikely to have a large effect in terms of reducing the impacts from the towers.

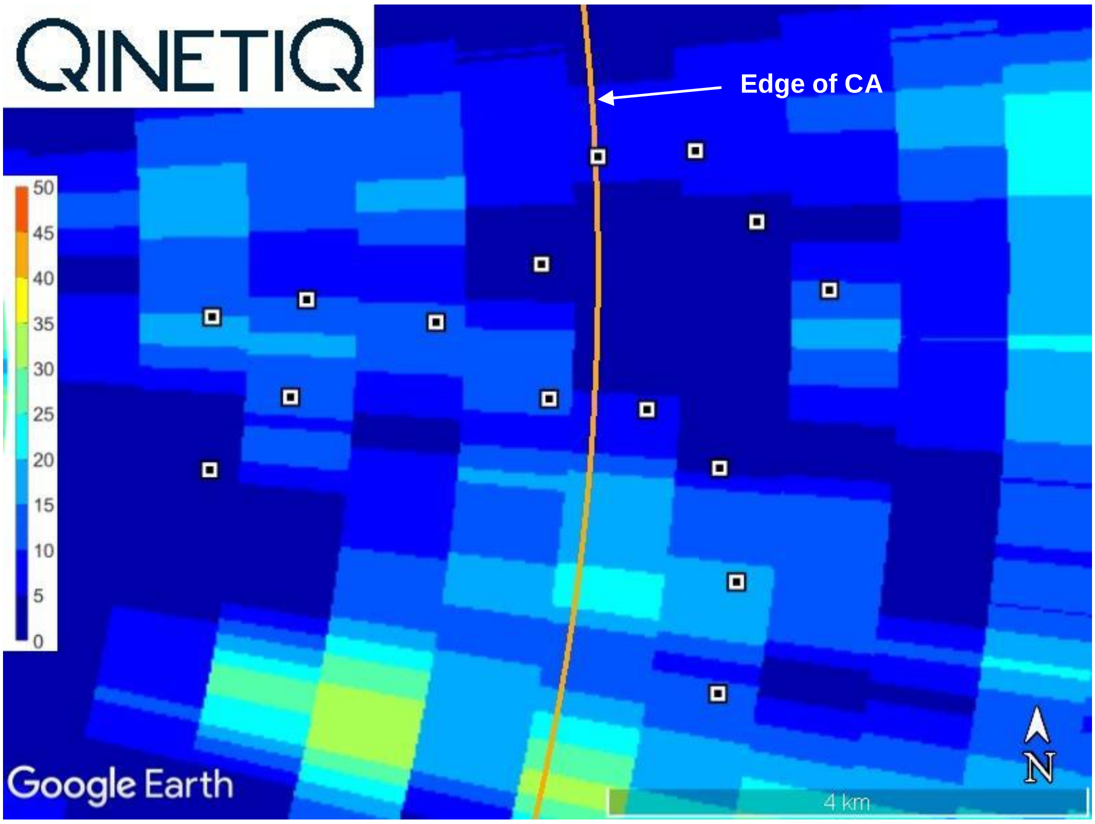

Figure 2-1: Height to LoS (m AGL) in the vicinity of the proposed turbines (white squares), as viewed from the Kouvola Kaipiainen radar

Figure 2-2 shows a view of the proposed turbines and the terrain, confirming that the proposed turbines are visible and there is no high terrain behind the turbines that could truncate the shadowing impact.

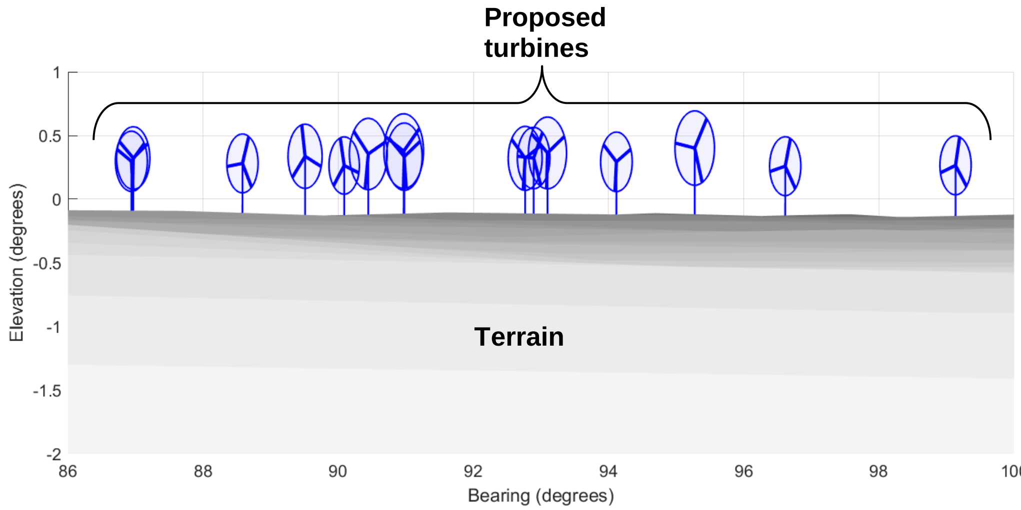

Figure 2-2: Elevation-azimuth view of the proposed turbines, as viewed from the Kouvola Kaipiainen radar

3 Turbine RCS

In this section the radar cross-section (RCS) of the proposed turbines is quantified. The RCS of an object is a measure of the strength of the radar echoes, depending on factors including the direction and distance of the object from the radar, the radar frequency, the shape and orientation of the object, and the construction materials. The larger an object's RCS, the more energy it reflects, and the more significant the potential impacts on a radar system. RCS has the dimensions of area, and can vary over many orders of magnitude. Accordingly, it is usually expressed in logarithmic units (dBsm[B]).

In the QinetiQ model, the turbine RCS is broken down into two components: the RCS from the stationary tower and the RCS from the moving blades.

3.1.1 Blade RCS

RCS scaling laws were used to estimate the peak (maximum) blade RCS of the proposed turbines, as viewed from the Kouvola Kaipiainen radar. A rotor diameter of 172 metres was used in the calculations.

Using the peak blade RCS value is critical to assessing the worst case impact. However, due to the blade rotation and the long integration time for a weather radar, the peak RCS from a blade flash will only be seen intermittently, with a lower RCS most of the time. A detailed analysis of the RCS distribution is outside the scope of this analysis. Based on an internal analysis of turbine datasets, the typical blade RCS, i.e. the RCS of the blades averaged over time, will be around 20 dB lower than the peak.

Figure 3-1 shows the blade RCS (peak and typical) at the proposed turbine locations. The data points are labelled from left (WTG1) to right (WTG15) as indicated in the figure. The peak blade RCS is approximately 56 dBsm for all locations; the typical blade RCS is approximately 36 dBsm.

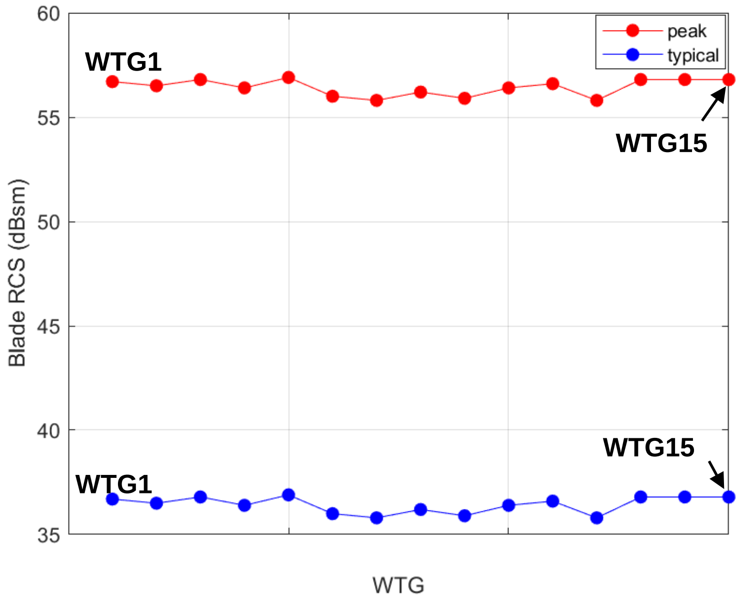

Figure 3-1: Peak and typical blade RCS values at the proposed turbine locations

[B] The logarithmic units for RCS are decibel referenced to one square metre (dBsm). For example, an RCS of 10 square metres is equivalent to 10log10(10) = 10 dBsm in logarithmic units.

3.1.2 Turbine towers

As the tower is approximately a cylindrical, stationary object that is typically highly reflective, the RCS can be estimated mathematically, rather than having to use scaling techniques. The peak RCS (σ_{max}) of a cylindrical turbine tower constructed from a perfect electrically conductor (PEC) material, such as steel, can be estimated by using Equation 3-1 [9]:

$$\sigma_{\max} = \frac{2 \cdot \pi \cdot R \cdot H^2}{\lambda}$$

Equation 3-1: Peak RCS of a PEC cylindrical tower

R = tower radius, H = tower height and λ = radar wavelength. However, the peak RCS given by Equation 3-1 only occurs in one direction. In other reflection directions the RCS is usually lower, depending on the shape of the tower and the relative positions of the radar and turbine. To be able to predict the RCS for a wind farm's turbine towers, the geometry of the reflections needs to be accurately understood.

As an example, Figure 3-2 shows the tower reflections for turbine location WTG5, as viewed from the Kouvola Kaipiainen radar[C]. The representative tower shape from Figure 1-2 was used in the calculation. The colours in the plot represent the strength of the reflections in the atmosphere: the value at the location of the radar is the monostatic RCS; the values in other reflection directions is the bistatic RCS. The monostatic tower RCS is used in the CLOUDSiS 1.0 assessment. It can be seen from the figure that the reflections from the bottom tower section are the dominant contribution to the monostatic RCS; the top section reflects most of the energy upwards and away from the radar, resulting in a much smaller contribution. The behaviour is the same for the other proposed turbine locations.

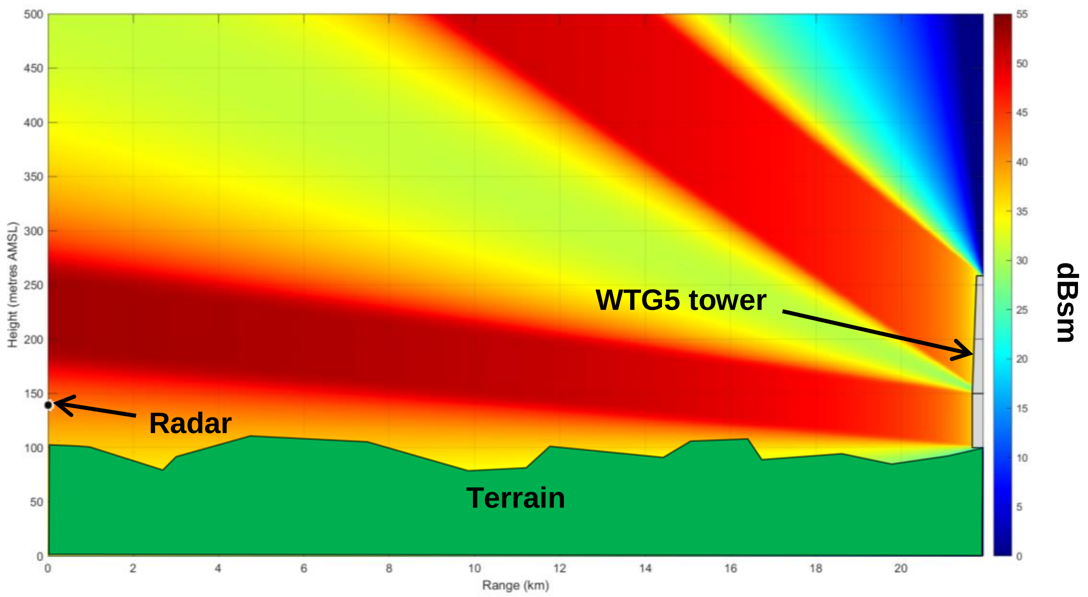

Figure 3-2: WTG5 tower reflections

[C] The terrain shown in the figure is only indicative. The proposed turbines are nearly fully in LoS, therefore, terrain shielding effects were not taken into account in the tower RCS calculations.

Figure 3-3 shows the predicted monostatic tower RCS values at all proposed turbine locations. The values range from 41.5 dBsm (WTG5) to 53.0 dBsm (WTG15). The RCS data points are labelled WTG1 (left) to WTG15 (right) as indicated in the figure.

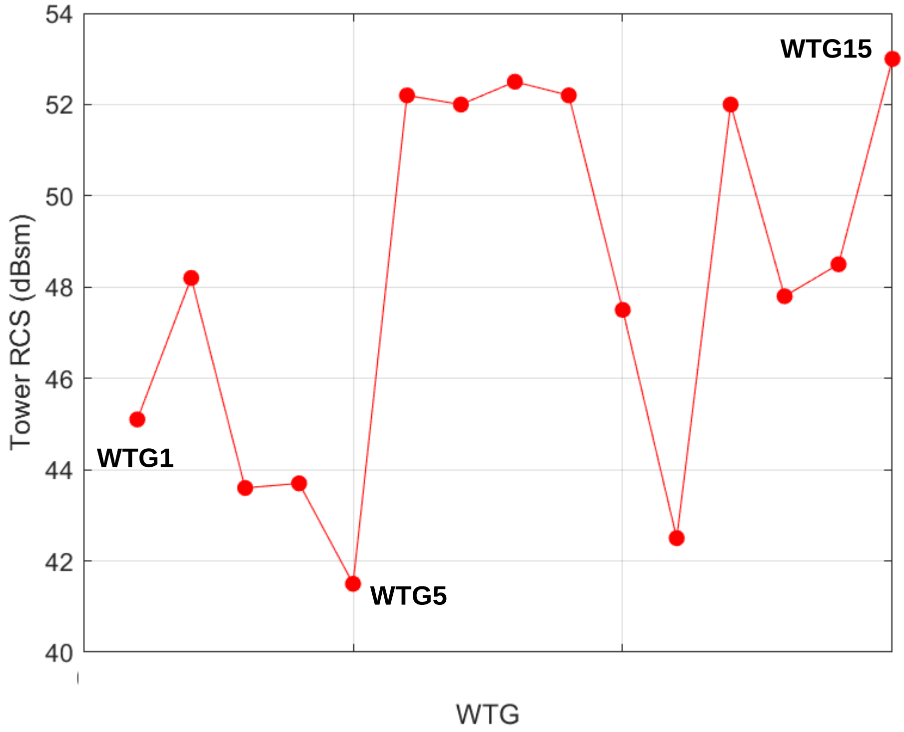

Figure 3-3: Monostatic tower RCS results for the proposed turbine locations

From this point on, all references to “tower RCS” will refer to the monostatic tower RCS. The word “monostatic” will be omitted for brevity.

4 Impact Assessment

4.1 Occultation (C1)

Any object in radar LoS may act as a blockage to radar, reducing the signal strength behind the object (shadowing). Large objects like wind turbines can have a significant influence on signal strength which, in the case of a weather radar, can result in rainfall rates being underestimated.

In the QinetiQ CLOUDSiS 1.0 method, the shadowing impact is assessed using a physical occultation model, which calculates the percentage of the beam area that is blocked by a wind turbine. Parts of the beam that are already blocked by the terrain, are not included in the calculation. If a turbine is fully outside the beam, or is out of radar LoS, it is considered to have no impact.

Figure 4-1 illustrates the occultation impact for a fictitious wind turbine and three radar scan angles. At the lowest scan angle (1) the bottom of the beam is truncated by the terrain and is not included in the calculation. The towers and blades are both within the beam and have an occultation impact; at scan angle 2 the tower is fully outside the beam, there is only a partial impact from the blades; and at the highest scan angle (3) the turbine is fully outside the beam and has no occultation impact for this scan angle. The illustration is for a single turbine. If there are multiple turbines, the individual occultation contributions for all turbines in the beam are added together to give the cumulative occultation impact.

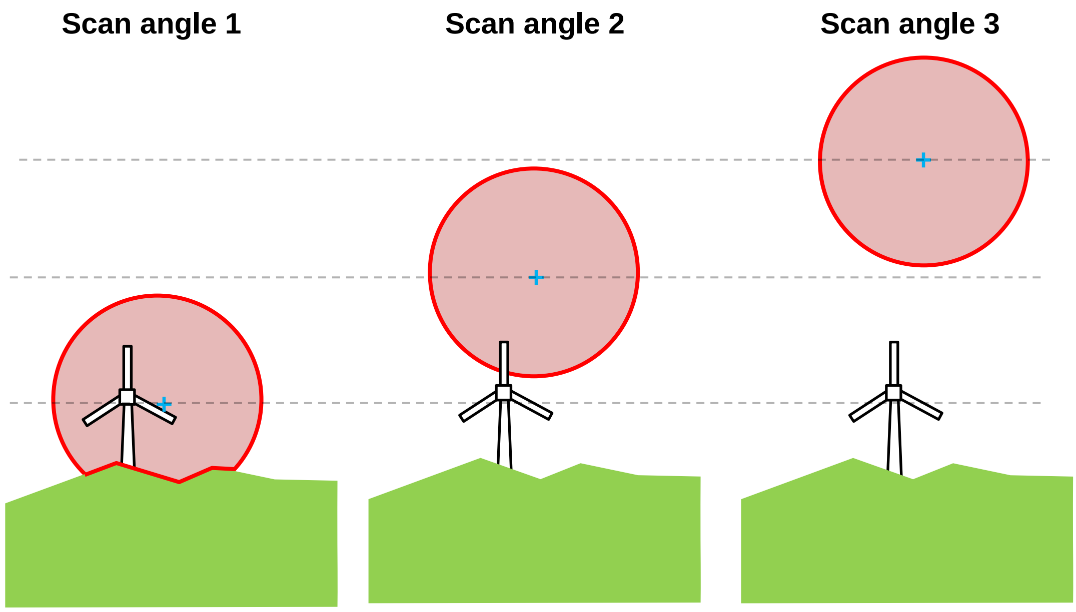

Figure 4-1: Illustration of occultation for three radar scan angles; white polygon = turbine; green = terrain; red polygon/circle = area of beam, taking into account terrain clipping; blue cross = antenna boresight

It is noted the FMI guidelines use the term “total power loss” in the description for C1, rather than “percentage occultation”. The physical occultation method is a simplified power loss model, with approximate equivalence between power loss and area of beam blocking. The physical occultation method was judged adequate for wind farm safeguarding during the CLOUDSiS validation for France weather radar safeguarding. The term “power loss” will be used in the assessment in order to be consistent with the FMI terminology.

Figure 4-2 shows the cumulative power loss from the proposed Luumäki-Suurikangas turbines, calculated for the lowest scan angle[D]. The maximum power loss is 8.3%, which is within the 10% acceptable limit. Therefore, the project is compliant with respect to C1.

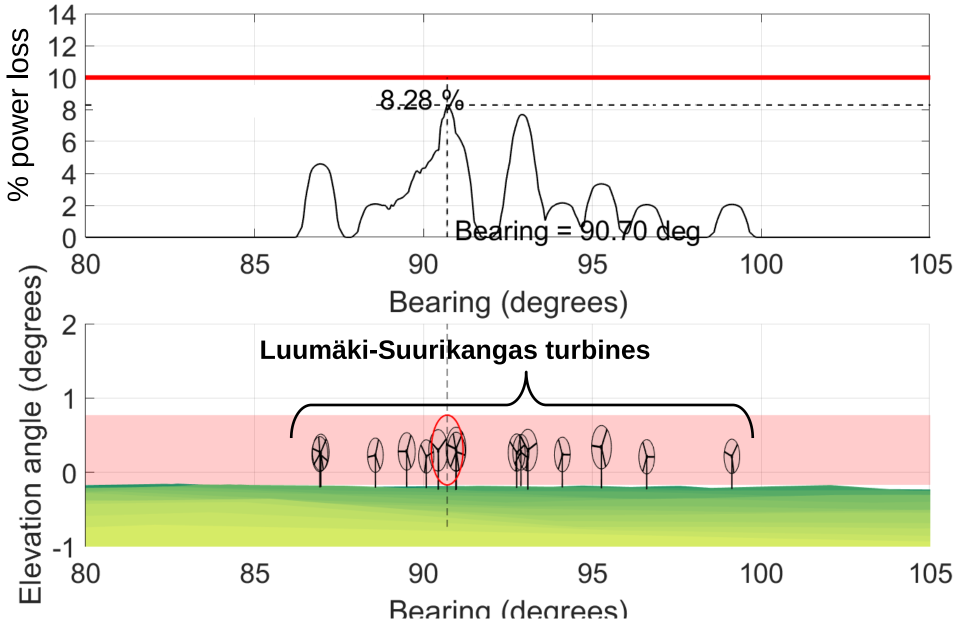

Figure 4-2: Percentage power loss from the Luumäki-Suurikangas turbines, calculated using the lowest scan angle; pink = vertical extent of the beam; green = terrain

4.2 Impact zones (C2, C3 and C4)

In weather radars, the strength of echoes from precipitation is displayed as reflectivity, which has units of Z. The data is usually presented in units of dBZ, which are decibels of Z. Unwanted reflectivity from sources of clutter in the environment (e.g. wind turbines, ground reflections) will potentially be detected and appear as fictitious rainfall in the weather radar data. As wind turbines contain both static and moving parts, all data channels[E] could be affected.

A wind turbine will have an impact if its reflectivity exceeds the impact threshold – this is the limit set by radar stakeholder to ensure wind farm reflections do not adversely affect detection of precipitation and Doppler measurements. The impact threshold is a judgement based on the operational requirements for the radar, and is different for different radar stakeholders. For example, Météo-France uses a 0 dBZ threshold, whereas FMI uses a more conservative -6 dBZ threshold [1][F].

[D] The power losses are smaller at higher scan angles.

[E] Weather radars use Doppler processing to separate the returns from static and moving objects into different channels: the returns from static objects (e.g. turbine towers, terrain, buildings) will predominantly appear in the zero-Doppler channel of the radar; whereas the returns from moving objects (such as the turbine blades) will predominantly appear in the non-zero Doppler channels.

[F] The FMI guidelines request additional results are shown for other impact thresholds (noise level, 8 dBZ, and 45 dBZ). These are included in the Appendix and are provided for information only. Only the results using the -6 dBZ threshold are used in evaluating C2 and C3 (C4 is not relevant because there are no other wind farms within the CA radius).

In the CLOUDSiS 1.0 method, the impact zone due to a wind farm is defined as all grid cells[G] where the composite wind farm reflectivity (the maximum reflectivity out of all scan angles) exceeds the impact threshold. The lowest four scan angles are used in the calculations. Turbines are only included if they are in radar LoS. If a turbine is fully out of radar LoS it is considered to have no impact.

Figure 4-3 shows an example impact zone (red polygon) for a fictional wind farm within the CA radius for Kouvola Kaipiainen. The colours show the composite reflectivity values from the turbines (black dots) overlaid on the grid. It can be seen from the figure that there are two distinct regions of reflectivity:

- A region of high reflectivity, located at the range of the turbines. This is due to direct reflections. Side lobe detections[H] are taken into account; and
- A region of low reflectivity, extending behind the turbines – this is attributed to multipath scattering between turbines, and between turbines and the ground. The QinetiQ model assumes that significant ground-turbine multipath can only occur within 6 km of the turbines.

Note the strength of the multipath will depend on the characteristics of the turbines and the angle subtended by the radar beam and the terrain. If the elevation angles between the radar and the turbines are much lower than the radar scan angles, the multipath effects may be much smaller or might not be observed at all.

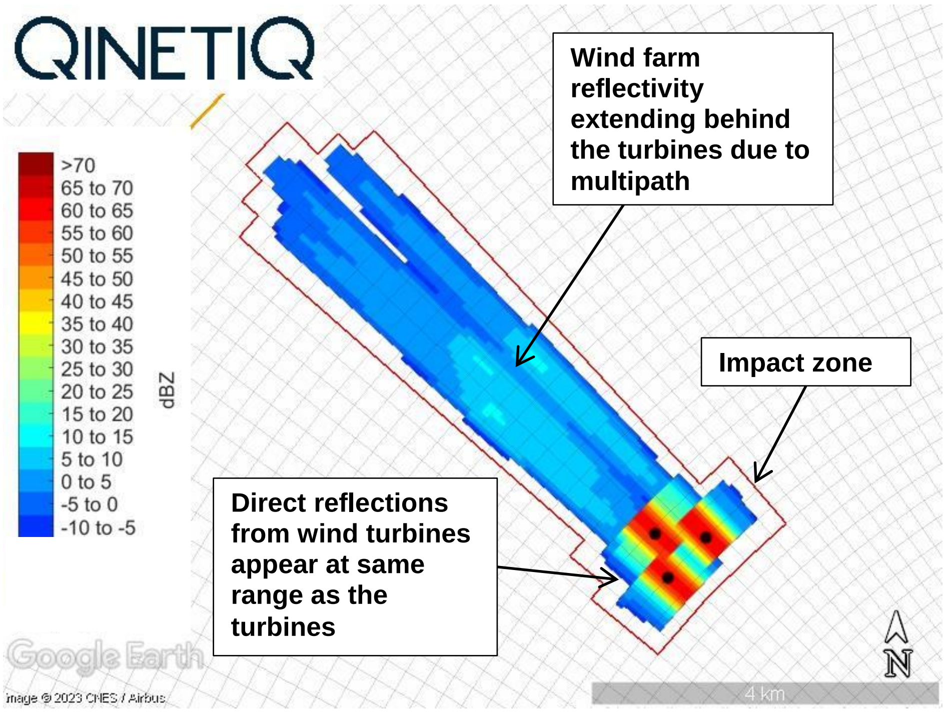

Figure 4-3: Example impact zone (red polygon) due to towers and blades for a fictional wind farm (black dots), overlaid on wind farm composite reflectivity. An impact threshold of -6 dBZ threshold was used; grey lines = 250 m x 1 degree cells

[G] The raw radar data is processed onto polar or Cartesian grids before it is released to the general public. A polar grid of 250 m x 1 degree cells is used for the assessment, as agreed with FMI.
[H] The antenna beam for a weather radar consists of a narrow main lobe and lower side lobes. Most of the energy is transmitted/received along the main lobe. However, if the return from an object is high enough, it may be detected through the side lobes as well as the main lobe; this is called side lobe breakthrough.

The impact zones for the proposed Luumäki-Suurikangas wind turbines are reported in sections 4.2.1 to 4.2.4. In accordance with the FMI guidelines, results are shown for the following four turbine/RCS[I] cases [1]:

- Blades only, peak RCS;
- Blades only, typical RCS;
- Whole turbine, peak RCS; and
- Whole turbine, typical RCS;

For each case, the impact zone is shown, overlaid on a map of the wind farm composite reflectivity. The maximum dimension of the impact zone, the angular extent of the impact zone, and the maximum wind farm reflectivity[J], are reported. The separation from other impact zones is not relevant because there are no other wind farms within the CA radius.

[I] The RCS values used for each case are described in the relevant sections.
[J] The maximum reflectivity is not used in the acceptance criteria, but is included at the request of FMI [1].

4.2.1 Blades only, peak RCS

Figure 4-4 shows the impact zone from the blades, calculated using the peak blade RCS from Section 3.1.1. The main results are:

- Maximum size of impact zone = 13.1 km;
- Angular extent of impact zone = 29 degrees (077.5°N to 106.5°N); and
- Maximum turbine reflectivity = 88.5 dBZ (WTG12).

This is considered to be a valid 'footprint' of where impacts could occur, but an overestimate of the true impact at any one radar scan. The turbine RCS will fluctuate quickly, and it is unlikely that the maximum RCS persists during the radar dwell. Also, it is unlikely that all turbines will simultaneously have their maximum RCS.

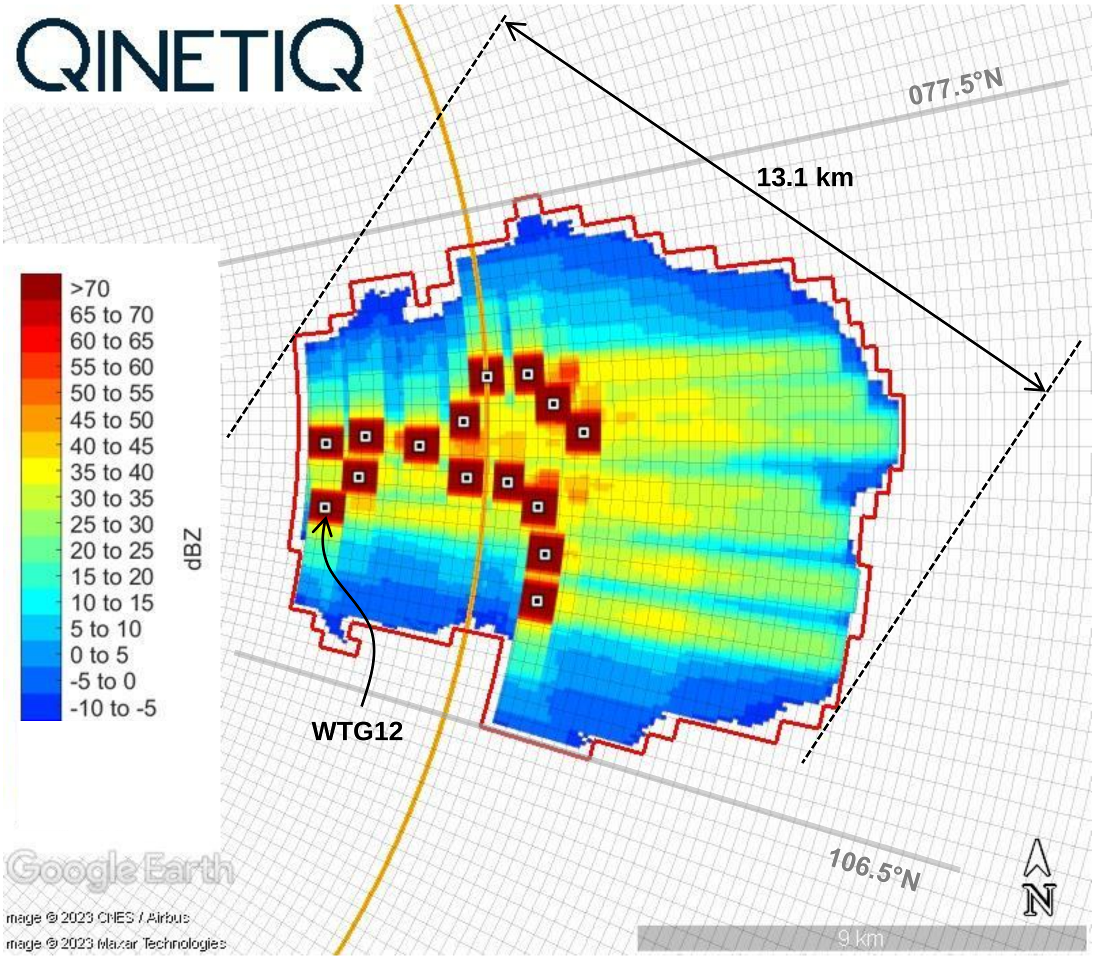

Figure 4-4: Luumäki-Suurikangas impact zone (red polygon) due to reflections from the blades (peak blade RCS)

4.2.2 Blades only, typical RCS

Figure 4-5 shows the impact zone from the blades, calculated using the typical blade RCS from Section 3.1.1. The main results are:

- Maximum size of impact zone = 12.5 km;
- Angular extent of impact zone = 21 degrees (082.5°N to 103.5°N); and
- Maximum turbine reflectivity = 68.5 dBZ (WTG12).

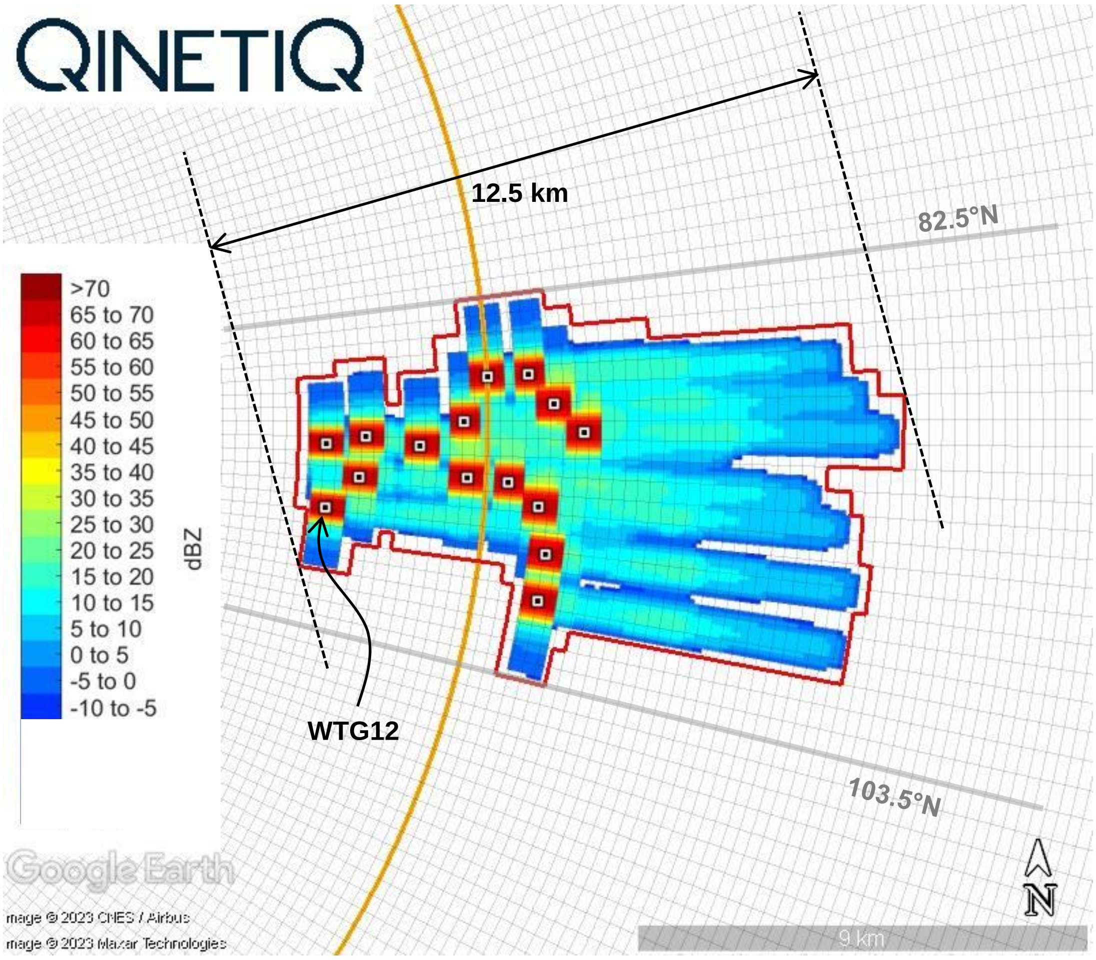

Figure 4-5: Luumäki-Suurikangas impact zone (red polygon) due to reflections from the blades (typical blade RCS)

4.2.3 Whole turbine, peak RCS

Figure 4-6 shows the impact zone from the tower and blades, calculated using the peak blade RCS values from Section 3.1.1 and the tower RCS values from Section 3.1.2. The main results are:

- Maximum size of impact zone = 13.1 km;
- Angular extent of impact zone = 29 degrees (077.5°N to 106.5°N); and
- Maximum turbine reflectivity = 88.5 dBZ (WTG12).

For the same reasons as discussed in Section 4.2.1, the results presented are considered to be an unrealistic worst-case scenario.

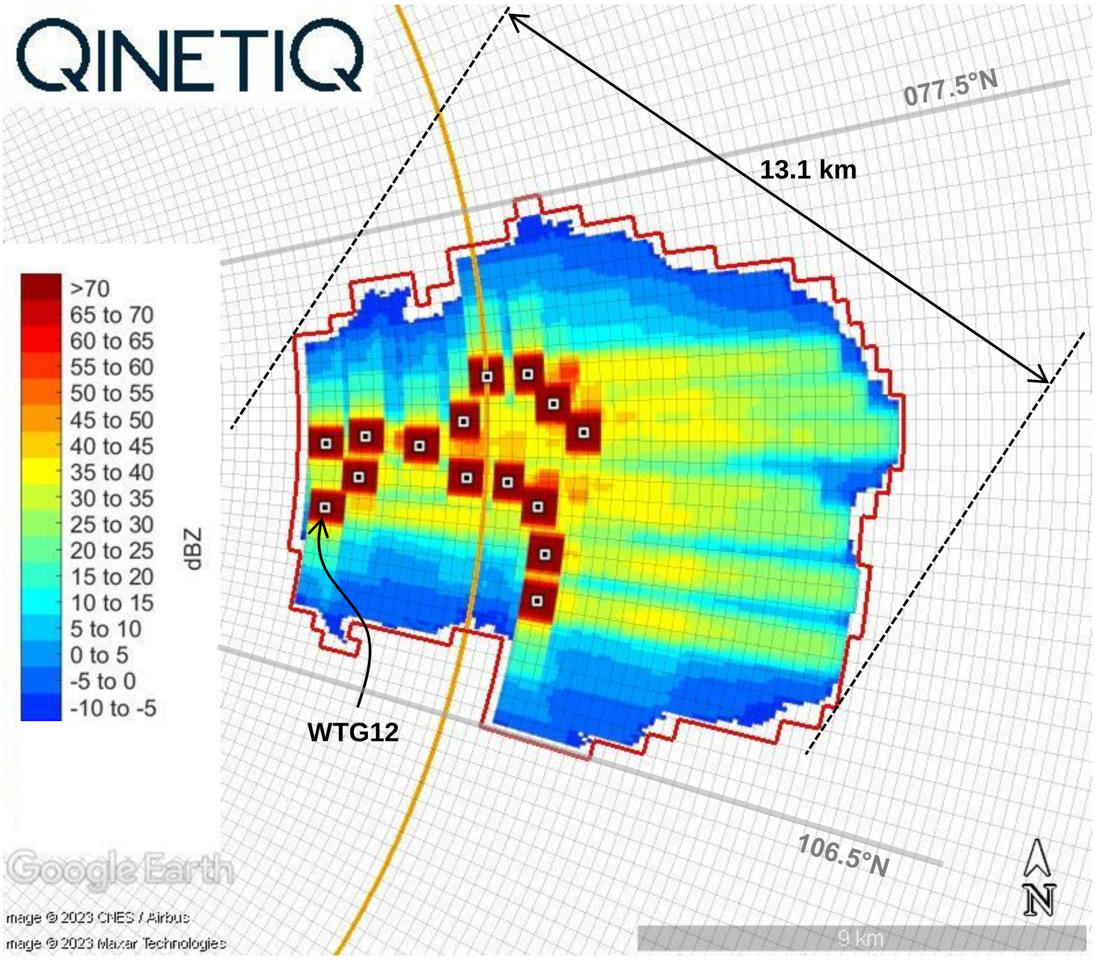

Figure 4-6: Luumäki-Suurikangas impact zone (red polygon) due to reflections from the towers and blades (peak blade RCS)

4.2.4 Whole turbine, typical RCS

Figure 4-7 shows the impact zone from the tower and blades, calculated using the peak blade RCS values from Section 3.1.1 and the tower RCS values from Section 3.1.2. The main results are:

- Maximum size of impact zone = 12.9 km;
- Angular extent of impact zone = 24 degrees (081.5°N to 105.5°N); and
- Maximum turbine reflectivity = 84.8 dBZ (WTG12).

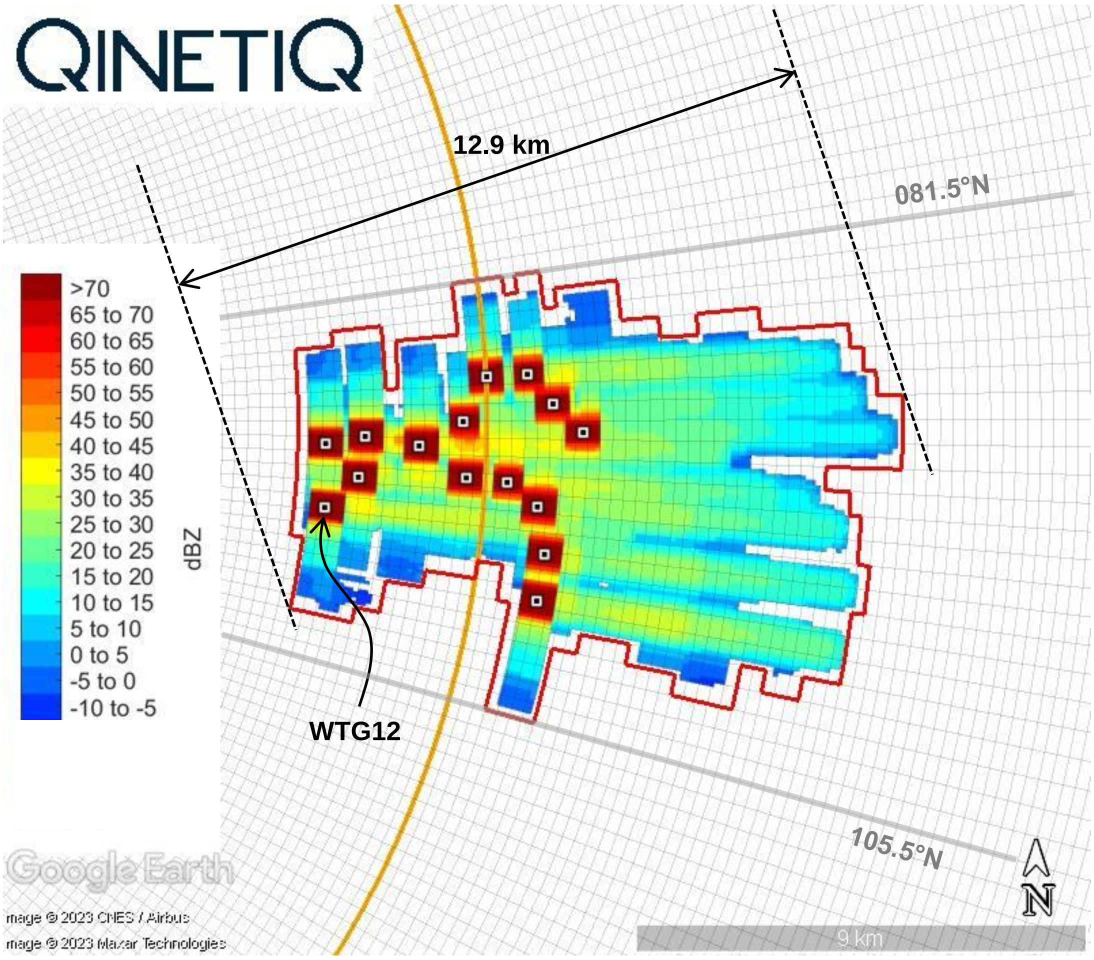

Figure 4-7: Luumäki-Suurikangas impact zone (red polygon) due to reflections from the towers and blades (typical blade RCS)

4.3 Acceptability

The impact metrics are summarised in Table 4-1 (C1) and Table 4-2 (C2 to C4). Regarding the C2 to C4 metrics, it is not known which of the four cases will be used by FMI to assess the acceptability. However, the overall conclusions are the same for all cases:

- The proposed wind farm passes C1 and C3;
- The proposed wind farm fails C2; and
- C4 is not relevant (no other wind turbines within the CA radius).

As the project fails C2 (all cases), it is likely the project will receive an objection from FMI. Refining the tower shape will not remove the constraint for any of the cases. It might be possible to remove the C2 constraint by removing turbines, however, it is likely this would require several turbine locations to be deleted from the layout. If FMI is concerned about the size of the impact zone and removing turbines is a viable option for Myrsky Energia Oy, this can be investigated.

Criterion	Description	Result
C1	Maximum power loss must be less than 10%.	8.3% (PASS)

Table 4-1: Summary of results for C1

Criterion	Description	Turbine / RCS cases			
		Blades only, peak RCS	Blades only, typical RCS	Whole turbine, peak RCS	Whole turbine, typical RCS
C2	Size of impact zone must be less than 10 km.	13.1 km (FAIL)	12.5 km (FAIL)	13.1 km (FAIL)	12.9 km (FAIL)
C3	Angular extent of impact zone must not exceed 30°.	29° (PASS)	21° (PASS)	29° (PASS)	24° (PASS)
C4	Minimum separation from other impact zones must be greater than 10 km.	Not applicable	Not applicable	Not applicable	Not applicable

Table 4-2: Summary of results for C2 to C4, for the four turbine/RCS cases

4.4 Saturation check

The results in Section 4.2 showed the maximum reflectivity due to the direct returns from individual turbines is just under 90 dBZ. This is much higher than the estimated saturation level (between 67 dBZ and 69 dBZ depending on the turbine location[K]). Therefore, there is a risk the received signals from the turbines could cause the radar's receiver to go into saturation, resulting in a loss of sensitivity and, consequently, a loss of detection.

[K] The saturation level was estimated using the known noise level for the radar (-112 dBm) and a representative dynamic range for the receiver, based on the known dynamic range for other FMI radars.

It is stressed that this simple check does not take into account the separate reflection contributions from the towers and blades, or the cumulative effects from multiple turbines detected in the same range cell. Also, if FMI uses techniques for suppressing the reflections from close-range objects, it is possible these will mitigate the impact.

If FMI is concerned about saturation, the report can be updated to include a detailed analysis of the impact.

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5 Conclusions

Myrsky Energia Oy is developing the Luumäki-Suurikangas wind farm, located within 20 km of the Kouvola Kaipiainen weather radar. The project consists of fifteen Vestas V172 turbines, with a hub height of 161 m and a maximum blade tip height of 247 m. All turbines are in LoS and will have an impact.

An impact assessment was carried out using the QinetiQ CLOUDSiS 1.0 method, using an impact threshold of -6 dBZ. A representative tower shape was used in the calculations. The results were compared against the four FMI acceptance criteria (see Section 1.4). For the C2 and C3 metrics, results were shown for four cases: blades only (peak RCS); blades only (typical RCS); whole turbine (peak RCS); and whole turbine (typical RCS).

The main findings are:

- The proposed wind farm is compliant with respect to C1 (power loss) and C3 (angular extent of impact zone);
- The proposed wind farm fails C2 (size of impact zone) for all four modelling cases; and
- C4 is not relevant (no other wind turbines within the CA radius).

Following the FMI guidelines, the project is likely to receive an objection from FMI due to the C2 metric exceeding 10 km. Refining the tower shape will not remove the constraint.

The impact zones for scenarios using the peak RCS are considered to be a valid ‘footprint’ of where impacts could occur, but an overestimate of the true impact at any one radar scan. The turbine RCS will fluctuate quickly, and it is unlikely that the maximum RCS persists during the radar dwell. Also, it is unlikely that all turbines will simultaneously have their maximum RCS.

A saturation check showed there is the potential for saturation effects to occur due to reflections from the turbines. This was not a rigorous analysis and did not take into account techniques that may (or may not) be used by the radar to suppress the returns from nearby objects.

Finally, additional results for other impact thresholds are given in the appendix at the request of FMI, but are not included in the main analysis.

A Appendix

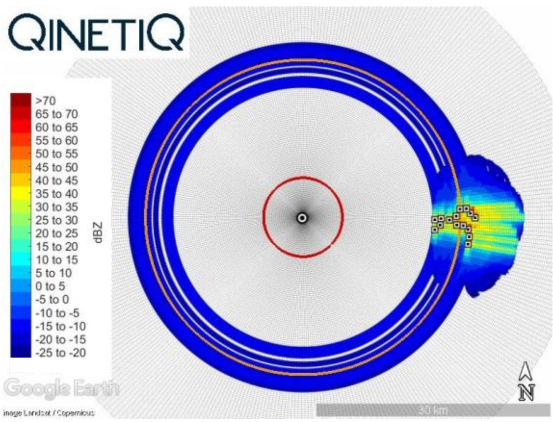
This section show the wind farm reflectivity for different thresholds:

- -22 dBZ (Figure A-1). This threshold is representative of the noise level at the range of the turbines;
- 8 dBZ (Figure A-2); and
- 45 dBZ (Figure A-3).

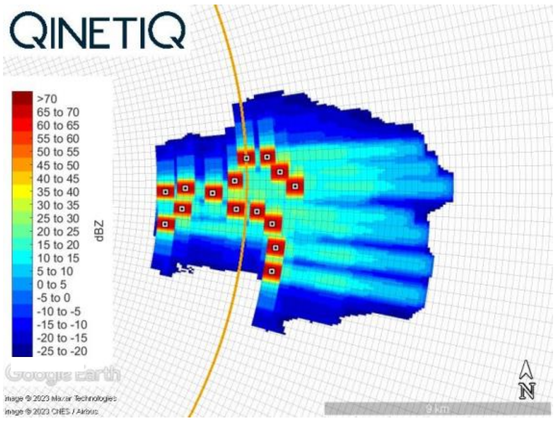
In each figure, white circle = radar; orange line = CA radius; grey lines = grid cells; and white squares = proposed turbines. The wind farm reflectivity is only shown in the areas that are impacted (for the given threshold). For some figures, the PZ radius (red line) is also shown.

Note the complete ring around effect for three of the modelling cases when the -22 dBZ threshold is used. However, it is stressed that the antenna beam provided by FMI only covered a small angular range, and was extrapolated to cover the full angular range. Accordingly, the reflectivity values at wide angles are indicative only. Also, the predicted reflectivity values at wide angles are very small, much lower than the detection thresholds for precipitation, and will perhaps be of less operational significance (this would need to be confirmed by FMI).

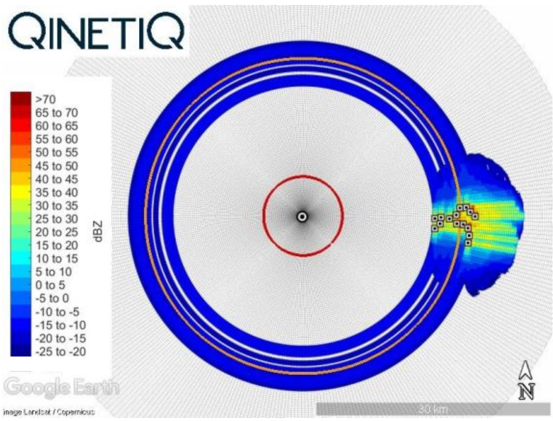
Blades, peak RCS



Blades, typical RCS



Towers and blades, peak blade RCS



Towers and blades, typical blade RCS

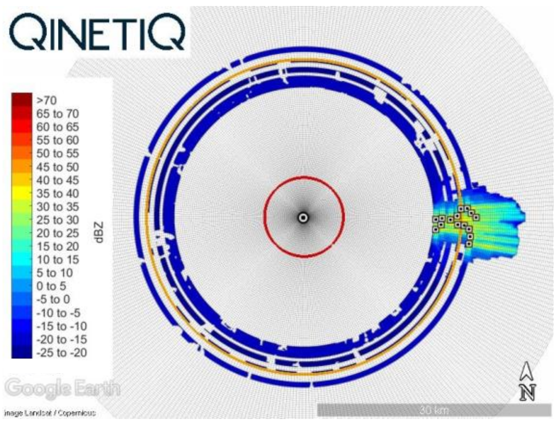
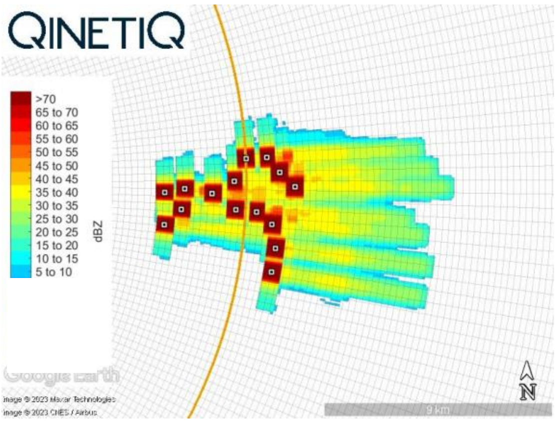
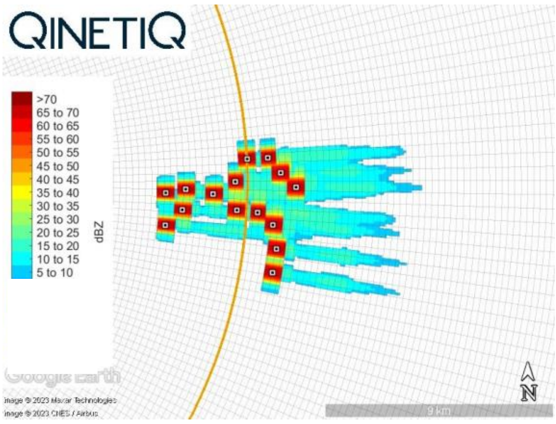


Figure A-1: Luumäki-Suurikangas impact, calculated using -22 dBZ impact threshold

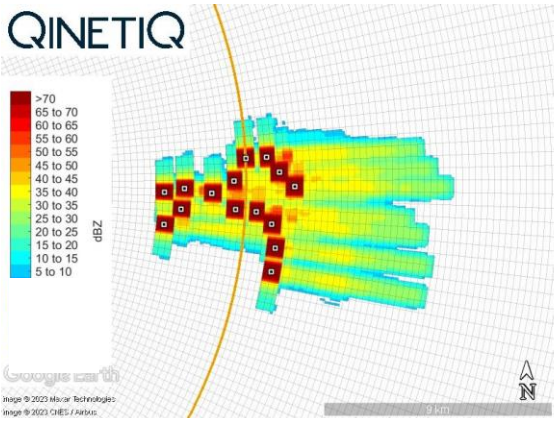
Blades, peak RCS



Blades, typical RCS



**Towers and blades,
peak blade RCS**



**Towers and blades,
typical blade RCS**

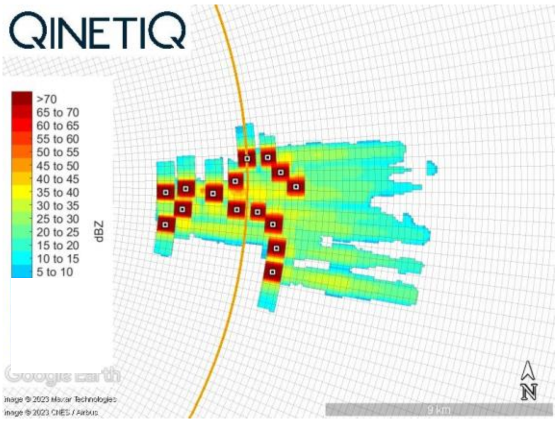


Figure A-2: Luumäki-Suurikangas impact zones, calculated using 8 dBZ threshold

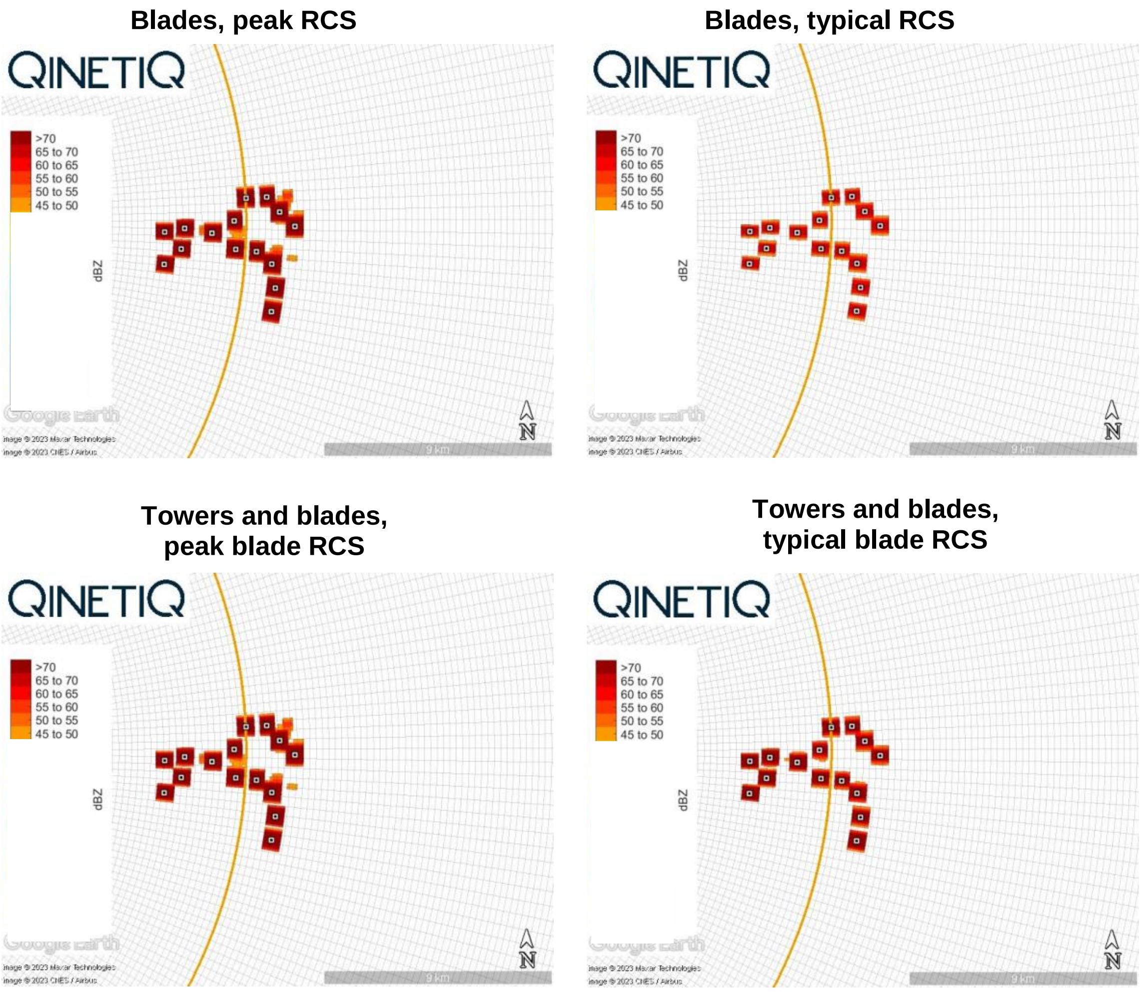


Figure A-3: Luumäki-Suurikangas impact zones, calculated using 45 dBZ threshold

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