Appendix 14-1:
Aviation Technical Report

ORIEL WINDFARM
OFFSHORE RENEWABLE ENERGY

RPS A TETRA TECH COMPANY

PARKWIND JERA GROUP

ESB Energy for generations

ORIEL WIND FARM PROJECT

Environmental Impact Assessment Report
Appendix 14-1: Aviation Technical Report

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Glossary

Term	Meaning
Aerodrome	A small airport or airfield.
Lowest Astronomical Tide (LAT)	The lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions
Safeguarding	The process established to ensure that all appropriate measures are taken to secure the safety of aircraft when taking off, landing or flying within the vicinity of an airport.

Acronyms

Term	Meaning
ADR	Air Defence Radar
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CTA	Control Area
DoD	Department of Defence
ERCoP	Emergency Response Co-operation Plan
IAA	Irish Aviation Authority
ICAO	International Civil Aviation Organisation
LAT	Lowest Astronomical Tide
LoS	Line of Sight
MGN	Marine Guidance Note
MoD	Ministry of Defence
NATS	National Air Traffic Services
NAVAIDS	Navigation Aids
OLS	Obstacle Limitation Surfaces
PSR	Primary Surveillance Radar
SAR	Search and Rescue
SSR	Secondary Surveillance Radar
WTG	Wind Turbine Generator

1 INTRODUCTION

1.1 Purpose and scope

The purpose of the Aviation Technical Report is to identify the key aviation and radar risks associated with the Oriel Wind Farm Project (hereafter referred to as “the Project”). The offshore wind farm area is located in the Irish Sea, off the coast of County Louth, Ireland (approximately 22 km east of Dundalk town centre and 18 km east of Blackrock).

The scope of the assessment considers potential impacts upon Primary Surveillance Radar (PSR), Secondary Surveillance Radar (SSR), aviation operations and aerodromes. The analysis is based on the proposed Project layout and dimensions (volume 2A, chapter 5: Project Description).

1.2 Interference mechanisms

Wind turbines have the potential to impact upon aviation operations and infrastructure in the following two ways:

1. Physical Obstruction: wind turbines undergoing construction or decommissioning (and associated cranes) and operational turbines can present a physical obstruction at or close to aircraft airspace routings or aerodromes; and

2. Radar/Air Traffic Services (ATS): in the use of PSR, the rotation of wind turbine blades is detected and forms “clutter” on the radar display screen. This can affect the safe provision of air navigation services as it can mask unidentified aircraft from the controller and prevent them from accurately identifying aircraft under their control. This could result in miscommunication and confusion causing an increase in workload for the controller and unsafe service provision; and in some cases, radar reflections from the wind turbines can affect the performance of the radar system itself.

All relevant aviation operations and infrastructure have been reviewed in relation to the interference mechanisms listed above to determine the potential impact of the Project.

1.3 Methodology

The guidance documents outlined in Table 1-1 have been used to inform this assessment. The Civil Aviation Authority (CAA) Civil Aviation Publications (CAP) have been referenced from a technical perspective.

Table 1-1: Relevant guidance documents.

Relevant Guidance
IAA (2014) Land Use Planning and Offshore Development
IAA (2015a) Aeronautical Services Advisory Memorandum (ASAM), Guidance Material on Offshore Wind Farms, ASAM No 018
CAP 168 – Licensing of Aerodromes
CAP 670 – Air Traffic Services Safety Requirements
CAP 764 – CAA Policy and Guidelines on Wind Turbines
ICAO EUR DOC 015 – European Guidance Material on Managing Building Restricted Areas
ICAO Annex 10 – Annex 10 to the Convention on International Civil Aviation. Aeronautical Telecommunications. Volume II Communication Procedures including those with PANS status
ICAO Annex 14 – Annex 14 to the Convention on International Civil Aviation. Aerodrome Volume I. Aerodrome Design and Safety
Eurocontrol Guidelines – How to Assess the Potential Impact of Wind Turbines Surveillance Sensors
OPERA III, WORK PACKAGE 1.5b – Site protection (wind turbines) OPERA deliverable: OPERA_2010_05.

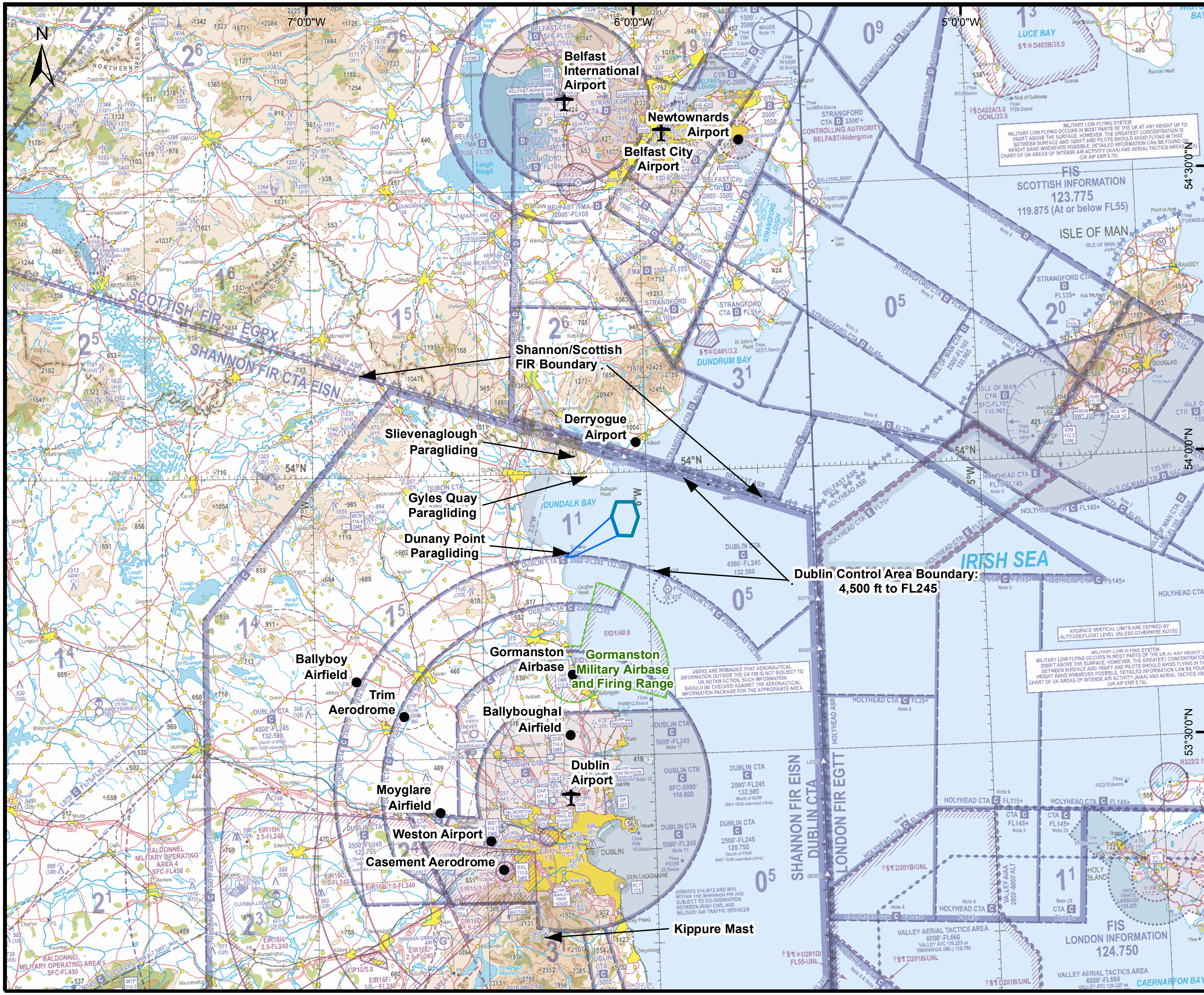
The methodology for radar Line of Sight (LoS) assessment is provided in Appendices A.3 to A.5. The coordinates of each point location are shown in Appendix A.1 and their location is shown relative to the assessed aviation infrastructure in Figure 1-1.

The specific wind turbine dimensions assessed are presented in Table 1-2 below. The dimensions assessed are the maximum turbine parameters. The assessment therefore represents worst-case results in terms of aviation and radar.

Table 1-2: Wind turbine dimensions assessed.

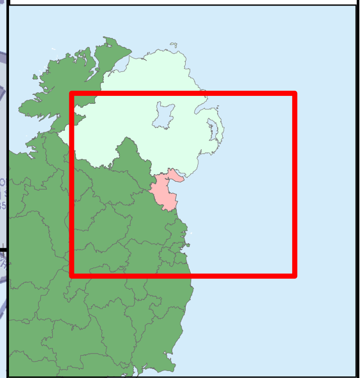
Hub height (m LAT)	Rotor diameter (m)	Upper blade tip height (m LAT)
145-152[1]	236	270

[1] Wind turbine hub height will vary within the range stated across the offshore wind farm area. The design and height of each wind turbine foundation is specific to the subsoil geology and geotechnical properties at each wind turbine location. The foundation height will affect the hub height of each wind turbine.



Legend

- Offshore Wind Farm Area
- Offshore Cable Corridor
- Gormanston Military Airbase and Firing Range
- Major Civil
- Civil Airports/ Military Aerodromes
- Areas of Controlled Airspace



Client

ORIEL WINDFARM
OFFSHORE RENEWABLE ENERGY

Project

Oriel Wind Farm Project

Title

Figure 1-1
Wind farm layout, major civil airports and military airbases.

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Issue Details

Drawn By:	NG	Project No.	EOR0822 (MDR1520B)
Checked By:	NG	File Ref:	
Approved By:	AOS		EOR0822_AVI_T_1050_FINAL
Scale:	1:1,000,000@ A4	Projection:	ITM (IRENET95)
Date:	12/03/2024		Geographic Co-ordinates: ETRS89

NOTE:
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2 AVIATION CONSULTATION SUMMARY

Consultation with identified aviation stakeholders was undertaken in two phases in late 2019 and in early 2021. The purpose of consultation in 2019 was to provide an opportunity for stakeholders to comment on the EIA scoping report. In 2021, consultation was undertaken to update stakeholders on proposed changes to the project design and to seek responses from stakeholders that did not respond as part of the EIA scoping consultation. Further consultation was undertaken between 2022 and 2024 on the Project and the Lighting and Marking Plan. A summary of the key issues raised during consultation specific to Aviation and Military is outlined in Table 2-1, together with how these issues have been considered in the production of this Technical Report.

Table 2-1: Summary of key consultation undertaken with aviation stakeholders on the Project.

Date	Consultee and type of response	Responses and issues raised	Response to issue raised and/or where considered in this Technical Report
Civilian Aviation Interests			
September 2019	Belfast International Airport – scoping response	Response confirming that the Project would have no effect on the operations at this airport.	N/A
February 2021	Belfast International Airport – pre-planning response	No change anticipated from the 2019 response and therefore not reconsulted.	Civil aviation interests are discussed in section 3.
September/ November 2019	National Air Traffic Services (NATS) – scoping response	No impact on radar anticipated based on wind turbine upper blade tip height at 270 m above LAT.	N/A
February 2021	NATS – pre-planning response	Reconsulted - no objection. The turbines are beyond the range of visibility to NATS' nearest radar considering a tip height of 270 m above LAT	Civil aviation interests are discussed in section 3.
September 2019	IAA – scoping response	No impact on Navigation Aids (NAVAIDs).	Civil aviation interests are discussed in section 3.
November 2019	IAA – scoping response	Consultation response confirming status of IAA guidance and confirming acceptability of CAP 764. Marking and lighting requirements to be in accordance with IAA ASAM No. 018. February 2021 – reconsulted – no objection on radar, NAVAIDS or operations. Requests for lighting and marking.	Civil aviation interests are discussed in section 3.
February 2021	IAA – pre-planning response	No objection on radar, navigation aids or operations. Requests for lighting and marking.	Civil aviation interests are discussed in section 3.
March 2021	IAA – pre-planning response	Discussion on lighting and marking. Recommendation for a high-level report to inform lighting requirements although no issues anticipated.	Airspace and operations are discussed in section 3. A Lighting and Marking Plan is included in appendix 5-9 of this EIAR.
January 2023	IAA - consultation	No response for comments on draft Lighting & Marking Plan.	A Lighting and Marking Plan is included in appendix 5-9 of this EIAR.
November 2019	Dublin Airport – scoping response	No response during 2019 consultation.	N/A

Date	Consultee and type of response	Responses and issues raised	Response to issue raised and/or where considered in this Technical Report
February 2021	Dublin Airport – pre-planning response	Reconsulted –response received in March stating their position is in line with that of the IAA.	Civil aviation interests are discussed in section 3.
November/ December 2019	Belfast City Airport – scoping response	Response confirming that the Project is outside of the Belfast City Airport Obstacle Limitation Surfaces, >30 km from the airfield and not in line of sight of the radar (considering 247 m tip height turbines). Therefore, no aerodrome safeguarding related concerns.	N/A
February 2021	Belfast City Airport – pre-planning response	No change anticipated from the 2019 response and therefore not reconsulted.	Civil aviation interests are discussed in section 3.
November 2019	Civil Aviation Authority (CAA)	No response during 2019 consultation.	Civil aviation interests are discussed in section 3.
February 2021	CAA – pre-planning response	Reconsulted – no response received however this is the typical CAA procedure for individual wind farm developments	N/A
September 2023	Isle of Man, Department of Infrastructure	Potential for Project to impact on Primary Surveillance Radar (PSR) and Instrument Flight Procedures (IFPs).	Due to the distance between the Project and Ronaldsway Airport (52 nm), it is not expected that the Project will impact on the PSR or IFPs. The Applicant will continue to engage with the airport's air traffic services and Department of Infrastructure and if required radar mitigation will be considered.
February 2024	Ronaldsway Airport – meeting		
Military Aviation Interests			
November 2019	Department of Defence (DoD) – scoping response	No response during 2019 consultation.	N/A
February 2021	DoD – pre-planning response	Reconsulted – no objection on radar, navigation aids or operations. Requests for lighting and marking.	Military interests are discussed in section 3.
January 2023	DoD - consultation	No response for comments on draft Lighting & Marking Plan.	A Lighting and Marking Plan is included in appendix 5-9 of this EIAR.
February 2021	UK Ministry of Defence (MoD) – pre-planning response	Consulted – no objection on radar, navigation aids or operations. Requests for lighting and marking.	Military interests are discussed in section 3.
Other			
March 2021	CHC Heli (search and rescue) – pre-planning response	Consulted – no response received.	Discussed in section 3.8
March 2021; November 2022	Irish Coast Guard – pre-planning response	2021: Consulted – no response received; Requirements from Marine Guidance Note (MGN) 654 should be used for SAR helicopters to enter the wind farm.	Discussed in section 3.8

3 IDENTIFICATION AND ASSESSMENT OF AVIATION AND RADAR INFRASTRUCTURE

3.1 Overview

A search of aviation and radar infrastructure has been undertaken to identify potential impacts associated with the development of the Project. The following infrastructure is considered within the assessment:

- Airspace;
- PSR;
- SSR;
- Aeronautical Radio Navigation Aids (NAVAIDS);
- Civil Airports;
- Heliports and Routes (and Coast Guard operations);
- Meteorological (Weather) Radar;
- Military Air Traffic Control PSR;
- Military Air Traffic Control SSR; and
- Military Airbases.

The hypothetical grid layout has been assessed against all known infrastructure listed above.

3.2 Airspace

The offshore wind farm area is located under the Dublin Control Area (CTA) which exists from 4,500 ft to 24,500 ft. The airspace surrounding the offshore wind farm area is uncontrolled from sea level to 4,500 ft.

There are no other airspace-based considerations with respect to the Project. The Irish Aviation Authority (IAA) is the Air Navigation Service Provider (ANSP) in this area.

No impact is anticipated with respect to airspace usage considering airspace alone because it is not located within restricted airspace.

Consultation with the IAA indicated no objections on radar, NAVAIDS or operations. The IAA noted that a report would be required regarding marking and lighting of the turbines as obstacles. This is presented in volume 2A, appendix 5-9: Lighting and Marking Plan.

3.3 Primary Surveillance Radar (PSR)

PSR are used for non-co-operative surveillance of both approaching and departing aircraft, and for the en-route phase of flight.

The nearest PSRs to the offshore wind farm area are located at Dublin Airport (Dublin Head 2 and 3). These radars are located 51.2 km and 51.45 km south southwest of the nearest wind turbine within the offshore wind farm area respectively. The radars are safeguarded by the IAA/Dublin Airport. The IAA guidance on safeguarding radar systems from wind farm projects (IAA, 2014) identifies four safeguarding zones for PSR systems: Zone 1 (0 m – 500 m) where no developments will be agreed to; Zone 2 (500 m – 15 km) where a detailed assessment is required; Zone 3 (>15 km) where a simple assessment is required; and Zone 4 (not in radar LoS) where no assessment is required.

The Project is located within LoS to both Dublin Airport PSR and falls within Zone 3 using the above criteria, which requires a simple assessment of PSR performance. The results of the line-of-sight assessment have shown that all of the wind turbines would be visible to Dublin Head 2 and 23 of the 25 wind turbines would be visible to Dublin Head 3. Considering the level of visibility, it is likely that the most visible turbines will be detectable to the PSR. A line-of-sight chart for the closest wind turbine (OR E1) is presented in Appendix A.5.

Consultation with Dublin Airport/IAA was completed to understand their position with respect to the Project. The consultation revealed that the IAA and Dublin Airport have no radar-based objection. The IAA has however requested the appropriate lighting and marking of the wind turbines. This can be dealt with through an appropriate planning condition as is standard practice for lighting scheme designs for wind turbines.

NATS was consulted with respect to their UK-based radar. Considering their safeguarding response which identified no key issues (see Table 2-1), and review of the NATS safeguarding maps (NATS, 2019), no impact upon NATS radar is expected and no objection has been received.

No other PSR are considered relevant based on their distance from the offshore wind farm area and therefore no significant impact upon other PSR is expected.

3.4 Secondary Surveillance Radar (SSR)

SSR are used for co-operative surveillance of both approaching and departing aircraft, and for the en-route phase of flight. Only aircraft with a transponder can be detected by an SSR.

The nearest SSR to the offshore wind farm area are located at Dublin Airport (Dublin Head 2, 3 and Forrest Little) are on average 54.7 km, 54.8 km and 54.7 km south southwest of the offshore wind farm area respectively. IAA guidance on safeguarding surveillance systems from wind farm projects (IAA, 2014) identifies four safeguarding zones for SSR systems: Zone 1 (0 – 500 m) where no developments will be agreed to; Zone 2 (500 m – 16 km) where a detailed assessment is required; and Zone 4 (>16 km or not in radar LoS) where no assessment is required. Based on these criteria and considering the identified SSR systems, the Project is located within Zone 4, and therefore no further assessment is required. A line-of-sight calculation has however been undertaken for the Project. The results have shown that the wind turbines are expected to be visible to the SSR to varying degrees but are located beyond the range at which impacts would be anticipated.

No other SSR are considered relevant based on their distance from the offshore wind farm area and therefore no impact upon other SSR is expected.

3.5 Aeronautical radio navigation beacons

No aeronautical radio navigation beacons have been identified within 15 km of the offshore wind farm area (i.e. a distance to which safeguarding concerns could be raised). All NAVAIDS are located on land, well beyond the appropriate safeguarding distances as per International Civil Aviation Organisation (ICAO EUR DOC 015 and CAP 670.

The IAA confirmed through consultation that no impact upon navigation beacons was anticipated and had no objection.

No impact upon any aeronautical radio navigation beacons is therefore expected.

3.6 Civil airports and unlicensed aerodromes

The major civil airports located closest to the offshore wind farm area are Dublin Airport (51 km south southwest), Belfast City Airport (75 km north northeast) and Belfast International Airport (78 km north northwest).

No impact upon Obstacle Limitation Surfaces (OLS), Instrument Flight Procedures or any other obstacle related impact is expected considering the distance of these airports from the offshore wind farm area (i.e. beyond 15 km, which denotes the maximum distance to which the OLS can extend).

The nearest unlicensed aerodrome is Derryogue Airport located in Northern Ireland. The airfield is located over 11 km north of the offshore wind farm area. At 11 km, no issues are anticipated because typical safeguarding guidance does not apply for unlicensed aerodromes.

The locations of the identified major civil airports relative to the offshore wind farm area are shown in Figure 1-1 above.

3.7 Heliports and routes

No regular helicopter routes have been identified in the vicinity of the offshore wind farm area. No heliports have been identified and there is no offshore oil and gas infrastructure in the vicinity of the offshore wind farm area which may require helicopter access. Any helicopter traffic along regular routes will likely originate from Dublin Airport or one of the Belfast airports and are very unlikely to traverse the offshore wind farm area at a low level where the wind turbines would present an obstruction.

Considering that no helicopter routes have been identified, no impact is expected, however the Project should be marked on the appropriate aviation charts.

3.8 Coast guard operations

Wind turbines can present a physical obstruction to helicopters flying at low levels. Military and civilian helicopters routinely fly down to low levels over the sea, including helicopters conducting Search and Rescue (SAR) operations. These aircraft may not follow specific routes. SAR pilots are called upon to rescue personnel whose lives are in danger at sea.

The Irish Coast Guard operate a number of SAR helicopters deployed at bases in Dublin, Waterford, Shannon and Sligo, which respond to emergencies at sea, inland waterways, offshore islands and mountains of Ireland (DTTS, 2022). The UK SAR helicopter service provides SAR helicopters from 10 strategically located bases in the UK. The nearest SAR bases to Northern Ireland are at Prestwick and Caernarfon (Maritime and Coastguard Agency, 2021).

The Irish Coast Guard has been consulted and responded by stating they would be responsible for ensuring that adequate emergency plans were in place particularly for the use of helicopter involvement in SAR operations. It was mentioned that an Emergency Response Co-operation Plan (ERCoP) for the Project would be required. An ERCoP has been prepared (see volume 2A, appendix 5-8) in consultation with the Irish Coast Guard, which considers helicopters undertaking SAR operations when rendering assistance to vessels and persons in the vicinity of the Project.

3.9 Meteorological (weather) radar

Meteorological radars are typically safeguarded within 30 km of their location for wind turbines (Meteo France, 2010). The nearest meteorological radar is Castor Bay, located over 60 km northwest of the offshore wind farm area and therefore beyond this safeguarding range.

No impact upon any meteorological radar is therefore expected.

3.10 Military Air Traffic Control PSR and Air Defence Radar

Military Air Traffic Control (ATC) radar and military Air Defence Radar (ADR) may be safeguarded to their maximum operational range. This means that potential objections can be given at any distance from a radar if there is LoS and detectability of a wind turbine.

What is understood to be a military ATC PSR[2] at Casement Aerodrome is located 70.1 km southwest of the closest Wind Turbine Generators (WTG) within the offshore wind farm area. The radar located at the aerodrome may have partial LoS to a few of the wind turbines[3] - the level of visibility will however be low. A line-of-sight chart for the closest wind turbine (OR E1) is presented in Appendix A.5. Considering the anticipated level of visibility and distance to the WTGs, no significant impact is anticipated. Consultation was

[2] The radar was located via a map search however it was not confirmed that it was the specific military radar. No objection on the basis of radar was however received.

[3] This is dependent on the height of the radar above ground level, which is unknown.

completed with the Department of Defence (DoD) to confirm this. No ADR are located in the Republic of Ireland or Northern Ireland and there are no ADR on the west coast of the UK which would have LoS to the wind turbines, therefore no impact is possible.

The consultation with the DoD revealed they have no radar-based objection. The DoD has however requested the appropriate lighting and marking of the wind turbines. A lighting and marking plan is provided in volume 2A, appendix 5-9: Lighting and Marking Plan.

3.11 Military Air Traffic Control SSR

No military SSR have been identified within safeguarded range (within 16 km) which could be affected by the Project.

No impact upon any military SSR is expected.

3.12 Military airbases

The nearest military aerodrome to the offshore wind farm area is Casement Air Base (70 km south southwest). The Gormanston Aerodrome (29 km south southwest) is disused (IAA, 2019) however Gormanston Aerodrome/Camp is used for training exercises including air to ground firing.

Considering the location of the Casement Air Base relative to the offshore wind farm area, no impact upon OLS, Instrument Flight Procedures or any other obstacle related impact is expected.

The locations of the identified military airbases relative to the offshore wind farm area are shown in Figure 1-1.

3.13 Military low flying areas/Practice areas

Gormanston Military Firing Range operates from Gormanston Aerodrome and does not overlap with the offshore wind farm area or offshore cable corridor (IAA, 2015b). Gormanston is used for air-ground firing training, air-defence training and general military training.

There are no other relevant military low flying or practice areas in the vicinity of the offshore wind farm area. No impact is expected.

4 DISCUSSION AND CONCLUSIONS

4.1 Identified impacts

Wind turbines within the offshore wind farm area will be visible to the PSR at Dublin Airport at an average range of 54.9 km. Consultation with Dublin Airport/the IAA has revealed they have no objection based on radar, NAVAIDS or operations.

No other civil or military PSR or SSR are considered relevant based on their distance from the offshore wind farm area and therefore no significant impact upon other PSR or SSR is expected.

An ERCoP has been prepared in in consultation with the Irish Coast Guard and considers helicopters undertaking SAR operations when rendering assistance to vessels and persons in the vicinity of the Project (see volume 2A, appendix 5-8: ERCoP). The ERCoP will be developed and issued for consultation again with the key stakeholders prior to construction.

No significant impact upon aviation infrastructure or operations has been identified. As the proposed wind turbines are 270 m in height above LAT, the turbines will require aviation lighting (ICAO, 2018). Appropriately, the MoD, DoD and IAA have requested the relevant marking and lighting of the wind turbines. The lighting and marking scheme for the Project is provided in volume 2A, appendix 5-9: Lighting and Marking Plan.

4.2 Recommendation and next steps

The IAA, Dublin Airport and the DoD will be consulted to ensure they continue to be fully aware of the Project with respect to lighting and marking of the wind turbines following submission of the planning application. It is anticipated that the final requirements for lighting and marking of the turbines will be managed through an appropriate planning condition following an application decision.

To align with the stakeholder requests, best practice and the associated aviation guidance, the presence of the wind turbines will be denoted on the relevant aviation charts with the coordinates, dimensions and elevations of each wind turbine, and a suitable lighting scheme will be developed following an application decision.

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NATS (2019) Self-assessment maps. Available at: https://www..aero/services/information/wind-farms/self-assessment-maps/. Accessed 03/11/2022.

A.1 Project layout coordinates

Table A1-1: Project layout coordinates.

Point	Latitude (º)	Longitude (º)
ORI-A01	53.915167	-6.102477
ORI-A02	53.924904	-6.094756
ORI-A03	53.934256	-6.088268
ORI-A04	53.943666	-6.078149
ORI-A05	53.945955	-6.059518
ORI-B01	53.912002	-6.085403
ORI-B02	53.923302	-6.077714
ORI-B03	53.932828	-6.072022
ORI-B04	53.936448	-6.053531
ORI-B05	53.945172	-6.042308
ORI-C01	53.908247	-6.071480
ORI-C02	53.917838	-6.064263
ORI-C03	53.927031	-6.059756
ORI-C04	53.924432	-6.042517
ORI-C05	53.934134	-6.036687
ORI-D01	53.899219	-6.076248
ORI-D02	53.902179	-6.057484
ORI-D03	53.914341	-6.049277
ORI-D04	53.909440	-6.036430
ORI-D05	53.920007	-6.029646
ORI-E01	53.900294	-6.094598
ORI-E02	53.889121	-6.084943
ORI-E03	53.889885	-6.065905
ORI-E04	53.888102	-6.049571
ORI-E05	53.899154	-6.042756

A.2 Terrain based analysis

A.2.1 Terrain based analysis – overview

There are many approaches that may be used to undertake terrain-based assessments such as radar LoS profile charts. The overall accuracy of any terrain-based assessment is dependent on the following factors:

- Accuracy of coordinates and height data for the infrastructure being assessed;
- Resolution and quality of digital terrain or surface data; and
- Choice of algorithm for determining land height from terrain data.

Coordinates and height of existing infrastructure may be obtained from the infrastructure owner, custom databases, various forms of mapping or via a site survey. Sometimes the coordinate and height data used may be inaccurate because of coordinate rounding or confusion between height and altitude. Verification of infrastructure position data makes the results of terrain-based assessments more reliable.

The resolution of digital data is described by its post. Digital terrain and surface data has a vertical accuracy described by a statistical relationship between database and actual vertical values.

Digital terrain data is used to calculate the terrain or surface height at specific locations. There are many processing algorithms for achieving this. These algorithms vary in accuracy and some are more appropriate for certain types of calculations than others. The nearest neighbour algorithm runs quickly and is effective for some applications. A weighted average algorithm is more accurate and generally gives conservative results for wind farm radar calculations. A more advanced algorithm using twelve data points is more accurate yet less conservative when determining the likelihood of a radar detecting a wind turbine.

Figure A2-1 shows an example of how terrain data will be interpreted for an algorithm using the nearest neighbour approach, the weighted average approach and the 12-point approach. The circles represent the DTM/DSM points, which are effectively the raw data and can be considered accurate. The coloured lines show the apparent height that will be calculated by the three algorithms. It can be seen that whilst the 12-point method is in most cases more accurate, it is less conservative than the bilinear weighted average method for line-of-sight analysis and radar detectability analysis. This is because the weighted average method is more likely to reduce the apparent height of the blocking point, thereby increasing the visibility of the turbine.

The bilinear weighted average method for its analysis.

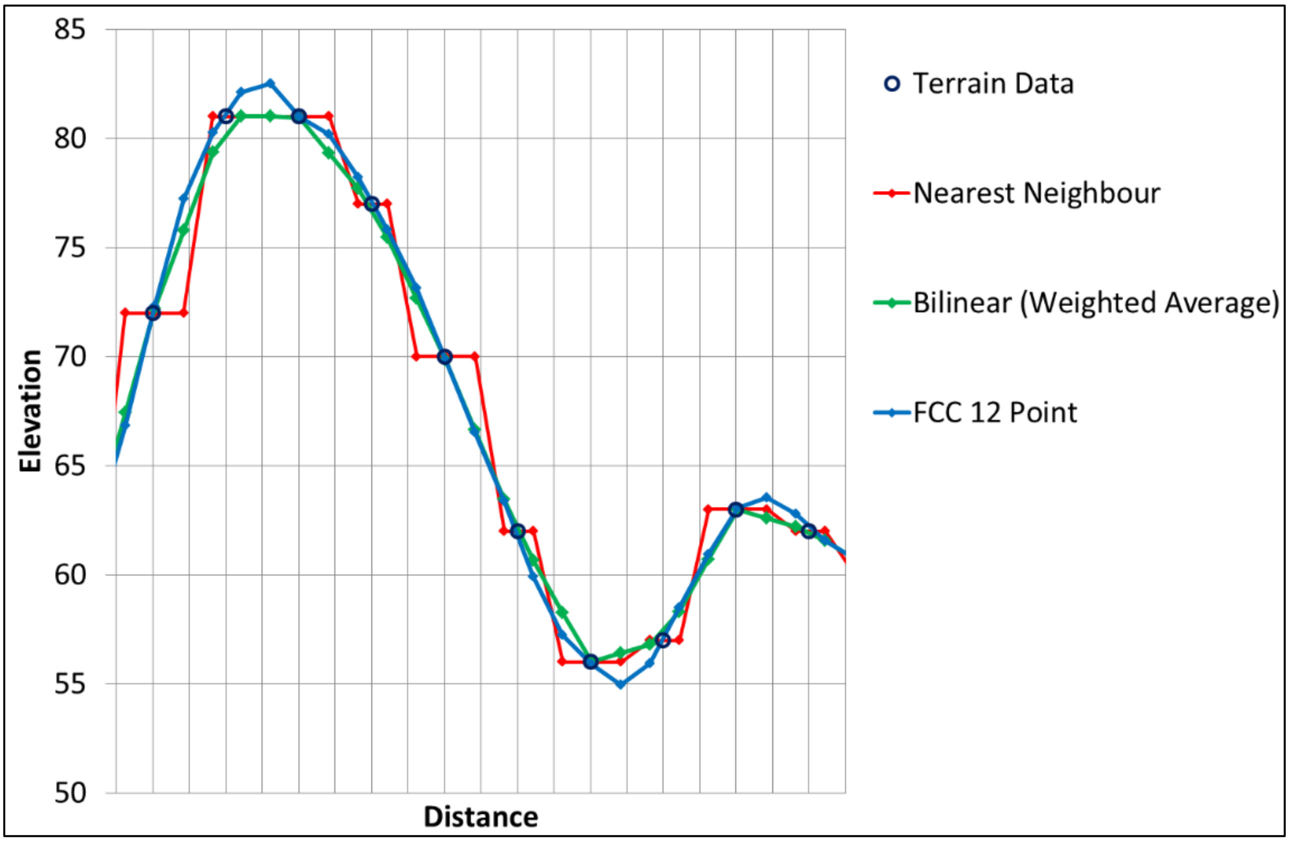


Figure A2-1: Example of terrain data algorithms.

A.3 Radar analysis – general principles

A.3.1 Overview

LoS analysis is used to determine the extent to which a planned wind development could be detected by a specific radar installation.

This analysis takes into account:

- The curvature of the Earth;
- Refraction of the radar signal by the atmosphere;
- The Effective Radar Height;
- The Effective Turbine Height; and
- The height profile of the terrain between the radar and turbine.

Land height may be adjusted for forests, buildings or other obstructions however further shielding analysis will be required for this to be incorporated. Only bare earth terrain has been assessed at this point.

A.3.2 Overall radar height

The radar height determines the Line-of-Sight angle. This in turn determines the Ceiling Height. The higher the radar, the lower the Line-of-Sight Ceiling will be.

The Overall Radar Height is the height of the radar radiation centre above datum.

A.3.3 Earth Curvature

Curvature of the Earth limits the distance at which objects can be detected, using visual and radar techniques.

The effect of Earth Curvature increases as the separation between radar and wind turbine increases.

The effect of Earth Curvature is calculated by determining the vertical separation of two lines running between the radar and wind turbine.

The first is the arc of the great circle that passes through the radar and wind turbine. This is the shortest arc between the two points.

The second is the chord between the radar and wind turbine. This line cuts through the Earth's surface.

A.3.4 Radar signal refraction

Radar signals travel in straight lines in free space. Variations in the atmosphere cause bending of radar signals. This bending is caused by lower denser air having a higher refractive index than higher less dense air.

The result of this bending is that effective radar range is extended beyond the visible horizon. Radar system designers compensate for this effect by using a larger effective Earth Radius in their calculations. This compensation allows radar signals to be treated as straight lines, even though they are actually being refracted.

The Earth Radius is multiplied by a refraction constant k to give an increased effective Earth Radius. The standard figure used for k is 4/3. This value is known as Standard Refraction. Measured values of k in the USA range from 1.25 to 1.90[4].

The Earth Curvature curve is redrawn, by recalculating each point using the adjusted Earth radius. This is shown on the Land Profile charts denoted as ‘Earth Curvature with compensation for Radar Refraction’ (Appendix A.5).

A.4 Earth Curvature / Refractive Constant

A.4.1 Earth Curvature

The distance between the Earth's surface and the associated chord passing through the Earth's crust increases with point separation. This is shown in Figure A4-1 below.

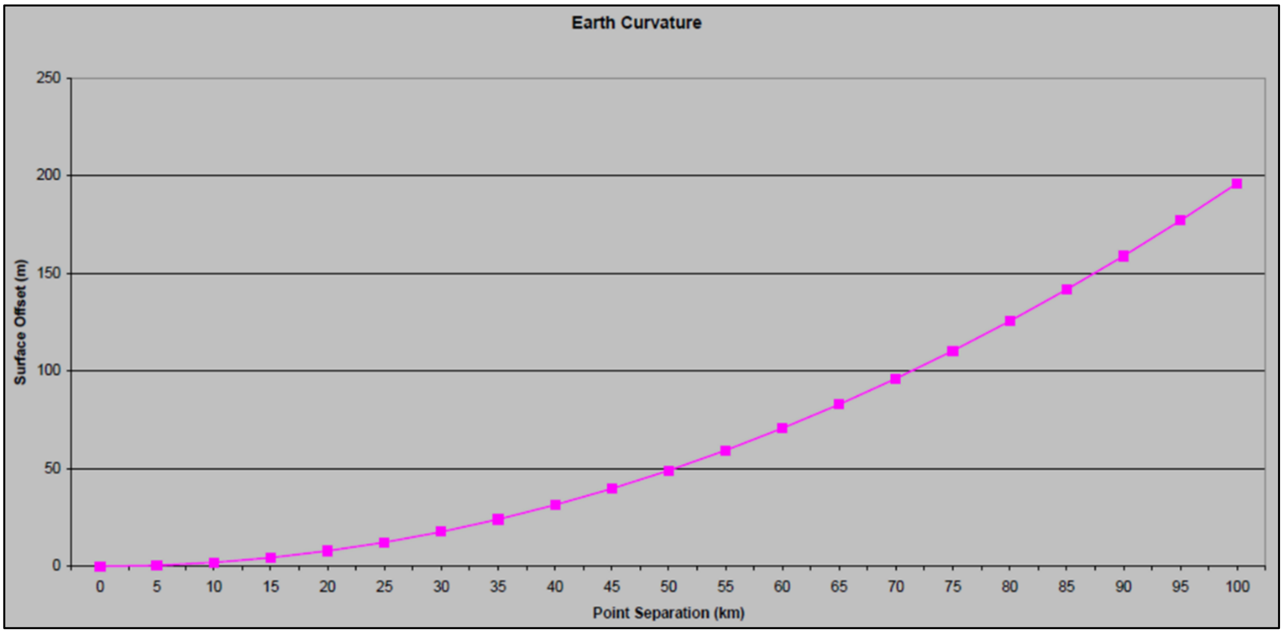


Figure A4-1: Earth curvature with distance.

A.4.2 Standard Refraction

The Standard Refraction constant k is 4/3. This constant was used in the line-of-sight analysis.

Figure A4-2 below shows the effects of variations in k over a range of distances (data from the USA).

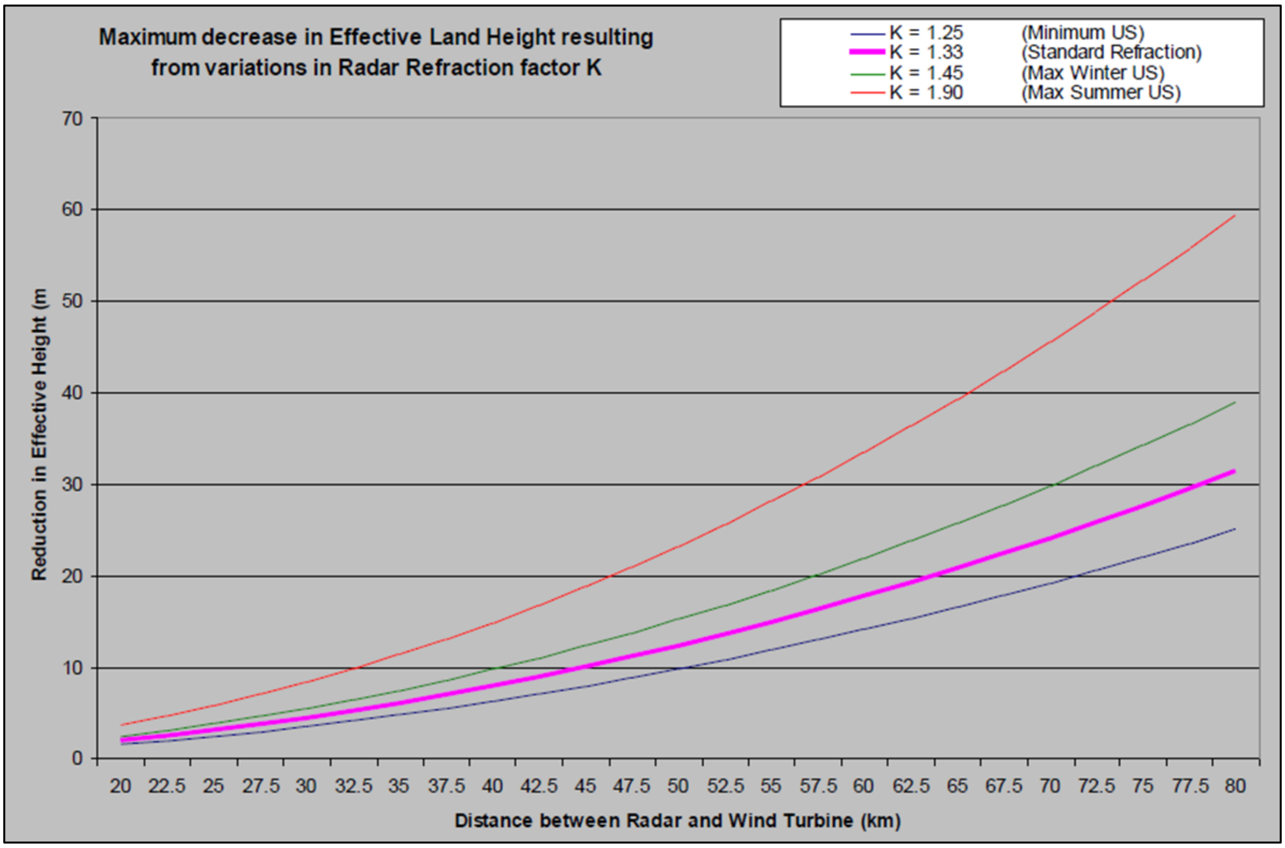


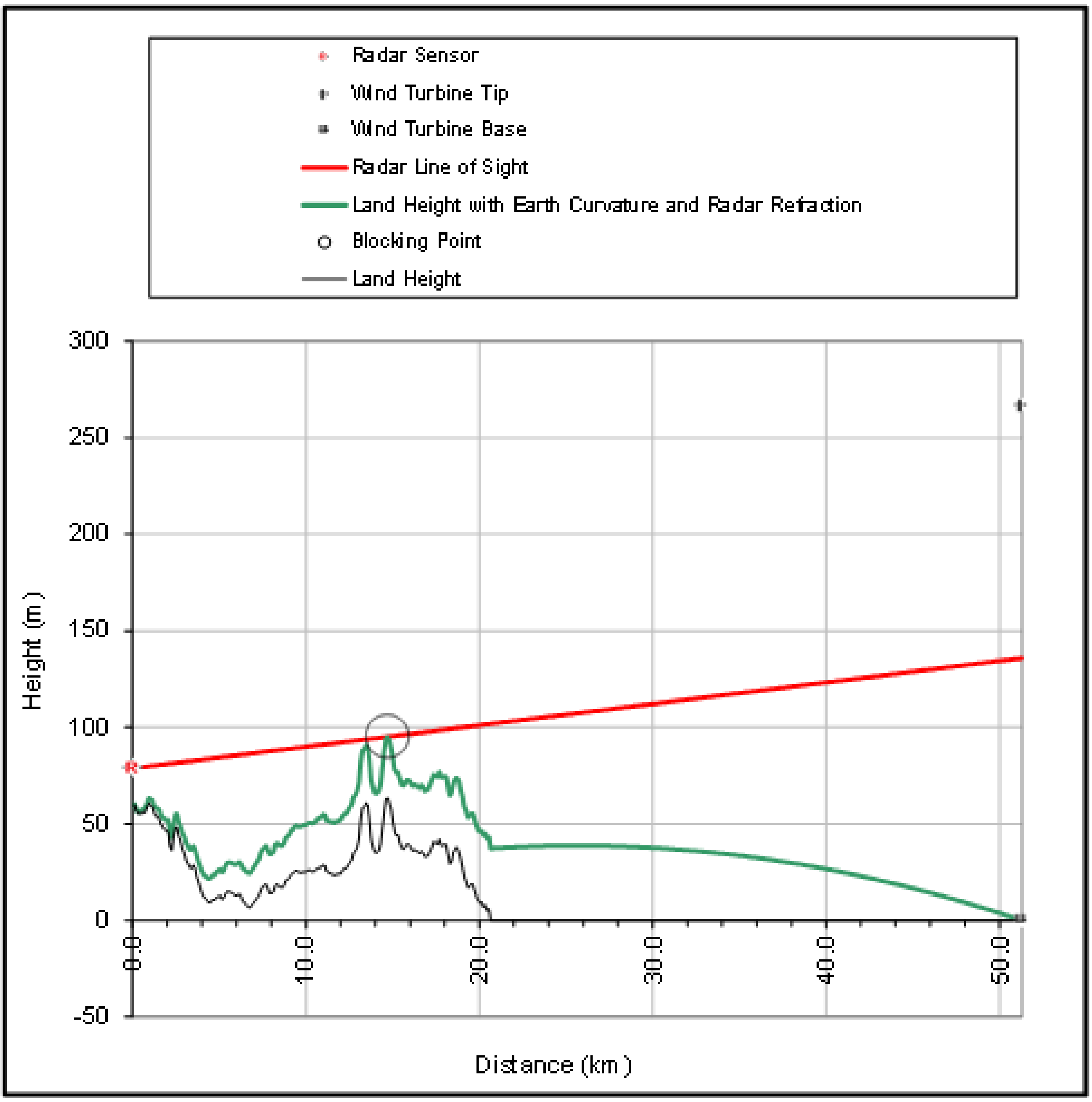
Figure A4-2: Radar refraction variation with distance.

A.5 Reference radar Line of Sight calculations

Reference radar LoS charts are presented in Figure A5-1 and Figure A5-2 below. In each case the chart is shown for the nearest wind turbine.

Radar Line of Sight Calculation

Radar LOS Dublin Head 2 PSR	
Turbine	OR E1
Result	VISIBLE
Certainty	131.4 metres



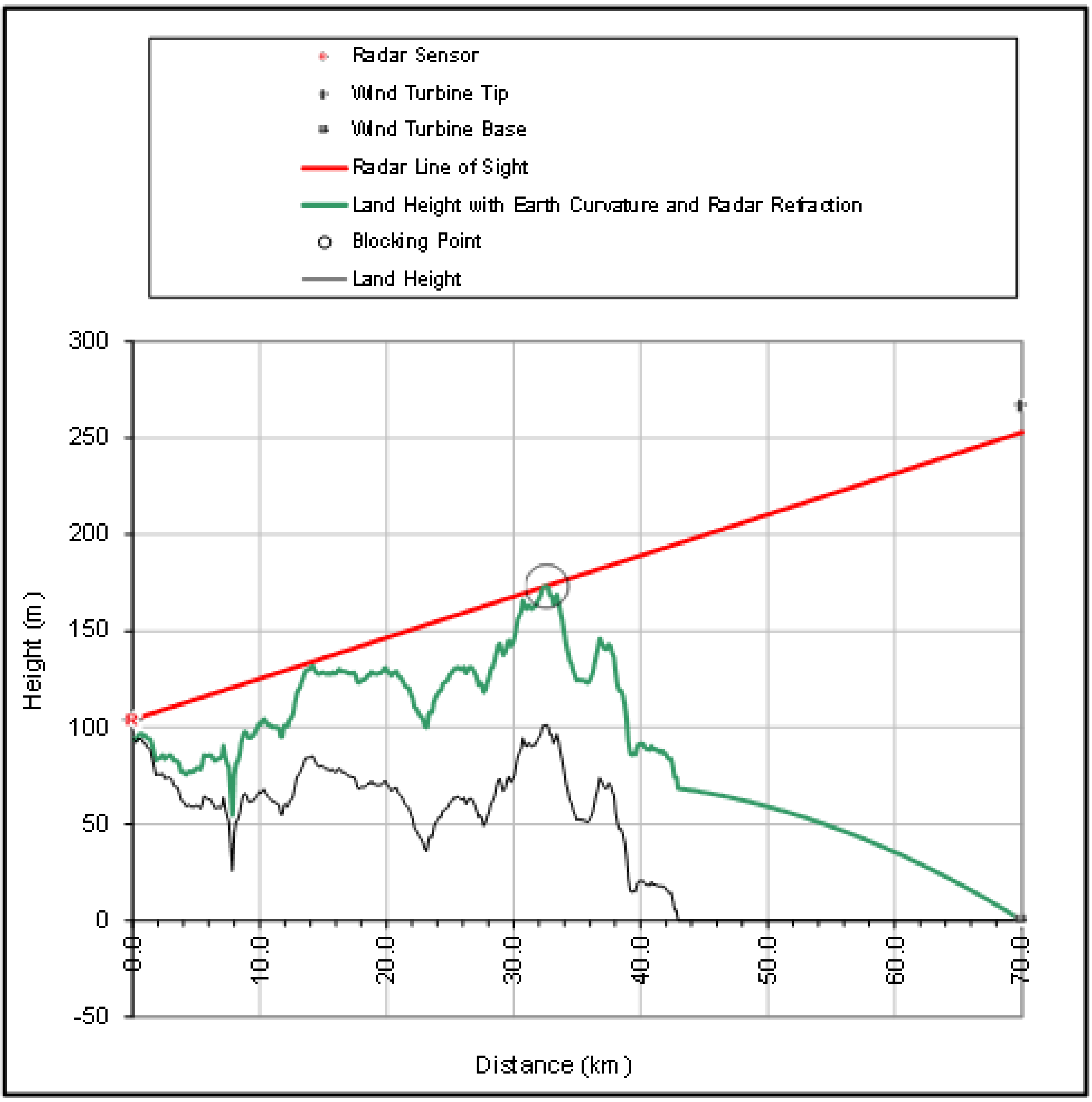
Turbine Height (m)	267.25
Hub Height (m)	147.25
Rotor Diameter (m)	240
Turbine Elevation (m)	0.0
Turbine Location	Ln:-6.0849 Lt:53.8891
Distance to radar (km)	51.3
Blocking Point Location	Ln:-6.2047 Lt:53.5681
Distance to BP (km)	36.6

Additional Analysis	
Angle (Radar to Tip)	0.038 degrees up
Maximum Tip Height	135.80 metres

Figure A5-1: Line of Sight profile from the nearest PSR at Dublin Airport to turbine OR E1 (Note: wind turbine tip heights are above mean sea level).

Radar Line of Sight Calculation

Radar LOS Casement PSR	
Turbine	OR E1
Result	VISIBLE
Certainty	14.4 metres



Turbine Height (m)	267.25
Hub Height (m)	147.25
Rotor Diameter (m)	240
Turbine Elevation (m)	0.0
Turbine Location	Ln:-6.0849 Lt:53.8891
Distance to radar (km)	70.0
Blocking Point Location	Ln:-6.2792 Lt:53.5727
Distance to BP (km)	37.5

Additional Analysis	
Angle (Radar to Tip)	0.103 degrees down
Maximum Tip Height	252.85 metres

Figure A5-2: Line of Sight profile from the observed PSR at Casement to turbine OR E1 (Note: wind turbine tip heights are above mean sea level).