Study of the Impact of La Perrière on the Weather radar of Colorado for Quadran

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1 Introduction

1.1 Background

Quadran, the Customer, is planning to repower the existing La Perrière wind farm, located in the commune of Sainte-Suzanne on the north coast of the French island and department of Réunion. The site is approximately 17.4 km to the east of the Colorado weather radar, safeguarded by Météo-France. Quadran has requested a radar impact assessment to quantify the radar impacts of the proposed wind farm, and compare them against the acceptance criteria in the French legislation [1].

1.2 Scope of work

The assessment is carried out in accordance with the approved [2][3] QinetiQ CLOUDSiS 1.0 method for assessing the impacts on Météo-France weather radars.

1.3 La Perrière repowering

The proposed repowering consists of nine Vestas V110 turbines, with hub heights above ground level (AGL) of 80 metres. These will replace the existing turbines, which will all be dismantled. Figure 1-1 shows the proposed turbine layout (white square icons) along with turbine identification (ID) numbers. Some of the existing turbines can be seen in the background as black wind turbine icons.

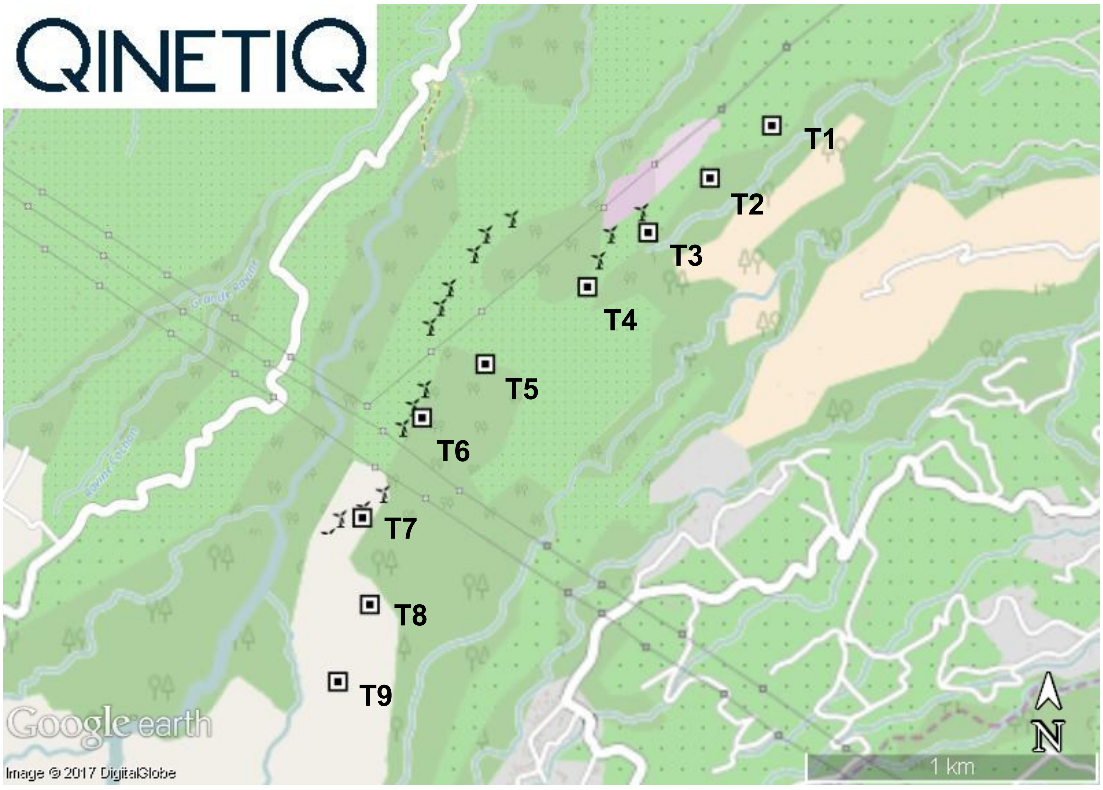

Figure 1-1: Turbine layout of the proposed repowering

The locations of the repowering turbines were supplied by Quadran in World Geodetic System 1984 (WGS84) latitude and longitude format [4]. The individual turbine locations are shown in Table 1-1, along with the NGF ground elevations in metres above mean sea level (AMSL), provided by the Customer.

Turbine ID	WGS84 coordinates (degrees decimal)		Ground elevation, NGF (m AMSL)
	Latitude (North)	*Longitude (East)*	
T1	-20.948792	55.594714	333
T2	-20.950414	55.592672	358
T3	-20.952092	55.590631	389
T4	-20.953772	55.588625	413
T5	-20.956150	55.585253	458
T6	-20.957811	55.583164	487
T7	-20.960897	55.581192	526
T8	-20.963572	55.581439	558
T9	-20.965953	55.580386	580

Table 1-1: Turbine coordinates [4] and ground elevations in NGF altitude format [4] for the proposed wind farm

Details of the Vestas V110 turbine types were provided by the Customer [4][5]. The dimensions used in the assessment are summarised in Table 1-2. A linear tower shape was assumed in the modelling [6].

Parameter	Value
Turbine type	Vestas V110
Hub height (metres)	80
Tower base diameter (metres)	3.7
Tower top diameter (metres)	2.5
Rotor diameter (metres)	110
Blade tip height (metres)	135

Table 1-2: Turbine parameters used in the assessment for the proposed wind farm [4][5]

1.4 Colorado weather radar

Météo-France owns and operates the Colorado meteorological radar. Radar parameters were provided by Météo-France [7]. The main parameters used in the assessment are shown in Table 1-3.

Parameter	Value
Latitude (WGS84, degrees north)	-20.911784
Longitude (WGS84, degrees east)	55.421948
Antenna altitude AMSL (metres) in Institut géographique national (IGN) 1989 (IGN-89) format	749.8
Frequency (GHz)	2.81
Peak power (kW)	740
Pulse duration (seconds)	2×10^{-6}

3dB beamwidth (degrees)	1.2
Maximum antenna gain (dB)	42.5
Receiver noise floor (dBm)	-114
Detection threshold above noise floor (dB)	2
Noise figure (dB)	4.3
Clutter cancellation factor (dB)	30
Maximum operating range (km)	250
Antenna rotation rate (degrees / second)	6
Total losses (dB)	5.4
Lowest three scan angles (degrees)[A]	0.3 / 0.8 / 1.4
Radar constant (dB)	-72

Table 1-3: Main radar parameters used in the assessment

The antenna pattern used in the modelling is shown in Figure 1-2.

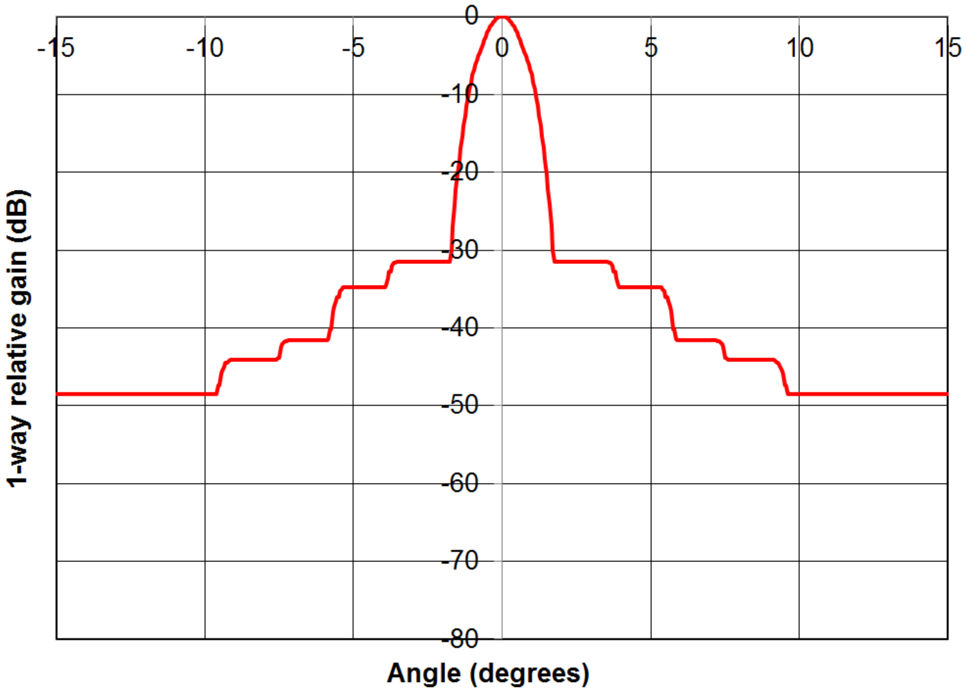

Figure 1-2: Beam pattern used in the modelling

A grid resolution[B] of 1 km was assumed.

[A] Scan angle refers to the elevation angle of the weather radar beam. Elevation detection is achieved by utilising a circular dish as an antenna, which produced a highly focused, torch like beam propagating into the atmosphere. To enable different heights to be monitored, the antenna is mechanically scanned in both azimuth and elevation, creating a volume coverage pattern (VCP). This creates a series of layers in elevation, with each layer containing range and bearing information.

[B] The raw radar data is usually ordered into cells of a defined range and bearing. The angular width of each cell fixed, and therefore, the cell area increases with range from the radar. The majority of weather products released to the general public are converted from these range-azimuth grids, into

1.5 Impacts of wind turbines

There are three main ways in which wind turbines can affect weather radars, as outlined in the 2006 and 2010 reports by the OPERA (Operational Programme for the Exchange of weather Radar information) group of EUMETNET (European Meteorological Services Network) [8][9]. The main effects outlined are:

- Blocking of the beam (occultation) by obstacles such as wind turbines, which can result in the reduced visibility of objects such as precipitation and hail;
- Reflections from wind turbines, which can result in increased clutter levels. This can lead to a decrease in the ability of the radar to detect less reflective objects in that region, such as precipitation or hail; and
- An interference of Doppler measurements that can cause erroneous values in the velocity measurements of any precipitation in the region, which is difficult to mitigate due to the variability of the reflections.

However, the actual effects produced by the turbines on a radar operator's display will depend on the exact filtering techniques used by the radar, and the environmental conditions on the day.

According to the 2010 OPERA report [9] the technical impacts can affect the following meteorological services: i) weather forecasting; ii) hydrological forecasts and warnings; iii) pollution and industrial and nuclear risk management; and iv) medium and long term products.

1.6 Safeguarding zones

The French legislation for the development of wind farms near radar facilities in France is laid out in [1]. The safeguarding zones for Météo-France C-band, S-band and X-band radar facilities[C], as given by the legislation, are shown in Table 1-4.

Radar band	**Distance between a turbine and a radar**		
	Protection zone	Coordination area	Authorised zone
S	< 10 km	10 km to 30 km	> 30 km
C	< 5 km	5 km to 20 km	> 20 km
X	< 4 km	4 km to 10 km	> 10 km

Table 1-4: Safeguarding zones for the development of wind farms near Météo-France radar facilities

According to the legislation, wind farms are not allowed to be developed inside the protection zone of a Météo-France radar facility, except in special cases where Météo-France has been consulted and they have judged that impacts on the provision of their services are not operationally significant [10]. If a proposed wind farm is physically inside the coordination area of a Météo-France radar facility, a radar impact assessment is required. In order for the wind farm to be compliant with the legislation, the following criteria must be satisfied:

square Cartesian grids (so called XY grids), with a constant cell size that is independent of range. This allows the released products to provide a consistent resolution over all regions.

[C] The 'S', 'C' and 'X' microwave bands refer to radar-frequency bands according to the institute of Electrical and Electronics Engineers' (IEEE) standard. The ranges are 2 GHz to 4 GHz for S-band; 4 GHz to 8 GHz for C-band; and 8 GHz to 12 GHz for X-band.

- **Criterion 1.** The maximum percentage occultation of the wind farm (including the existing wind farm environment) must not exceed 10%;
- **Criterion 2.** The size of the impact zone due to a wind farm must not exceed 10 km, measured along the longest dimension. Only the parts of the impact zone that are inside the coordination area are taken into account in the calculation [10];
- **Criterion 3.** The interdistance between impact zones from different wind farms must be at least 10 km; and
- **Criterion 4.** The interdistance between wind farm impact zones and sensitive sites[D] must be at least 10 km.

If a proposed wind farm is in the authorised zone, an objection against the proposed wind farm on the grounds of radar impacts is unlikely.

All proposed turbines are within the coordination area of the Colorado radar (10 km to 30 km at S-band frequency of the radar). An assessment is required to compare the impacts against the four criteria.

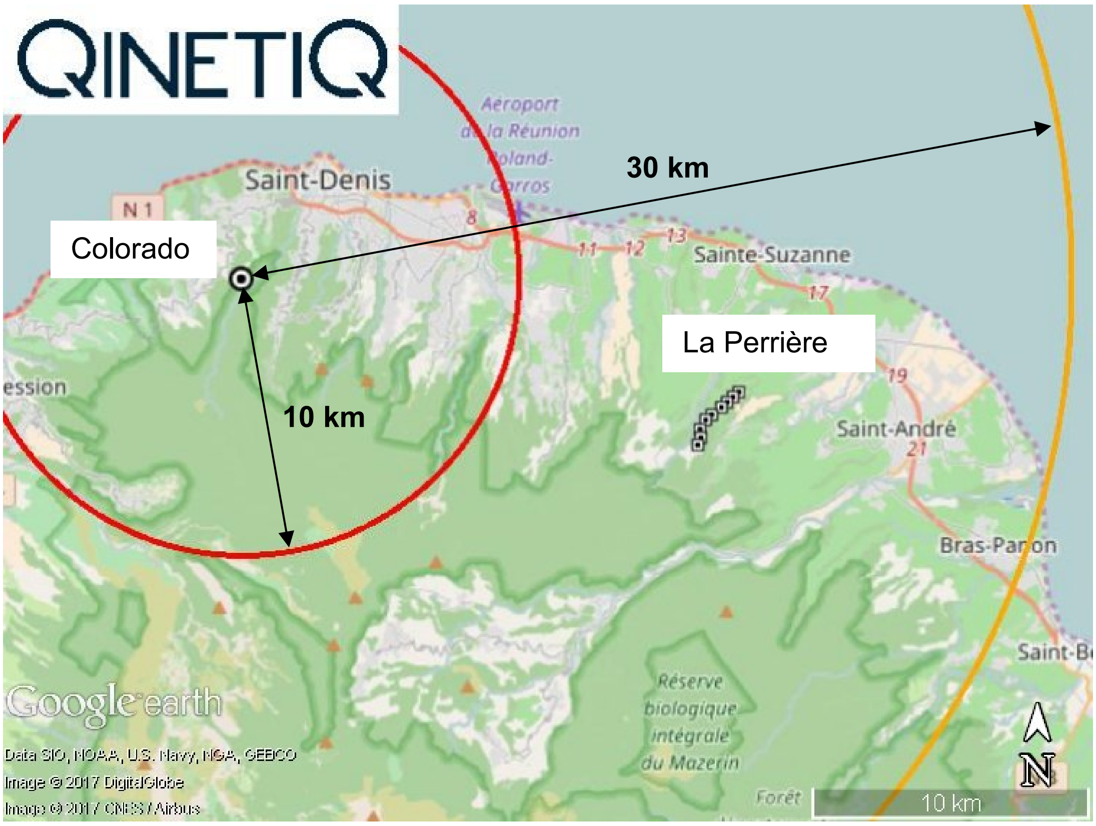

Figure 1-3: Proposed turbine locations (white squares) in relation to the protection zone (0 km to 10 km) and coordination area (10 km to 30 km)

1.7 Other wind farms

There are no other wind farms within the coordination area of the Colorado radar [4][11].

[D] Sensitive sites consist of Seveso sites (high threshold) and basic nuclear facilities (INBs) mentioned in Article L. 515-36 of the Environment Code.

1.8 Sensitive sites

Details of sensitive sites were provided by Quadran [12]. Additional information was obtained from [13][14]. Based on this information, there are four sensitive sites in the coordination area, namely SRPP, COROI SAS, EDF-PEI SAS, and SCPR. The locations of these sites were obtained from Quadran, and are listed in

Site	Latitude (WGS84, degrees north)	Longitude (WGS84, degrees east)
SRPP:	-20.925789	55.289728
COROI	-20.928428	55.285006
EDF-PEI	-20.929578	55.326619
SCPR	-21.025778	55.248156

Table 1-5: Locations of sensitive sites used in the assessment [12]

Figure 1-4 shows a map of the sensitive sites used in the assessment (green diamonds) in relation to the proposed turbines (white squares).

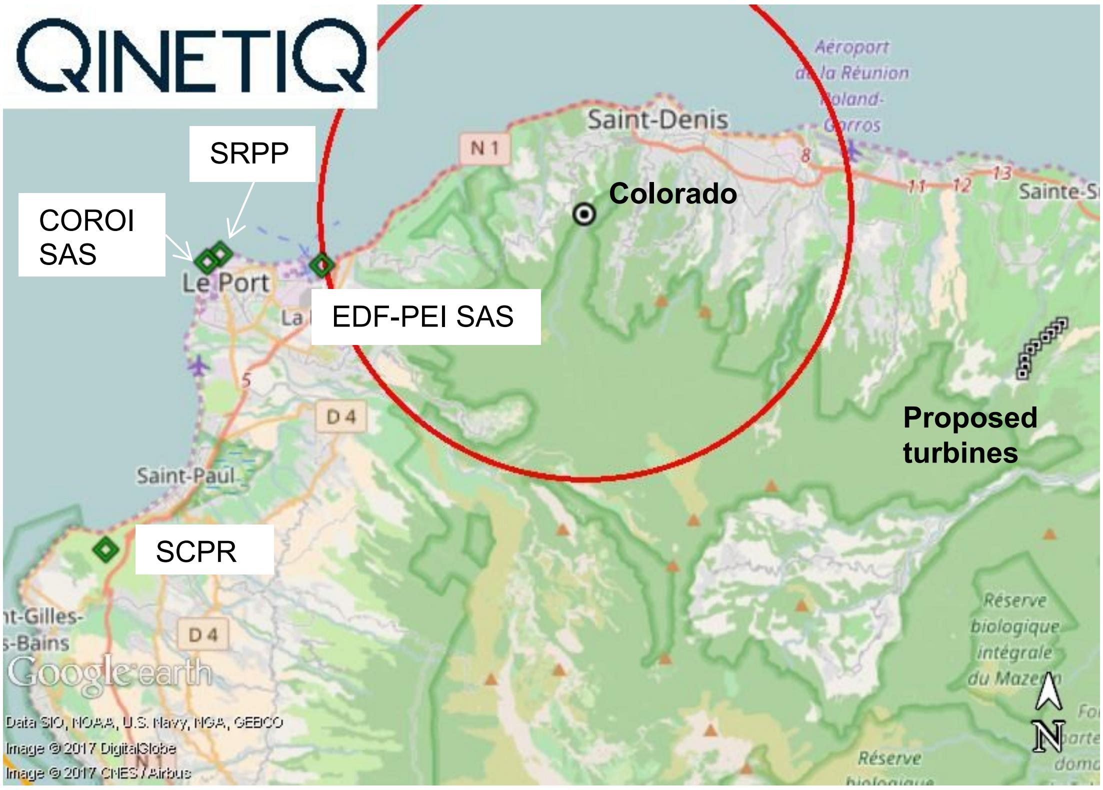

Figure 1-4: Locations of sensitive sites (green diamonds) used in the assessment

2 Assessment

In this section the impacts of the proposed wind farm will be quantified using the turbine layout from Table 1-1 and the worst case turbine type from Table 1-2. The results will be compared against the French legislation acceptance criteria to show whether or not the impacts are compliant.

2.1 Line of sight analysis

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.

Figure 2-1 shows the percentage LoS visibility in the vicinity of the proposed turbines (white squares), as viewed from the Colorado radar. The colours represent how much of the structure is in LoS. For example, light green (indicating a value of 50%) means that the top half of the obstacle will be in LoS and is likely to be detectable to the radar.

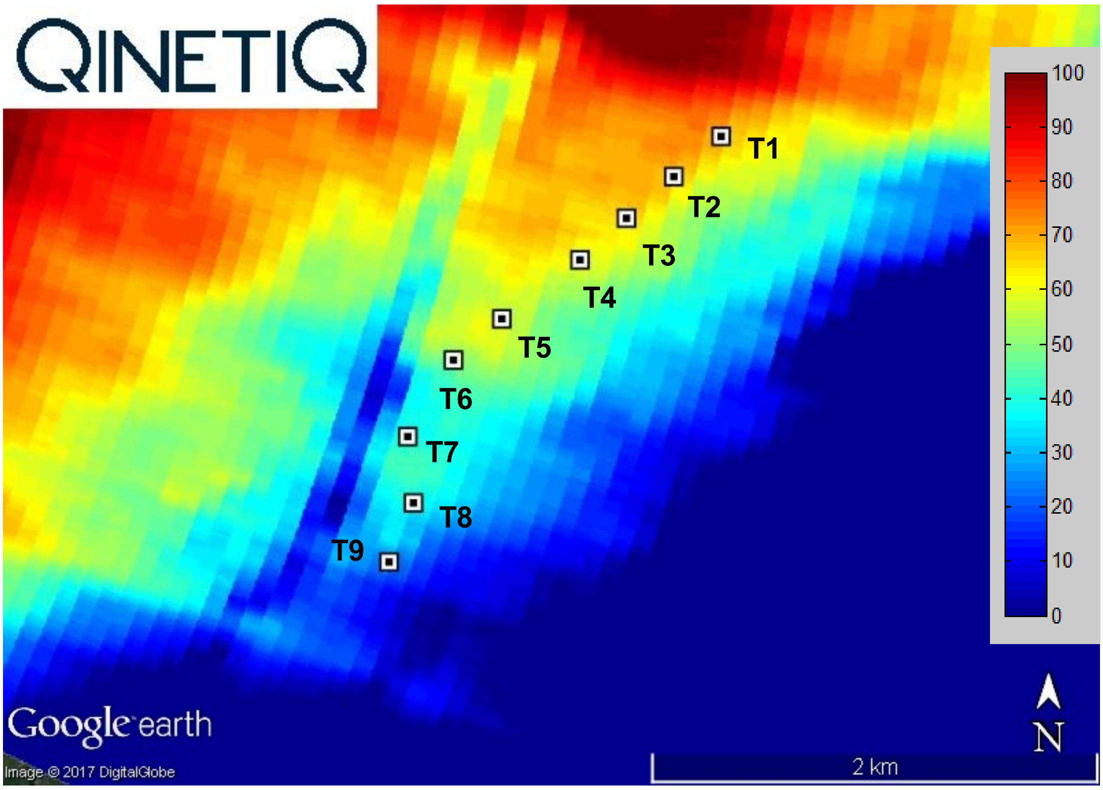

Figure 2-1: Percentage LoS visibility of a 135 metre structure as viewed from the Colorado radar

It can be seen from Figure 2-1 that the proposed turbines are partially in LoS. The LoS visibility ranges from 25.9% to 70.9%. The blades of all turbines are in radar LoS, and are likely to be detectable to the radar. For most turbines, the towers are also in radar LoS and are likely to be detectable. However, the towers are out of

LoS for turbines T7, T8, and T9. The towers of these turbines are less likely to be detectable, therefore, any impacts from the towers will be reduced.

2.2 Criterion 1: occultation

Any object in radar LoS may act as a blockage to radar, reducing the signal strength behind the object. 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 order to be compliant with the French legislation, the percentage occultation of a wind farm must not exceed 10%.

The occultation from the proposed wind farm was calculated using the dimensions from Table 1-2.

Figure 2-2 shows the percentage occultation results for the lowest scan angle, 0.3 degrees. The occultation will be less at higher scan angles. The results show that the maximum occultation due to the proposed wind farm is approximately 0.1 %, which is significantly less than the 10% limit. Accordingly, the repowering project is compliant with the legislation in terms of occultation.

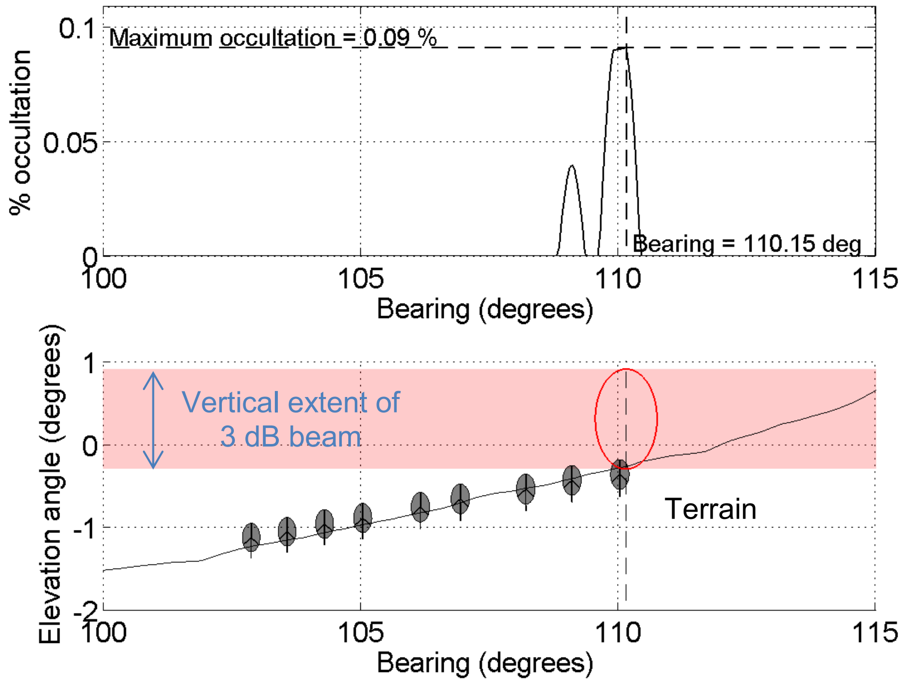

Figure 2-2: Percentage occultation due to the proposed wind farm, calculated using the V110 turbine type. Scan angle = 0.3 degrees

2.3 Criteria 2 and 3: Impact zone size and interdistance between impact zones

2.3.1 Composite reflectivity

In this section the reflectivity due to the combined wind farm is calculated, to show how strong the reflections from the turbines will be. There are two main types of information used in meteorology, often referred to as products, which can be derived from modern weather radars; reflectivity and radial velocity. Reflectivity is a display of the echo intensity, which is measured in units of Z, and is essentially the amount of transmitted power returned back to the radar receiver. Two forms of the reflectivity data are often presented; *base* and *composite*. Base reflectivity images are typically information from the lowest elevation angle that has been scanned, and are used to detect precipitation and hail that is closest to the ground. Composite reflectivity is the maximum echo intensity across all the layers in elevation, at all ranges from the radar, and is used to determine the highest reflectivity in all echoes. Composite reflectivity is often important for revealing storm structure features and intensity trends of storms. The data is usually presented in units of dBZ, which are decibels of Z. The decibel, or dB, is a logarithmic scale, often used by engineers to describe the signal levels in radar systems due to the large variations encountered, and is a unit of measurement that expresses the magnitude of a quantity relative to a specified or implied reference level.

Only the bottom three elevation layers are used in the calculation.

Figure 2-3 shows the composite reflectivity due to reflections from the proposed wind farm. The colours in the figure represent the composite reflectivity values, in units of dBZ. For example, an orange colour indicates that the composite reflectivity is between 40 dBZ and 45 dBZ. White areas mean that the reflectivity is less than 0 dBZ, while dark red means that the reflectivity is at least 60 dBZ. It can be seen from the figure that the maximum reflectivity is at least 60 dBZ. The biggest reflectivity values are in the local vicinity of the turbines, and are attributed to direct reflections from the turbines. The reflectivity downrange of the turbines is weaker, and is caused by multipath scattering between the turbines and between the turbines and the ground.

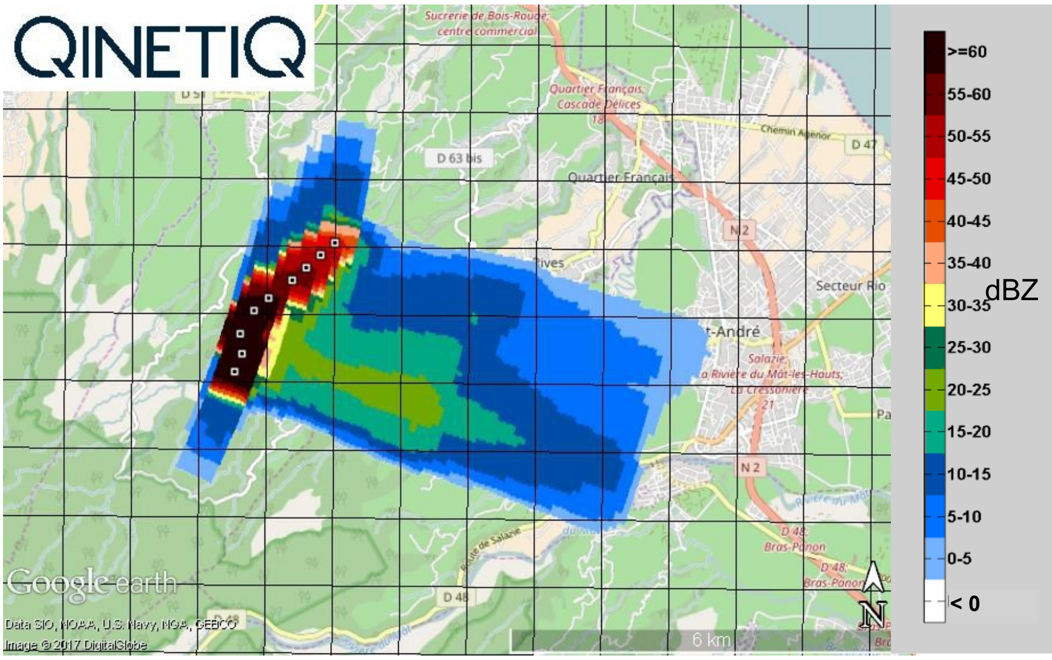

Figure 2-3: Composite reflectivity (dBZ) due to the proposed wind farm. White square icons = proposed turbines. Gridlines = 1 km x 1 km cells

2.3.2 Impact zone

Reflections from wind turbines can result in increased clutter levels. There are two main effects of wind farm clutter: i) reduced ability of the radar to detect less reflective objects in that region, such as precipitation or hail; and ii) interference of Doppler measurements that can cause erroneous values in the velocity measurements of any precipitation in the region.

The impact zone[E] is defined as the grid cells where, at any of the lowest three scan angles, a wind farm is predicted to cause an operationally significant impact on the raw radar data in any of the zero Doppler and non-zero Doppler channels[F]. The typical RCS[G] is used in the calculation to show what the time-averaged impact will be. There is an impact if, in any channel, the turbine reflectivity is i) greater than 0 dBZ and ii) greater than the terrain reflectivity. The size of the impact zone is measured along the longest dimension. Only the parts of the impact zone inside the coordination area are taken into account in the calculation [10].

2.3.3 Criterion 2: impact zone maximum size

Figure 2-4 shows the impact zone (red polygon) due to the proposed wind farm. The area where the raw radar data is impacted (purple area) has been overlaid on the impact zone. It can be seen from the figure that the size of the impact zone is 9.8 km. This is less than the 10 km limit stipulated in the French legislation, therefore, the wind farm is acceptable in terms of the size of the impact zone.

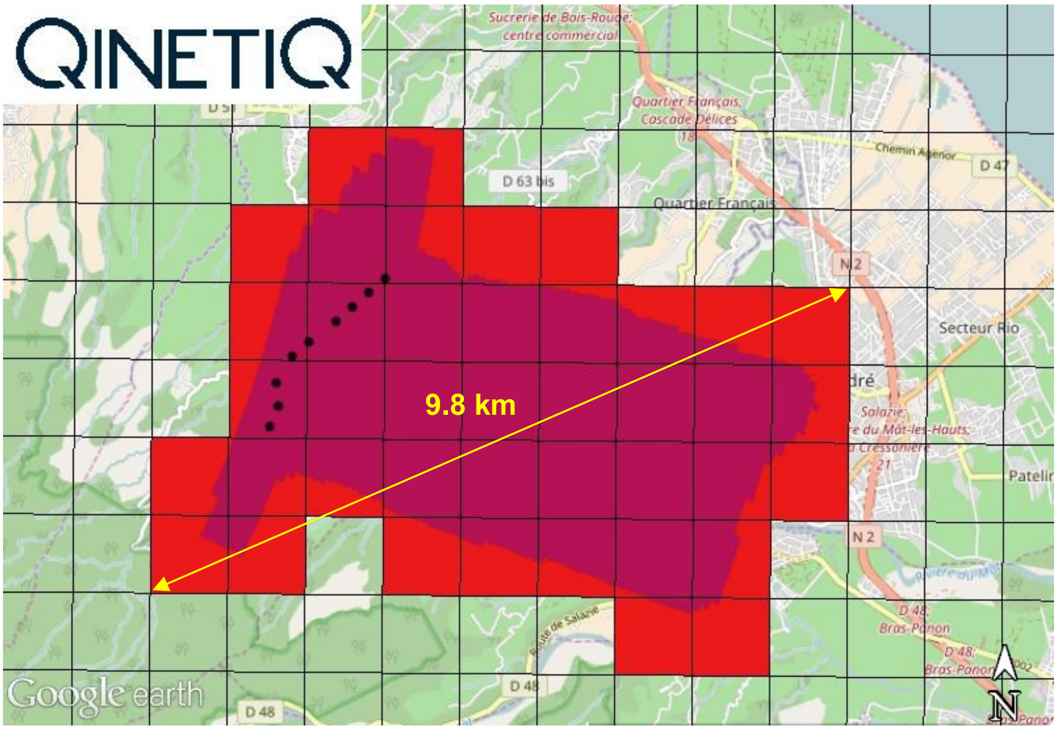

Figure 2-4: Impact zone (red polygon) due to the repowering project. Purple area = region where raw data is impacted. Black dots = proposed turbines. Gridlines = 1 km x 1 km cells. Orange line = outer edge of coordination area (range = 30 km)

[E] In the French legislation [1] this is referred to as the zone d'impact. This translates to 'impact zone' in the English language. The English version will be used in this report.

[F] The radar uses Doppler processing to filter out unwanted returns from stationary targets, such as the ground. Any static object, such as the turbine tower, can usually be filtered out using a technique called moving target indication/detection (MTI/MTD). MTI uses the familiar Doppler effect due to an object's motion towards, or away from, the radar to discriminate moving targets from stationary clutter. MTD is a similar but more advanced form of MTI. This filtering helps to separate the returns from static and moving objects.

[G] The assumption is made that the turbine blades are moving, therefore, the turbine RCS will be changing over time. The time-averaged turbine RCS is estimated based on an analysis of turbine RCS datasets, and this is referred to as the typical RCS of the turbine.

2.4 Criteria 3: interdistance between impact zones

There are no other wind farms in the coordination area. Therefore, the proposed wind farm is compliant with respect to criterion 3.

2.5 Criterion 4: interdistance to sensitive sites

The impact zone is outside the exclusion zones of sensitive sites (Figure 2-5), therefore, the project is compliant in terms of criterion 4. The minimum interdistance is 25.2 km (EDF-PEI SAS).

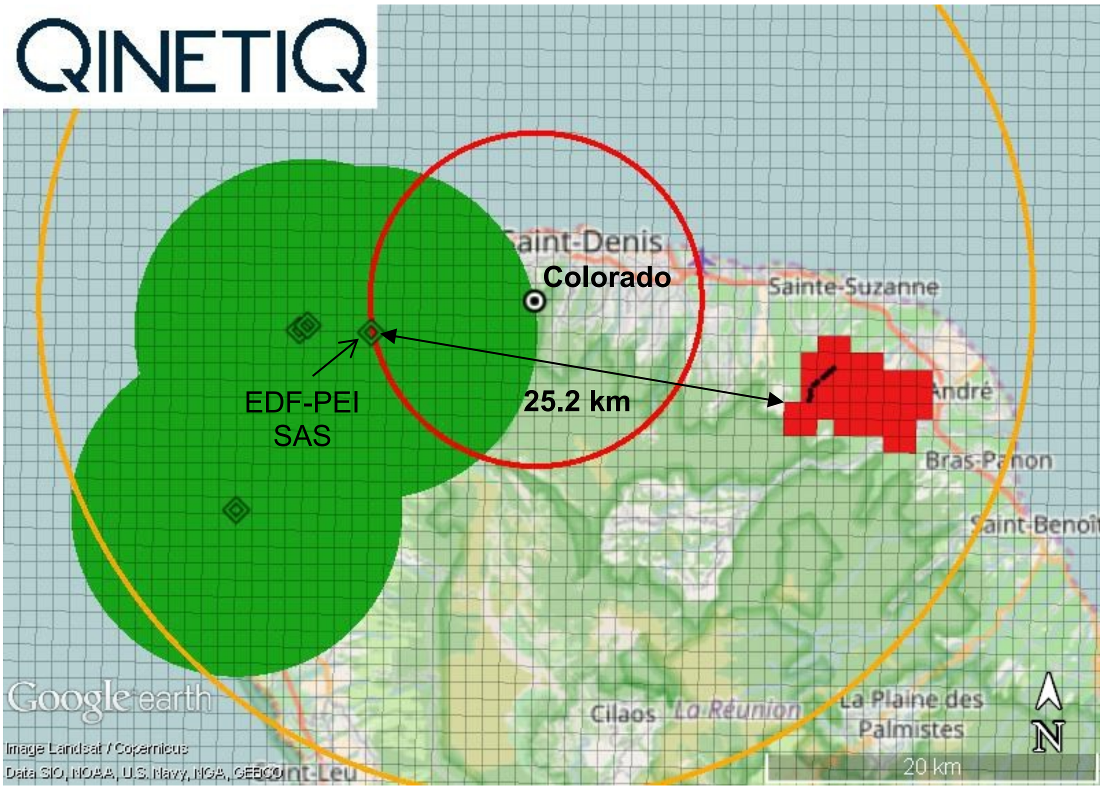

Figure 2-5: Impact zone (red) in relation to 10 km exclusion zones (green circles) around sensitive sites

3 Conclusions

A LoS analysis has shown that all turbines are partially in radar LoS, with percentage LoS values ranging from 25.9% to 70.9%.

A CLOUDSiS 1.0 assessment has been carried out on the proposed wind farm. The results are summarised as follows:

- The maximum percentage occultation is 0.1%, which is less than the 10% maximum limit stipulated in the French legislation
- The size of the impact zone is approximately 9.8 km measured along the longest dimension. This is less than the 10 km maximum limit stipulated in the French legislation;
- There are no other wind farms in the coordination area, therefore, the proposed wind farm passes criterion 3.
- The minimum interdistance to sensitive sites is 25.2 km. Therefore, La Perrière is compliant with respect to criterion 4.

The key results are summarised in Table 3-1.

Criterion	Impact	Result
Criterion 1	Maximum percentage occultation	0.1% (PASS)
Criterion 2	Size of impact zone	9.8 km (PASS)
Criterion 3	Minimum interdistance to other wind farm impact zones	No other wind farms in coordination area (PASS)
Criterion 4	Minimum interdistance to sensitive sites	25.2 km (PASS)

Table 3-1: Summary of results for La Perrière

4 References

[1] « *Arrêté du 6 novembre 2014 modifiant l'arrêté du 26 août 2011* », URL: http://www.legifrance.gouv.fr/eli/arrete/2014/11/6/DEVP1416471A/jo/texte

[2] *Décision du 20 novembre 2015, du Ministère de l'écologie, du développement durable et de l'énergie, relative à la reconnaissance de la méthode de modélisation des perturbations générées par les aérogénérateurs sur les radars météorologiques CLOUDSiS 1.0 et de la société Qinetiq Ltd chargée de sa mise en oeuvre*, reference NOR: DEVP1527649S, URL: http://www.bulletin-officiel.developpement-durable.gouv.fr/fiches/BO201522/bo201522.pdf

[3] Rectificatif publié au Bulletin Officiel numéro 24 page 35: http://www.bulletin-officiel.developpement-durable.gouv.fr/fiches/BO201524/bo201524.pdf

[4] Coyard, V. (Quadran), *RE: UC Wind farm impact assessment*, email to Savage, V. (QinetiQ), sent 7th April 2017

[5] Coyard, V. (Quadran), *RE: UC Wind farm impact assessment*, email to Ellis, J. (QinetiQ), sent 31st May 2017

[6] Savage, V. (QinetiQ), *RE: UC Wind farm impact assessment*, email to Coyard, V. (Quadran), sent 31st May 2017

[7] Météo-France, *PARAMÈTRES DES RADARS POUR LA MODELISATION DES IMPACTS EOLIENS*, version 6, 16th May 2017

[8] OPERA II, WORK PACKAGE 1.8, *Impact of Wind Turbines on Weather Radars*, OPERA deliverable OPERA_2006_18

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[10] Savage, V. *Weather Radar Impact Assessment Criteria*, May 2017, QINETIQ/15/04526/14.0, QinetiQ Proprietary

[11] Savage, V. (QinetiQ), *RE: UC Wind farm impact assessment*, email to Coyard, V. (Quadran), sent 2nd November 2016

[12] Coyard, V. (Quadran), *RE: UC Wind farm impact assessment*, email to ellis, J. (QinetiQ), sent 30th June 2017

[13] ASN, *ANNEXE A - Liste des installations nucléaires de base au 31 décembre 2015*, URL: http://www.asn.fr/Informer/Publications/Rapports-de-l-ASN/La-surete-nucleaire-et-la-radioprotection-en-France-en-2015

[14] MEDDE webpage, *Base des installations classées*, URL: http://www.installationsclassees.developpement-durable.gouv.fr/rechercheICForm.php

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