Annex 5.11.1

Radar Early Warning Systems (REWS) Technical Annex

PINS Document Reference: 7.5.11.1

APFP Regulation 5(2)(a)

January 2015
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1.1 General

1.1.1 SMart Wind is a 50/50 joint venture between Mainstream Renewable Power (UK) Ltd and Siemens Project Ventures GmbH. The company has been established to develop the 4 GW Hornsea Zone; SMart Wind was awarded the development through The Crown Estate (TCE) Round 3 bid process.

1.1.2 This assessment report provides technical information and modelling results on the impact Project Two may have on Radar Early Warning Systems (REWS) located on oil and gas platforms. This assessment report also provides the technical information and modelling results concerning the cumulative impact of Project Two and other developments. The first project within the Hornsea Zone, the proposed Project One development, has a potential turbine layout immediately adjacent to the Project Two turbines. The cumulative impacts of Project Two and Project One have therefore been assessed. No other developments have been identified as being within close enough proximity to Project Two to result in a cumulative impact on REWS.

1.1.3 This report will then inform the Infrastructure and Other Users assessment which is included as Volume 2, Chapter 11: Infrastructure and Other Users of the Environmental Statement. To undertake this assessment SMart Wind has worked with the University of Manchester who are recognised international leaders in the modelling of the impact of wind farms on marine based radar.

1.2 Background

1.2.1 Offshore wind farm technology is expected to make a significant contribution to meeting the UK Government targets for electricity generation through renewable sources. However, the site selection for wind farms undergoes a number of checks and consultations in order to avoid conflict of interest and objections from government agencies and other stakeholders. One of the possible objections that wind farm planning permissions may face is due to the potential interference of wind farms on radar systems.

1.2.2 Wind farms located within the line-of-sight (LOS) of radars may interfere with the radar performance and degrade the ability to distinguish between turbines and returns from targets of interest. The potential interference of wind farms with aviation, marine and other radar systems could be considered a significant concern to the regulating authorities and radar operators. As noted below, different types of radar use different approaches driven by different applications. As an example, typical civilian air traffic control radar is in a fixed location looking at small targets and uses various signal processing techniques to differentiate between the wanted aircraft and reflections from unwanted targets such as buildings, the ground etc. On the other hand, a small boat radar has no such sophistication and is looking for ships, not aircraft. The effect of wind farms on these different radars is therefore very different.

1.2.3 Wind turbines are very large structures with geometries and materials that may cause it to have a high radar cross-section (RCS). Furthermore, the rotation of the blades produces a time-variable RCS fluctuation and a Doppler frequency shift that can confuse radars that rely on moving target indicator (MTI) filters to distinguish between static objects and moving targets of interest. This is potentially a major problem in air traffic control (ATC) and air defence (AD) radars. The interference due to the rotating blades and the large reflection of the radar signal has been well reported and explained (Jago and Taylor, 2002; Poupart, 2003 and Wind Energy, Defence & Civil Aviation Interests Working Group, 2002). However, this technical report discusses and models the potential impact of Project Two on the REWS used on selected oil and gas platforms. Such radar systems do not employ Doppler processing and MTI filters.

1.2.4 For non-Doppler based radars such as the REWS the potential impact from wind farms may arise due to the large radar returns. The large RCS of turbines may cause target spreading at extended ranges and potential detections through the sidelobes at close ranges. This will cause smearing and cluttering of the radar screen and potentially mask other targets in the area. Additionally, depending on the thresholding techniques used within a radar system, the presence of wind farms may increase the threshold over parts of the wind farm area, which potentially may cause smaller targets to be lost.

1.2.5 Degradation of the radar performance may also be caused by the radar shadow due to the presence of wind turbines within the LOS of the radar as shown in Figure 1.1. Shadowing may cause smaller targets to temporarily disappear from the radar display as it moves in and out of the shadow regions. The extent of the impact caused by shadowing depends on the size and height of the turbine and the target of interest, i.e., different effects may be observed if looking at surface targets or air targets.

1.2.6 Other effects such as multiple reflections of the radar signals may also degrade the performance of radars operating near the wind farm. This may occur due to a number of scenarios such as; multiple bounces of the radar signal between the turbines within the wind farm, reflection of the radar signal between targets with large reflective surfaces and the turbines, or reflections from reflective/flat surfaces which are part of the superstructure near the radar antenna as shown in Figure 1.2. This tends to be a particular problem when the radar is close to the wind farm as, for example, in a ship mounted case.
1.2.7 This technical report uses a number of modelling techniques developed at the University of Manchester to model and predict the impact of wind farms on radar systems. These allow the radar returns coming both from the wanted target and the wind farm to be simulated so that the effects on radar detection can be evaluated. The results from the models can then be used to indicate the levels of target masking and shadowing along critical vessel paths which may trigger collision alarms.

1.3 Scope of Work

Target Masking

1.3.1 The size, geometry and the construction materials of turbines causes them to have a large radar return. This may cause target spreading (smearing) at extended ranges and potential detections through the sidelobes at close ranges. Such effects will add clutter to the radar screen and potentially mask other targets in the area. The report addresses such effects and compares the levels of the turbine returns against that of a vessel as it travels along a defined path through the wind farm.

Shadowing Effects

1.3.2 The extent and length of the shadow region cast by a turbine depends on the size of the turbine, the distance to the radar antenna, the height of the radar and the height of the target of interest. The severity of the shadow will also depend on the distance of the target from the turbine. This is illustrated in Figure 1.3. Due to the diffraction of the radar waves around the turbine, increasing the range between the target and the turbine will reduce the severity of the attenuation to the target’s returns. It has been reported that a target 1 km behind the turbine will experience 6 dB reduction in the returned power while targets that are significantly further suffer only 2 dB reduction in the received radar echo. This is an important characteristic of the radar shadow and is illustrated in Figure 1.3 (Butler and Johnson, 2003).

Figure 1.1 Illustration of the radar shadowing due to turbines.

Figure 1.2 Measurement showing the effects of multiple reflections between a ships superstructure (mast) and the wind farm (Baker, 2007).
Figure 1.3 Illustration of radar shadowing with diffraction effects.

1.3.3 Modelling the radar shadowing of large wind farms while accounting for the diffraction effects is complex and requires extended runtimes and detailed knowledge of the turbine geometry and surrounding environment. Within this assessment the radar shadows were modelled based on optical shadowing. Optical shadows assume no diffraction effects and therefore ignore the improvement in the shadow region at extended ranges. Depending on the turbine size and radar height, the optical shadows may extend all the way to the radar horizon. Optical shadows will also assume that a point scattering target falling within the shadow will have no returns at all (detection null). In practice, vessels may only experience partial shadowing due to the turbine’s narrow shadow regions, which can greatly enhance detectability and trackability of larger vessels. The use of optical shadows and point scattering models is used to assess worst case scenarios.

Rerouted traffic

1.3.4 Existing shipping lanes may be altered by the physical presence of Project Two. Vessels may be pushed nearer to the REWS platforms as they deviate around the wind farm. This is discussed within Volume 2, Chapter 7: Shipping and Navigation.

Tracker Modelling

1.3.5 REWS deploys a number of techniques for clutter thresholding, target extraction and tracking. Radar trackers provide the radar operator with a processed and clear image of the location and bearing of moving targets in the area of interest. It is also very common for current radar trackers to compensate for momentary loss of detection of a target over one or more radar rotations and maintain an active track. The presence of advanced tracking within REWS can greatly benefit and enhance the operator's ability in maintaining radar visibility of moving targets near or within a wind farm. REWS deploy proprietary tracker algorithms, which may vary depending on the system supplier. The impact of the wind farm on the tracker performance cannot be accurately modelled without detailed knowledge of the tracker and the proprietary tracking algorithms and hence no attempt was made to include it in this report.

UHF communication links

1.3.6 Depending on the REWS system and the tracker software, it is possible that returns from the turbines will add new target detections to the track-table. The track-tables are shared with Emergency Response and Rescue Vessels (ERRVs) via ultra high frequency (UHF) radio links. UHF links use a low-bandwidth telemetry system and have a limit on the total number of tracks that can be transmitted. The maximum size of the track-table is a system limitation that depends largely on the hardware used and hence cannot be modelled. A typical number for the maximum track table size is assumed to be between 400 – 600 tracked targets. Depending on the tracking software, the number of tracks can be reduced by applying non-acquire zones over the wind farm area or by applying filters to track moving targets only.
Other Effects

1.3.8 The variation of the radar returns over multiple range-cells may initiate false tracks. However, the radar tracker requires consecutive detections over a number of radar rotations, which will reduce the likelihood of false tracks initiation. Furthermore, to raise a TCPA alarm, the track vector must continue to breach the TCPA condition for multiple radar rotations. Thus, raising false alarms due to range-cell spreading is considered unlikely and was not included in this assessment.

1.3.9 The effect of multiple reflections within the wind farm and between the turbines and nearby large targets is also possible to model within the radar and WinR (Wind Turbine RCS) models developed at the University of Manchester. However, as the closest modelled turbine in Project Two is 19.5 km away from the REWS, the effects of the multiple reflections were considered to be of second order and were not included in the models (QinetiQ, 2005).

1.3.10 Depending on the detailed structure of the platform, the presence of external fittings near the radar antenna such as masts, wires and other structural elements may cause distortion of the antenna pattern and possibly the appearance of false reflection if a flat surface is near the antenna. These effects were not modelled and this was confirmed to be acceptable for the REWS on Saturn (meeting with ConocoPhillips 23 November 2012).

1.4 Document Structure

1.4.1 The document utilises the following structure:

- Section 1 (this section) gives an introduction to the report;
- Section 2 presents a summary of the modelling techniques and parameters used to assess the impact of Project Two;
- Section 3 presents the identification of the platforms with REWS in the vicinity of Project Two;
- Section 4 presents the results for the REWS on the Saturn platform;
- Section 5 presents the results for a potential REWS on a West Sole operated platform; and
- Section 7 presents the assessment conclusions and summary of the results along with further considerations for future modelling if required. This is then followed by the list of references used throughout the assessment.

2 MODELLING THE IMPACT OF WIND FARMS ON REWS

2.1 Introduction

2.1.1 The impact of wind farms on radar systems is dependent on the type and location of radar, the size and orientation of the turbines, the distance of the wind farm to the radar, target type and other parameters relating to the local environment. This section will give an overview of the methodology used to compute the RCS of the turbines, the tools used to model the shadow regions and the radar modelling parameters used to compute the returns from the wind farm and the target of interest.

2.2 Wind Turbine RCS Modelling

2.2.1 The general dimensions of the turbines used in Project Two and Project One are defined to give the overall size and rotor diameter. However, due to the electrical size of the turbines, which extends over many hundreds of radar wavelengths, better representation of the geometry is needed to give more accurate RCS modelling results.

2.2.2 The precise detail of the RCS will depend on the actual wind turbine used. However a good representation can be obtained from a generic model. For this study, a generic 5 MW turbine geometry, which includes the blades airfoil profile and nacelle geometry was used and scaled to achieve the needed dimensions of the turbines used in Project Two. The generic 5 MW turbine has a rotor diameter of 120 m and the meshed CAD model is shown in Figure 2.1.

Figure 2.1 Turbine CAD geometry and meshing.
2.2.3 Two turbine sizes were considered within this report for Project Two and are referred to as T-135 and the T-250 based on their rotor diameter. Project One was modelled using the T-180 geometry only. The scaled CAD geometries for the modelled turbines used to compute the RCS of the turbines are shown in Figure 2.2, Figure 2.3 and Figure 2.4. Details such as ladders, warning lights, wind measurement/lightning protection equipment etc., were removed from the turbine CAD for RCS modelling in order to speed up the modelling run time. The use of T-135 and T-250 is highlighted in Section 0.

Figure 2.2 Modelling geometry of the Project Two turbine (T-135) (relative to LAT).

Figure 2.3 Modelling geometry of the Project Two turbine (T-250).

2.2.4 When assessing the potential impact of Project Two (alone) and Project One and Project Two in combination on a given REWS, the wind is assumed to be in the direction from the radar site to the centre of the wind farm. This will result in the majority of the turbines facing the radar, which will then give the maximum RCS value (maximum adverse scenario). As the RCS of each turbine is individually computed, the blades rotation angle on each turbine is generated randomly as a value between 0° - 119°. This will result in a different RCS for each turbine rather than an unrealistic unified rotation angle across all the turbines.
2.2.5 REWS onboard offshore oil and gas platforms are used to detect and track all vessels on the radar horizon. One of its main functions is to protect offshore assets from collision with vessels. REWS has preset collision alarm rules. Typically, an Orange alarm is raised if a collision course is detected with Closest Point of Approach (CPA) of 0.5 NM or Time to Closest Point of Approach (TCPA) of 35 minutes and Red alarm is raised if the CPA is 0.27 NM or TCPA is 25 minutes. Should a vessel breach these rules an automatic alarm is raised to alert the operator. It is worth noting that TCPA alarms are only triggered if the vessel’s vector remains in breach of the TCPA condition for a set number of radar rotations (typically 5 – 10 radar rotations). This setting is included to avoid alarms due to temporary vector breach of the TCPA while vessels are turning.

2.2.6 REWS are often integrated with Automatic Identification Systems (AIS) fitted onboard ships. If a vessel is fitted with an AIS transponder and is detected by the radar, the REWS will include the AIS data into the track data.

2.2.7 Within this report, the performance of the REWS is based on the specification of the Raytheon’s Pathfinder/ST MK2 X-band transceiver with Mariners Pathfinder X-band 12 ft antenna system supplied by Ultra Electronics SML. The details of the modelling parameters used are shown in Table 2.1 and the antenna pattern used in the modelling is shown in Figure 2.5.

<table>
<thead>
<tr>
<th>Modelling Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>32 dB</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>25 kW</td>
</tr>
<tr>
<td>Frequency</td>
<td>9.411 GHz</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>250 ns</td>
</tr>
<tr>
<td>Rotation Rate</td>
<td>25 RPM</td>
</tr>
<tr>
<td>Pulse Repletion Frequency</td>
<td>2.0 KHz</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>5.5 dB</td>
</tr>
<tr>
<td>Dissipative Losses</td>
<td>1.0 dB</td>
</tr>
<tr>
<td>Beam-shape Losses</td>
<td>0.6 dB</td>
</tr>
<tr>
<td>Azimuth beam width</td>
<td>0.7°</td>
</tr>
<tr>
<td>Elevation beam width</td>
<td>22.0°</td>
</tr>
</tbody>
</table>

Table 2.1 Radar modelling parameters.
2.2.8 It is worth noting that only the medium pulse width of 250 ns was used throughout the study. This gives an approximated range resolution of 37.5 m which is then equated to the range-cell length. As the turbine rotor diameter is much larger than the range cell length (depending on the yaw angle with respect to the radar), parts of the blades will fall into adjacent range-cells as the turbine blades rotate. This effect is illustrated in Figure 2.6 and is modelled within this study by segmenting the turbine into small components. Each component is then treated as an independent point scattering target. This phenomenon will be referred to as “range-cell spreading” within this report.

2.2.9 The RCS model was used to segment each turbine, compute the RCS of each segment and then place it on the ‘map’. The radar models were then used to compute the power returned from the turbine segments and other targets on the map. Once the returns from all the targets are computed over a full antenna rotation the model outputs the results as a scan-converted plan position indicator (PPI) display showing the locations and magnitudes of the power received. The display can show the returns in a colour coded scale to compare the returns from the turbines to that of nearby targets, or in a monochrome to show the targets with returns above a set threshold. The threshold is set to represent the noise floor of the system which was approximated using the radar parameters provided.

2.2.10 REWS deploys a number of techniques tracking and clutter thresholding such as Constant False Alarm thresholding (CFAR). Such techniques were not included in the study as they contain proprietary algorithms depending on the system used. Therefore, the output of the model is set to detect target returns if the power received is above the system noise level. This is the most extreme case for detection. Normally the radar is set with a threshold 10 to 20 dBm above noise to limit false alarms/detections due to noise spikes. However, this assessment has taken a much lower threshold and removed the noise effects in order to see the detail of the wind farm impact more clearly. The effect of including the noise level and sea clutter is shown in Figure 2.7.
2.3 Target Modelling

2.3.1 REWS are mainly interested in detecting and tracking surface targets such as large fishing boats, maintenance vessels and larger ships and tankers. The role of the REWS is to alert the operator when a vessel is on a collision course with the platform. Although air targets may also appear on the radar display, the management and trafficking of air targets is regulated by other radar systems such as ATC primary and secondary radars or AD radar systems. Thus, the analysis of the potential impact of Project Two (alone) and Project Two and Project One in combination, on REWS is limited to surface targets only.

2.3.2 Large vessels in excess of 1,000 gross tons (GT) are the main concern to the safety of the platform. Smaller vessels are not deemed of significant risk to the platforms (Love, 2014). However, for the study undertaken within this report the target was set to represent a medium sized maintenance vessel with a steel/metallic hull. The test vessel is assumed to have an RCS of 100 m² and height of 6 m. These parameters were provided by the REWS supplier (Ultra Electronics) and they comply with the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) VTS guidelines for radar modelling of different vessel types. The test vessel was set to have an average speed of 12 knots (22.2 km/hr).

2.4 Turbine Shadow Impact Modelling

2.4.1 When turbines are placed within the LOS of radar systems radar shadowing will occur behind the structure. The extent and length of the shadow region depends on the size of the turbine, the distance to the radar antenna, the height of the radar and the height of the target of interest. Shadowing produced by turbines may cause targets to be lost as they move out of the shadow region. Depending on the size of the shadow region, this may cause existing tracks to be lost or discontinued.

2.4.2 As REWS are mainly used to detect and track surface moving targets (ships, boats etc.) only surface or near-surface shadowing is considered. This can be approximated by using the optical shadowing/blockage cast by the turbine over the sea surface. The use of optical blockage to estimate the radar shadowing is deemed to be acceptable for objects that are much larger than the radar wavelength. It is noted that optical blockage does not account for diffraction effects around the structure which would normally reduce the shadow length. Furthermore, the models assume that the shadow region will result in complete radar blindness and point scattering targets within the shadow region will not reflect any energy back to the radar.

2.4.3 1,000 GT vessels vary in size and typical vessel lengths are between 50 – 150 m. It will be shown in later sections that the shadow from the turbines are relatively narrow and are typically between 4 – 20 m in width. This indicates that a large 1,000 GT vessel will be partially shadowed by the turbine as it moves through the shadow regions. Partial shadowing will allow some of the radar energy to be reflected back to the radar and might be possible to be detected by the REWS. As stated previously in the scope of this study, vessels are assumed as point scatterers and partial shadowing is not considered. This is a very conservative approach and is considered to simulate worst case shadowing scenarios.

2.4.4 By studying the geometry of the various components, taking into account the typical height of the REWS, the range to the closest turbine and the height of the test target, only shadowing from the towers were considered. This assumption is explained in Figure 2.8 where it shows that the line to the target horizon does not cross the lower blade height. Figure 2.9 also illustrates that the shadows from the blades and nacelle may fall well beyond the detection range for the test target shown in the previous section. Hence, only the tower shadowing was considered within this study.
2.4.5 The size of the shadow region is computed based on the range between the turbine and the radar and the size of the turbine tower. The shadows are computed for each turbine and then a complete shadowing plot/map is produced based on the wind farm layout, which accounts for shadow overlapping. The shadowing map is then used when modelling the returns from the target as it moves through the wind farm. This is carried out for both the result on the PPI display or power received vs. range graphs. A sample shadowing plot for Project Two (alone) is shown in Figure 2.10, and for Project Two and Project One in combination in Figure 2.11.
2.5 Project Two Layout Modelling

2.5.1 Four possible layouts for Project Two were considered within this report. The number of turbines and sizes (T-135 or T-250) depended on the layout. The modelling of the shadowing effects and the radar returns was repeated for each layout in order to identify the maximum adverse scenario. The layouts are illustrated in Figure 2.12 to Figure 2.15 and include the following:

- Layout 1: 360 x T-135 turbines in regular grid;
- Layout 2: 120 x T-250 turbines in regular grid;
- Layout 3: 360 x T-135 turbines in regular grid and dense border; and
- Layout 4: 120 x T-250 turbines in regular grid and dense border.

Figure 2.12 Project Two proposed layout 1.

Figure 2.13 Project Two proposed layout 2.

Figure 2.14 Project Two proposed layout 3.
2.5.2 The RCS models, the shadowing analysis and the radar returns models were used to assess the impact of each layout on the radar. The results from the shadowing analysis and the radar returns were used to select the layout which may produce the worst effects on the REWS on the considered platforms (ConocoPhillips’s Saturn platform and Perenco’s West Sole platform, as identified in Section 3).

2.5.3 The shadowing analysis gives the total shadow area produced by the wind farm up to the 16 NM (30 km) detection range. This is then presented as a percentage of the affected sector and of the whole coverage area of the REWS. The radar returns model was set to calculate the total area which will appear on the radar screen when a given layout of Project Two is introduced. This gives an insight to the total area of the masking regions produced by the turbines. Additionally, the number of turbines that can be detected is also considered as it may affect the size of the track-table. The results of this analysis are shown in Table 2.2 and Table 2.3.

### Table 2.2 The effects of masking, shadowing and number of detections from Project Two on the REWS on the Saturn platform.

<table>
<thead>
<tr>
<th>Layout</th>
<th>Masking Area (km²)</th>
<th>Shadowing ratio of total coverage (%)</th>
<th>Shadowing ratio of affected sector (%)</th>
<th>Number of turbines detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.78</td>
<td>0.164</td>
<td>0.633</td>
<td>360</td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>0.089</td>
<td>0.344</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>5.52</td>
<td>0.158</td>
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<tr>
<td>4</td>
<td>1.98</td>
<td>0.08</td>
<td>0.311</td>
<td>120</td>
</tr>
</tbody>
</table>

### Table 2.3 The effects of masking, shadowing and number of detections from Project Two on the REWS on the West Sole platform.

<table>
<thead>
<tr>
<th>Layout</th>
<th>Masking Area (km²)</th>
<th>Shadowing ratio of total coverage (%)</th>
<th>Shadowing ratio of affected sector (%)</th>
<th>Number of turbines detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.29</td>
<td>0.019</td>
<td>0.222</td>
<td>346</td>
</tr>
<tr>
<td>2</td>
<td>0.41</td>
<td>0.01</td>
<td>0.115</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>1.58</td>
<td>0.023</td>
<td>0.226</td>
<td>350</td>
</tr>
<tr>
<td>4</td>
<td>0.59</td>
<td>0.015</td>
<td>0.174</td>
<td>120</td>
</tr>
</tbody>
</table>

2.5.4 The results indicate that Layout 1 and Layout 3 may cause the most masking and shadowing on the REWS on the Saturn and West Sole platforms respectively. Therefore, Section 4 and Section 5 of this report will use the respective layout to assess the potential impact of Project Two on the REWS on the Saturn and West Sole platforms.
3 PLATFORMS IDENTIFIED WITH REWS

3.1 Introduction

3.1.1 The installations equipped with REWS and located in close proximity to Subzone 2 of Project Two were identified through consultation with the relevant oil and gas operators.

3.1.2 There are no such installations within the Project Two area. Those installations identified as having REWS and that are located in the area surrounding Project Two are shown in Figure 3.1 and are listed in Table 3.1 below.

Table 3.1 Installations equipped with REWS and the range of the REWS (NM).

<table>
<thead>
<tr>
<th>Name of Installation</th>
<th>REWS Range (NM)</th>
<th>Operator</th>
<th>Block</th>
<th>Position Relative to Subzone 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturn</td>
<td>16</td>
<td>ConocoPhillips</td>
<td>48/10</td>
<td>South</td>
</tr>
<tr>
<td>LOGGS (North Valiant)</td>
<td>16</td>
<td>ConocoPhillips</td>
<td>49/16</td>
<td>South</td>
</tr>
<tr>
<td>Viking Bravo</td>
<td>16</td>
<td>ConocoPhillips</td>
<td>49/17</td>
<td>South</td>
</tr>
<tr>
<td>Murdoch</td>
<td>16</td>
<td>ConocoPhillips</td>
<td>44/22</td>
<td>Northeast</td>
</tr>
<tr>
<td>Ravenspurn South B</td>
<td>32</td>
<td>Perenco</td>
<td>42/30</td>
<td>Northwest</td>
</tr>
<tr>
<td>Cleeton CPQ</td>
<td>32</td>
<td>Perenco</td>
<td>42/29</td>
<td>Northwest</td>
</tr>
<tr>
<td>Rough CD</td>
<td>30</td>
<td>Centrica</td>
<td>47/08</td>
<td>Southwest</td>
</tr>
<tr>
<td>West Sole A</td>
<td>32</td>
<td>Perenco</td>
<td>48/06</td>
<td>Southwest</td>
</tr>
<tr>
<td>Amethyst A1D</td>
<td>32</td>
<td>Perenco</td>
<td>47/13</td>
<td>Southwest</td>
</tr>
<tr>
<td>Markham St-1</td>
<td>30</td>
<td>Centrica</td>
<td>49/05</td>
<td>East</td>
</tr>
<tr>
<td>Sean</td>
<td>16</td>
<td>Tullow</td>
<td>49/24</td>
<td>Southeast</td>
</tr>
</tbody>
</table>

3.1.3 The closest REWS system to Subzone 2 is the system on the Saturn platform operated by ConocoPhillips. An assessment was carried out on the potential impact of Project Two on this system and is presented in Section 4.

3.1.4 The closest platform operated by Perenco with the potential for REWS was identified as being West Sole. An assessment was carried out on the potential impact of Project Two on this system and is presented in Section 5.
Figure 3.1 Location of offshore oil and gas platforms with REWS installations.
4 MODELLING THE IMPACT ON THE MIMAS, SATURN AND TETHYS PLATFORM REWS

4.1 Introduction

4.1.1 Project Two is located within the LOS of the REWS on the Saturn platform. The platform is a normally unmanned installation and the REWS is operated by ConocoPhillips using a remote system. The height of the radar antenna on Saturn is 40.9 m above Lowest Astronomical Tide (LAT). By using the radar parameters in the previous section with the test vessel the maximum detection range for the test vessel was established to be approximately 16 NM (30 km). The turbine detection range is significantly more due to their size and height which will extend the radar detection range. Figure 4.1 shows the layout of Project Two with respect to the REWS on the Saturn platform located at the centre of the plot. The Saturn REWS is also used to provide traffic monitoring and early warning coverage for the Mimas and Tethys platforms, these assets are also included in the figure. An outline of the detection range for the specified test vessel is drawn around the REWS. This particular candidate layout (Layout 1) was chosen for the assessment based on the modelling results.

4.1.2 When modelling the impact of Project Two on the radar the wind bearing was set to 0°.

4.2 Project Two Modelling

4.2.1 Once the locations of the wind turbines in Layout 1 are imported into the models, each turbine is segmented and the RCS is computed. The returns from the turbines are then calculated based on their range from the radar and the selected rotation angle. Figure 4.2 shows the imported data and the locations of the Saturn, Mimas and Tethys platforms with their alarm zones. Figure 4.3 and Figure 4.4 show the power received from the wind farm. Figure 4.5 shows the processed radar screen with markers placed over the detected targets.
4.2.2 The modelling results show that the returns from each turbine can be identified individually. All of the 360 turbines are detected by the REWS. At closer ranges the turbine returns are high and may reach values of up to -55 dBm. However, no sidelobe detections are observed. In general, the levels of the returned power reduces as the turbines get further away from the radar, but the fluctuation in the levels are due to the randomly selected rotation angle for each turbine and the difference of aspect (yaw) angle with respect to the radar. Distant turbine returns appear as extended arcs (target spreading/smearing) which is a common phenomenon for large targets.

4.2.3 Mimas is the closest platform to the proposed Project Two layout. Therefore, the study examines the potential masking and shadowing of vessels moving towards the Mimas platform. Tethys was not included in this part of the study as it is further away from the proposed wind farm than the Saturn platform. Hence, the masking and shadowing effects on the paths towards Tethys is expected to be less than that of Saturn platform.

4.2.4 The shadowing analysis for Project Two was conducted based on the affected sector shown in Figure 4.6 and the geometry of the T-135 turbine used in Project Two Layout 1.

4.2.5 The affected sector extends between -65° – 25° azimuth angles.

4.2.6 The shadow regions caused by the presence of the turbines is 0.164% of the total radar coverage or 0.633% of the affected sector (as shown in Table 2.2).
4.2.7 These figures assume that the shadowing is based on optical shadowing with no diffraction around the edges of the tower. This implies that the shadow region from each turbine would extend up to maximum detection range regardless of the range between the tower and the radar.

4.2.8 To assess the impact of the wind farm on the detection of the test vessel a number of paths have been modelled across the wind farm. The test vessel is a medium sized vessel with steel hull of 100 m² RCS and 6 m height as stated in Section 2.3.

4.2.9 The model compares the returns from the turbines and the returns from the test vessel after applying the shadowing effects. Figure 4.7 shows the test paths used for this analysis. Although Path 1 is not considered a threat to the platform and will not cause the alarm to be raised, it does illustrate the effect of target masking and shadowing due to the turbines. The resolution at which the path was tested was at 1 m intervals to insure that all shadow regions are captured. The results for Path 1 are shown in Figure 4.8 and an enlarged section of the results are shown in Figure 4.9.

4.2.10 Figure 4.8 shows that the returns from the vessel appear to experience many nulls due to the shadowing from turbines. However, closer inspection as illustrated in Figure 4.9 shows that the shadow regions are very narrow and may range between 4 m – 15 m in width. The results for Path 1 are as follows:

- Vessel returns within the shadow region: 0.31 km of 27.2 km (1.14%); and
- Vessel returns less than wind farm returns: 0.38 km of 27.2 km (1.40%).

4.2.11 As discussed above, the coverage of the REWS on the Saturn platform also includes the nearby platforms, Mimas and Tethys. Thus, the REWS on Saturn is also used to monitor the traffic and provide early collision warning for those platforms. The effect of the static shadowing on the affected radar sector will remain unchanged when addressing the potential impact on the other platforms. However, the impact of the masking and the shadowing on vessels moving through the wind farm and on paths approaching Mimas or Tethys may differ.
4.2.12 Test Path 2 is chosen to illustrate a scenario where the vessel is travelling along a corridor and on a collision course with the Mimas platform which is the nearest platform to the Project Two wind farm. The results of Path 2 analysis are:

- Vessel returns within the shadow region: 0.18 km of 18.5 km (0.98%); and
- Vessel returns less than wind farm returns: 0.0 km of 18.5 km (0%).

4.2.13 Path 2 analysis shows that the wind farm has no effect on the radar’s ability to detect and track the vessel. This is mainly due to the large spacing between the turbines which for this selected layout is between 878 m – 1,323 m.

4.2.14 Test Path 3 is modelling a scenario where the vessel is not travelling along a corridor within the wind farm and is again on a head-on collision course with the Mimas platform. This path is chosen to simulate the vessel exiting the wind farm from the nearest point to the platform. The results of Path 3 analysis are:

- Vessel returns within the shadow region: 0.14 km of 19.1 km (0.73%); and
- Vessel returns less than wind farm returns: 0.24 km of 19.1 km (1.25%).

4.2.15 For Path 3 the nearest point at which the masking occurs is approximately 14.1 km away from the radar. By assuming that the vessel is travelling at 12 knots (22.2 km/hr) it would take the vessel 38 minutes to reach the platform. It is worth noting that the REWS tracker system will compensate for temporary loss of detection. Masking of vessels due to the returns from turbines is unlikely to exceed 2 - 4 radar rotations and, hence, is not seen as a potential cause for track termination. However, in the unlikely event that the tracker would lose the vessel track, with the specified rotation rate of the antenna and by assuming that it takes 10 radar antenna rotations to re-establish the vessel track (i.e., 24 seconds) the REWS should re-establish the track before the specified rule for the Orange alarm is breached.
4.2.16 Tracked vessels travelling at speeds exceeding 13.2 knots may temporarily be lost within the TCPA alarm conditions as it travels within the wind farm boundaries, in the unlikely event of a track being terminated due to turbine masking. The track loss duration depends critically on the acquisition delay of the radar and related tracker which is equipment specific. As noted above, it is understood that for the Ultra supplied equipment the track should be established within 5 - 10 rotations (12 – 24 seconds).

4.3 Cumulative Impact Modelling of Project Two and Project One

4.3.1 The combined impact modelling of Project Two and Project One on the Saturn REWS was conducted in the same manner as that shown previously for Project Two. The Project Two and Project One wind farm layout shown in Figure 4.10 are imported into the models and the power received is calculated based on the location and orientation of the T-135 turbine for Project Two (360 turbines) and the T-180 for Project One (335 turbines). The power received and the processed returns are shown in Figure 4.11.

Figure 4.10 The imported Project Two and Project One turbine locations for the Saturn REWS assessment.

4.3.2 It is noted that the Applicant for Project One has submitted during examination to reduce the overall maximum number of turbines within Project One from 332 to 240 and further that the Applicant confirmed that this reduction does not restrict it from maintaining the maximum generation capacity of 1,200 MW (The Applicant's Response to Deadline VI, 21 May 2014). The assessment for Project Two has been undertaken on the basis of a design envelope for Project One of up to 335 turbines as presented in the submission documentation in July 2013. However, if the Secretary of State awards the Development Consent for Project One in December 2014 and concurs with the reduction in design envelope as proposed by the Applicant on 21 May 2014, then the level of impacts on REWS would likely be reduced from those presented below.

4.3.3 The results show that target spreading and high radar returns from the turbines may cause masking of targets within the wind farm. No sidelobe detections are shown in the results.

4.3.4 The shadowing sector is shown in Figure 4.12 where it extends between -65° – 62° azimuth angles. Based on the tower geometries of the T-135 used for Project Two and the T-180 used for Project One, the shadowing analysis showed that:
4.3.5 A number of paths were considered to assess the impact of the combined Project Two and Project One wind farm on the radars ability to detect moving vessels on a collision course to the Mimas or Saturn platforms. The paths are illustrated in Figure 4.13. The results of the path analysis are shown in Table 4.1.

<table>
<thead>
<tr>
<th>Path Number</th>
<th>Length (km)</th>
<th>Vessel Masked by Farm Returns (km)</th>
<th>Masking (%)</th>
<th>Vessel Within Turbines Shadow (km)</th>
<th>Shadowing (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.33</td>
<td>0.23</td>
<td>0.84</td>
<td>0.61</td>
<td>2.22</td>
</tr>
<tr>
<td>2</td>
<td>31.70</td>
<td>0.0</td>
<td>0.00</td>
<td>0.63</td>
<td>1.99</td>
</tr>
<tr>
<td>3</td>
<td>30.0</td>
<td>0.075</td>
<td>0.25</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>30.0</td>
<td>0.22</td>
<td>0.76</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

4.3.6 As a final test of the impact of the wind farms on the operator’s ability to identify moving vessels within the wind farm the models were set to animate the returns from 6 test vessels moving within the wind farms as shown in Figure 4.14. The PPI display was set to show raw data illustrating the returns from the turbines and the vessels. The models were also set to show detection history of the targets as they move. The results are shown in Figure 4.15 and an enlarged portion is shown in Figure 4.16.
4.3.7 The figures suggest that moving targets can be identified through their detection history. However in practice the operator may be looking at a “processed” display rather than the raw data. This depends on the precise system and its setup. The processing of the returns will normally extract the target, fit a “track” to this data (the number of returns used to initiate and update such tracks varies with manufacturer and setup) from which the future position of the target can be estimated. The processing may also integrate data from the AIS system onboard the vessels. The tracking algorithms used are proprietary and of varying complexity dependent on the supplier. The operator display may also deploy filtering and thresholding techniques to adjust the display and reduce the apparent clutter on the display. In the presence of a large target such as a wind turbine some algorithms will tend to increase the threshold to decrease the return from the turbine but in so doing loose adjacent small targets. Unfortunately without access to proprietary information on such algorithms the effect cannot be modelled and no attempt has been made in this report.
5 MODELLING THE IMPACT ON WEST SOLE PLATFORM REWS

5.1 Introduction

5.1.1 West Sole was identified as the closest Perenco platform to the proposed wind farm with REWS. Therefore, the study presented in this section presents modelling results for the West Sole platform.

5.1.2 At the time of the assessment, no other platforms were assumed to be covered by the West Sole REWS. Thus, the impact assessment only concentrates on paths towards the West Sole platform.

5.1.3 When modelling the impact of the proposed Project Two (alone) and Project One and Project Two in combination on the West Sole REWS assumptions were made regarding the height of the radar antenna due to lack of data at the time. To give conservative results the height of the antenna was assumed to be 61.9 m above LAT which is considerably higher than the REWS on Saturn at 40.9 m above LAT. The added height will result in extended radar coverage. Other radar parameters were maintained as discussed in Section 2.2. To illustrate the detection range for the test vessel, the T-135 turbine and the T-180 turbine the power received was modelled from each object at varying ranges. The results are shown in Figure 5.1.

5.1.4 The modelling results show that the maximum detection range for the test vessel is approximately 35 km. Due to the size and height of the turbines they are detected at longer ranges extending to approximately 68 km and 74 km for T-135 and T-180 respectively. Using these results as a reference the detection range within this assessment was set to 35 km. This is shown in Figure 5.2 along with the Project Two Layout 3 used as the maximum adverse scenario within this section.

5.2 Project Two Impact Modelling

5.2.1 The Project Two layout 3 is imported into the models and the power received is calculated based on the turbine geometry (T-135), location and orientation. Layout 3 was chosen for this study as it has dense borders with the turbines being closely spaced resulting in more turbines falling within the detection range of the REWS. With more turbines being within the LOS of radar, more returns and target detections will be displayed on the radar screen. This will also result in an increased probability of target masking coupled with more shadowing within the wind farm.

Figure 5.1 Modelled power received from turbines and vessel against range from radar (radar antenna height = 61.9 m above LAT).

Figure 5.2 The imported Project Two turbines location for the West Sole REWS assessment.
5.2.2 It can be noted that the closest turbine is approximately 25 km away from the platform. Given that a vessel is moving at 12 knots, it would take more than 1 hour for the vessel to reach the platform as it exits the wind farm. This will give enough time for the REWS to re-establish any lost tracks of vessels travelling within the wind farm.

5.2.3 For this particular layout of Project Two (alone) 350 turbines were detected in a typical modelling scenario as stated previously in Table 2.3.

5.2.4 The shadowing sector is shown in Figure 5.3 where it extends between 36° – 67° azimuth angles. Based on the tower geometries of the T-135 turbines, the shadowing analysis showed that:

- The shadow regions caused by the presence of the turbines is 0.051% of the total radar coverage or 0.60% of the affected sector.

5.3 Cumulative Impact Modelling of Project Two and Project One

5.3.1 It is noted that the Applicant for Project One has submitted during examination to reduce the overall maximum number of turbines within Project One from 332 to 240 and further that the Applicant confirmed that this reduction does not restrict it from maintaining the maximum generation capacity of 1,200 MW (The Applicant's Response to Deadline VI, 21 May 2014). The assessment for Project Two has been undertaken on the basis of a design envelope for Project One of up to 335 turbines as presented in the submission documentation in July 2013. However, if the Secretary of State awards the Development Consent for Project One in December 2014 and concurs with the reduction in design envelope as proposed by the Applicant on 21 May 2014, then the level of impacts on REWS would likely be reduced from those presented below.

5.3.2 The Project One turbines are considered to be beyond the REWS's detection range for the test vessel. Therefore, the potential impacts of Project One on the path analysis or the shadowing analysis were not considered. Additionally, due to the range of the Project One wind farm from the REWS some turbines may be beyond the detection range of the T-180 turbine (74 km). Hence, some turbines may not be detected by the REWS. Thus, the number of detected turbines by the West Sole REWS was 685 detections from the combined Project Two and Project One under typical modelling conditions (see Figure 5.4).

5.3.3 As mentioned previously, the closest turbine is approximately 25 km away from the West Sole platform. Therefore, only one test path was considered within this study as shown in Figure 5.5.

5.3.4 The results of this path are as follow:

- Total Path Length: 35.0 km;
- Path resolution: 1 m;
- Vessel returns within the shadow region: 0.0 km (% 0.0);
- Vessel returns less than wind farm returns: 0.187 km (% 0.53);
- Nearest masking point: 25.3km from radar; and
- TCPA approximately 1 hour and 7 minutes if vessel is travelling at 12 knots.

5.3.5 For the assumed vessel parameters, modelling results show that the REWS can still detect and initiate a track before any of the alarm rules are breached.
6 SUMMARY AND CONCLUSIONS

6.1 General Modelling Remarks

6.1.1 The RCS profile will depend on the size and the geometry of the turbines used within the proposed projects along with other external factors such as blade bending and tower vibration.

6.1.2 Generic turbine geometries were modelled. Towers with monopile transition pieces were modelled which give high RCS. The T-250 model assumed the same transition piece height and diameter as the T-135 turbine which cannot be confirmed at this stage. A larger transition piece will increase static RCS of the turbine.

6.1.3 Optical shadowing was used to approximate the shadowing effects produced by the turbine towers. This assumes no diffraction around the tower and hence extended shadow lengths.

6.1.4 The shadows from the towers are assumed to generate detection nulls. The modelling results show that the width of the nulls varies between 4 – 15 m. For larger vessels over 1,000 GT, the dimensions of the vessel may exceed the width of the shadowing null. This can cause a portion of the radar signal to be reflected back to the radar. Depending on the levels of the reflected energy, it may be possible to detect the vessel while moving behind the turbines.

6.1.5 The effects of the platform superstructure on the radar performance were not modelled.

6.1.6 The test vessel parameters were chosen based on the provided information from the REWS operators and comply with the IALA VTS modelling standards.

6.1.7 For a detailed view of the wind farm impact the noise speckle and sea clutter were removed from the PPI display.

6.2 Saturn REWS Impact Assessment

Project Two

6.2.1 Target spreading due to large turbine RCS occurs and may cause occasional masking of targets depending on the vessel size and path. The modelling indicates no appearance of side-lobe detection.

6.2.2 The radar is considered to be sufficiently far that the possibility of significant multiple reflections between turbines (only) is small, and therefore have not been modelled.
6.2.3 When a target is very close to the turbines (less than 1.5 km) it is possible that multiple reflections between the target and the turbine can occur which could generate false detections. However as this is normally considered a second order effect it has not at this stage been computed. Such effects can be included in the simulations as a standard feature, but add significantly to the modelling run time.

6.2.4 Shadowing produced by Project Two will cause 0.63% of the affected sector to be in shadow.

6.2.5 The modelled vessel paths show a possible loss of target due to shadowing of 1.14% at the worst case scenario modelled for Project Two.

6.2.6 All 360 turbines of the considered Project Two layout will be detected by the REWS.

Project Two and Project One

6.2.7 Shadowing produced by Project Two and Project One will cause 2.7% of the affected sector to be in shadow.

6.2.8 Project Two and Project One in combination will introduce 695 new target detections on the REWS.

6.3 West Sole REWS Impact Assessment

6.3.1 The Subzone 2 boundary falls within the detection range of the West Sole REWS and will introduce shadow regions of about 0.60% of the affected sector.

6.3.2 Assuming typical vessel speeds of 12 knots, the vessel will take 1 hour and 7 minutes to reach the platform as it exits from the closest point in Project Two to the radar.

6.3.3 Given the rotation rate of the radar antenna and assuming that it takes 10 rotations to initiate a track, the REWS will be able to detect and track the vessel before any of the alarm rules are breached.

6.3.4 Using the outlined radar parameters, the wind farm layout data, the turbine geometries and the test vessel parameters, impact modelling results of Project Two (alone) and Project One and Project Two in combination, show some degree of impact but no significant effects on the radar detection of a surface vessel of 100 m² RCS.

6.4 Further Considerations

6.4.1 The variation of returns in range cells due to rotation of the blades may cause the tracker to initiate false tracks. In order for the false track to raise a TCPA alarm the generated track needs to maintain its vector for a set number of radar rotations (typically 5 - 10). This is deemed to be unlikely; however, the effect of this cannot be quantified due to the supplier proprietary algorithms used within the system.

6.4.2 Care will be needed to set the threshold within the wind farm area to ensure small targets are not lost.

6.4.3 The study of the shadowing and masking depend largely on the detailed layout of the wind farm and was based on the worst case of the proposed layouts. Should the final turbine positions change significantly, the shadowing and masking analysis may be affected and may need checking. Slight changes within 10s of metres due to seabed conditions are not expected to change the shadowing effects significantly.

6.4.4 The introduction of turbines to the radar coverage area will increase the number of target detections. Depending on the tracker configuration, turbine detections may be included in the track-table. The track-table is transmitted to ERRV’s via a low bandwidth UHF telemetry link. Using non-acquire zones and configuring the tracker to include only moving targets in the track-table may reduce the load on the UHF links. However, the effect of the track-table size and the UHF links are not considered to be required within the scope of this study.

6.4.5 The system assumed to be in use, uses a tracking algorithm to predict the vessels movement and compensate for momentary loss of detection. Such tracking algorithms are proprietary to the manufacturer. In general such tracking may allow improved performance in the wind farm vicinity.

6.4.6 It is noted that in most cases a track will be established within typically 5 - 10 rotations of the radar antenna (for antenna with 24 RPM, this is equivalent to 12.5 seconds).
REFERENCES


QinetiQ (2005) An assessment of the impact of the proposed Gwynt y Môr wind farm on marine radio navigation and communications systems.