Spiorad na Mara Offshore Wind Farm

Offshore Project

Environmental Impact Assessment Report

Appendix 18.5: Visibility of Aviation Warning Lights, Volume 2c

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Contents

List of Tables

List of Plates

1 INTRODUCTION

1.1 OVERVIEW

1.1.1.1 This appendix of the Environmental Impact Assessment Report (EIAR) presents findings regarding the effect of aviation and navigation warning lights at night arising from the proposed Spiorad na Mara Offshore Wind Farm (hereafter referred to as 'the Offshore Project') with respect to Seascape, Landscape and Visual Impact Assessment. This appendix accompanies **Chapter 18: Seascape, Landscape and Visual Impact Assessment, Volume 2a** of the EIAR.

1.1.1.2 This background paper has been prepared by Dr Stuart Lumsden. Dr Lumsden has almost 40 years of experience in observational optical and infrared astronomy, and over the past decade has provided advice and evidence regarding the use of aviation warning lights in dark environments. A fuller description of his experience is given in Section 9.1.

1.1.1.3 This appendix should be read in conjunction with the project description provided in **Chapter 3: Project Description, Volume 1a** and the relevant parts of the following chapters and appendices:

- **Chapter 18, Volume 2a;**
- **Appendix 18.6: SLVIA Figures and Photomontage Visualisations, Volume 2c.**

1.1.2 PROJECT BACKGROUND

1.1.2.1 Spiorad na Mara Limited (hereafter referred to as 'the Applicant') is proposing to develop the Project. The Project is an offshore wind farm (OWF) that will consist of up to 60 fixed-bottom wind turbine generators (WTGs).

1.1.2.2 The Project will include both offshore and onshore infrastructure. This Offshore EIAR supports the application for the offshore components of the Project as outlined in **Chapter 1: Introduction, Volume 1a**. The offshore components of the Project (the Offshore Project) includes all infrastructure and activities located seaward of Mean High Water Springs (MHWS) within the Array Area and Offshore Cable Area of Search (OCAS) (**Figure 1.2: Offshore Project Location, Volume 1b**). Further detailed information is provided in **Chapter 3, Volume 1a**.

1.1.2.3 The Offshore Project is situated off the northwest coast of Isle of Lewis/*Eilean Leòdhais* and the Array Area is located approximately 5-13 km offshore and is approximately 161 km^2 in size. It will comprise WTGs, foundations, Offshore Cables, Offshore Substation Platform (OSP) (if required), and Landfall. The Array Area combined with the OCAS is defined as the Offshore Project Boundary. The water depths across the Turbine Area range from 37 m-67 m with the southwest corner of the Array Area reaching 72 m. The proposed WTGs and fixed foundations will be located within a Turbine Area of approximately 140 km^2, within the Array Area.

1.2 PURPOSE OF THIS APPENDIX

1.2.1.1 This appendix describes the following:

- A summary of the lighting requirement and the night-time viewpoints considered;
- The properties of night-time vision and light pollution;
- The night-time characteristics of the overall region;
- The meteorological characteristics of the region;
- The scientific principles behind light attenuation in the atmosphere and the calculated effects;
- Assessment of the lighting as seen from specific viewpoints;
- Discussion and conclusions.

2 LIGHTING REQUIREMENTS

2.1.1.1 Peripheral WTG locations within the Offshore Project will be required to have aviation warning lights at hub height, and a selection of these will also carry maritime navigation lights near the WTG base. The Offshore Project has included 2 indicative layout options to assess the maximum design scenario parameters (see **Chapter 3, Volume 1a**); an up to 60 WTG layout of which 30 will have aviation lights, and an up to 44 WTG layout of which 26 will have aviation lights. The hub heights for the 2 options are 175.8 m and 198.4 m respectively. The 2 options have 14 and 12 navigation lights respectively, though these numbers may vary in future consultation with the Northern Lighthouse Board (NLB). Only the 44 WTG layout is considered in detail in this appendix as it will have greater visibility (due to height) of the aviation warning lights, and the difference in number of lit navigation lights is negligible. The small differences actually seen are considered by **Plate 6-2.**

2.1.1.2 The aviation warning hub lights are red in colour, operating at 200 candela when the visibility is greater than 5 km in any direction, and 2,000 candela when it is poorer. The switch-over will be made automatically according to the readings on a local visibility sensor. Unless otherwise noted, the values used in this appendix are the 10% levels appropriate to good weather (CAP 764 and Article 223 of the Air Navigation Order 2016). The regulation can also require a synchronised flashing W-morse pattern rather than steady lights. The effect of flashing lights will be considered separately in paragraph 8.1.1.3.

2.1.1.3 Article 223 further notes that:

- (a) the angle of the plane of the beam of peak intensity emitted by the light must be elevated to between 3 and 4 degrees above the horizontal plane;
- (b) not more than 45% or less than 20% of the minimum peak intensity specified for a light of this type is to be visible at the horizontal plane;
- (c) not more than 10% of the minimum peak intensity specified for a light of this type is to be visible at a depression of 1.5 degrees or more below the horizontal plane.

2.1.1.4 **Plate 9-1** illustrates graphically how these requirements could be met. The intensity profile of that example is used in modelling the aviation lights in the calculation herein.

2.1.1.5 Navigation lights are located between 6 and 30 m above the highest astronomical tides, and below the lowest point swept by the arc of the blades (IALA G1162). WTGs identified as significant peripheral structures (SPS) by maritime safety regulators must carry nautical navigation lights visible up to at least 5 nautical miles (9.3 km). The navigation lights are defined as yellow in colour (570-590 nanometres which covers orange light as well) and typically flash for 1s every 5s. Intermediate peripheral structures (IPS) carry light visible from a range of 2 nautical miles (3.7 km), and typically flash for 1s every 2.5 s (Marine Guidance Note 372 2022).

2.1.1.6 Manufacturer's guidance on the brightness of these lights varies considerably, but are typically above 100 candela for the SPS rated lights. However, the minimum levels are set in International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) recommendation R0202 (E200-2) "Marine Signal Lights – Calculation, Definition and Notation of Luminous Range". The calculation using those values suggests a bare minimum of 57 candela is permissible. Existing offshore wind farms have clearly visible navigation lights at 10 km which suggests the brightness of the light is over 100 candela, more in keeping with the typical manufacturer's values. The lights emit horizontally with a sufficiently broad beam that all mainland locations likely see a similar brightness. A guideline value of 140 candela for the SPS lights is assumed in this appendix in accord with a SABIK LED-160-NAI datasheet. Again, **Plate 9-1** illustrates graphically what this means in practice. For the current appendix, all navigation lights are considered as SPS: there are 14 for the 60 WTG layout and 12 for the 44 WTG layout. Following engagement with NLB, NLB have agreed that shore-facing SPS lights may use a reduced intensity (range of 2 nm rather than the nominal range of 5 nm) and this will not adversely impact upon the safety of navigation. Other parameters such as flash sequence could also be considered if they serve as mitigation for visual concerns. This formal agreement would be approved post consent when final layout plans are provided and so this reduction in SPS intensity has not been included in the assessment that follows.

2.1.1.7 The night-time viewpoints are a subset of the full selection which provide a range of representative views along the coast, within the NSA and from the Callanish Scheduled Ancient Monument. These are listed in the **Table 2-1** of which VPs 29, 30 and 32 lie within the South Lewis, Harris and North Uist National Scenic Area (NSA)/*Siorrachd Leòdhais a Deas, na Hearadh agus Uibhist a Tuath* (hereafter referred to as 'the NSA').

Table 2-1 List of adopted night-time viewpoints

Viewpoint	**Location**	**Appendix 18.6, Volume 2c figure reference**
VP 4	Melbost Borve	Figure 18.28
VP 13	Barvas	Figure 18.37
VP 23	Shawbost	Figure 18.47
VP 29	Bostadh	Figure 18.53
VP 30	Gallan Head	Figure 18.54
VP 32	Reef Beach	Figure 18.56
VP 37	Callanish	Figure 18.61

2.1.1.8 The selected viewpoints vary in distance from the WTG lights as well as the elevation angle the lights are viewed at, and both will be factored into the analysis. Both distance and angle of elevation strongly effect how bright the lights appear at any location.

3 NIGHT-TIME VISION AND LIGHT POLLUTION

3.1.1.1 Most people have very similar day-time vision, after appropriate correction with glasses. The same is not true at night, where age, in particular, strongly affects the capability. Given this caveat, some general principles can be considered (Lamb, 2016).

3.1.1.2 In a truly dark environment, our eyes rely on the more sensitive, monochrome, rods rather than the colour sensitive cones that make up our daytime vision. This leads to a gradual “blue-ing” (rods have no sensitivity to very red light, and less sensitivity to yellow light than cones) and fading of colour response as the light levels drop, as the cones gradually “switch-off” in the transition.

3.1.1.3 Full dark adaptation takes time (it can be up to 30 minutes for the full switch to “rod-only” vision, though a moderate degree is obtained within the first few minutes when both rods and cones are active – this is known as mesopic vision). Someone who is in, or emerging from, a lit environment (eg. a house) will therefore have limitations on how faint an object they can immediately see, and only gradually will fainter objects appear visible to them. Where street lighting exists in a settlement, the chance of full dark adaptation is limited. Even indirect emission (such as streetlights scattered back off the ground) can have a significant impact on adaptation.

3.1.1.4 In addition, if there is any background light, whether that be streetlights a few hundred metres away, factories or other facilities with security lighting, or crucially natural background light such as twilight, or a moon at or near full, the eye is also limited by a contrast effect. The effect varies with the brightness of the background and whether cones or rods are more dominant. Even at the end of the earliest phase of twilight, the sky will be too bright to see any but the very brightest stars for example. The main takeaway message therefore is simply that any additional light source will make it “harder” to see faint distant lights, whether those be aviation or navigation lights or stars.

3.1.1.5 This is less true for a camera image, which is a good match for our daytime vision but less so at night. In addition, photomontages taken in twilight rather than full night also mask any existing local light pollution which can be obvious to the eye after longer dark adaptation in truly dark conditions.

3.1.1.6 Man-made light pollution includes a diverse variety of sources, all of which affect dark adaptation and the contrast issue noted above. Some of these are permanent like street lighting, and some transitory, such as car headlights. Drivers are always limited in their ability to see their surroundings because of the brightness of their headlights for example, whereas their passengers might be less sensitive to that if they are not always looking directly forwards.

3.1.1.7 In summary, what is visible at night will vary greatly between individuals, and even more between the settings of those individuals. In what follows, it is assumed that the “typical” response lies at the greater sensitivity end of this variance except where noted, and the satellite background light level will be assumed as a guide to the light pollution present, except where noted.

4 NIGHT-TIME CHARACTERISTICS

4.1.1.1 **Plate 4-1** shows the night-time light sources in the area nearest the Offshore Project. These data are the combination of 2 nights from the NOAO NPP satellites, and particularly the Day-Night Band sensor in the VIIRS instrument. This is sensitive to light between 500 and 900 nanometres, so misses part of any cool modern LED lighting. The satellite transits every night between about 1am and 3am. The most obvious local feature is Stornoway/*Steòrnabhagh*, where streetlights are kept on.

4.1.1.2 Many of the settlements along the A857/858, the main road(s) along the northwest coast of Lewis/*Eilean Leòdhais*, also have streetlights. Comahirle nan Eilean Siar have recently introduced a policy of turning most of these off at 10pm. As a result, through the late evening and most of the night, these areas are largely unlit. Since a single nearby streetlight can affect the ability to see the aviation warning lights due to the contrast effect discussed in paragraph 3.1.1.4, this change will affect the perception of these lights from these settlements at times when the sky is otherwise dark. The magnitude of this effect cannot be ascertained from the satellite image given the lights are turned off before the satellite passes.

4.1.1.3 The other clear late-night light sources seen in the satellite image can be identified as the BASF factory near Callanish/*Calanais*, the Sea Trek landing near Miavaig/*Miabhaig*, and the Gearrannan Blackhouse Village near Carloway/*Càrlabhagh*. There is weaker emission from the Mill at Shawbost/*Siabost*, and a location near the road junction between the A857 and A858 in Barvas/*Barabhas*.

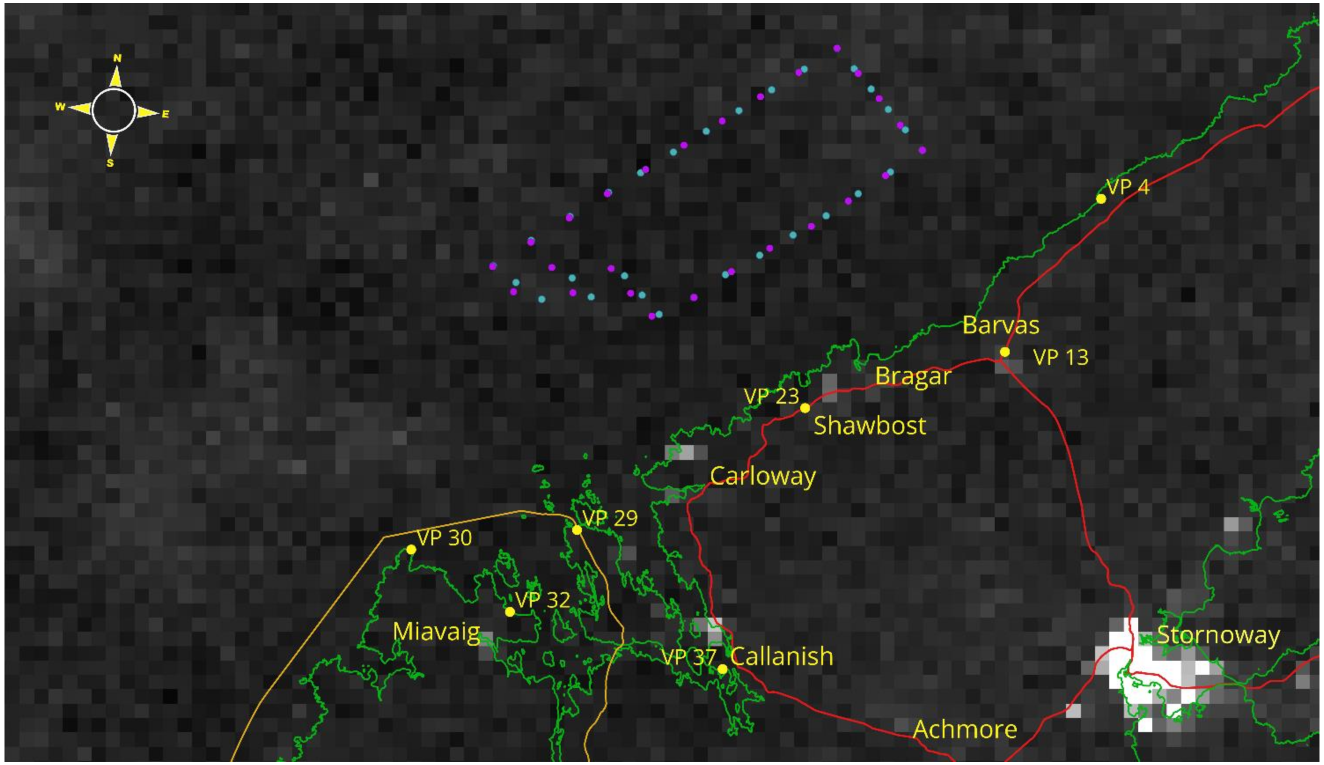
4.1.1.4 The night-time viewpoints which have multiple streetlights include VP 4 Borve/*Borgh*, which has lights largely on the main road; VP 13 (Barvas/*Barabhas*) where most of the 40 mph zone is lit; and VP 23 (Shawbost/*Siabost*) where much of the settlement, including side roads, are lit. The other night-time viewpoints have no significant external lighting at the viewpoint itself.

4.1.1.5 There is little man-made background light pollution in the normal field of view from any viewpoint which includes the direction of the Offshore Project, with the exception of VP 37 (Callanish/*Calanais*) which looks directly towards the BASF factory.

4.1.1.6 Natural sources of light also need to be considered in assessing the visibility of the WTG lights. The 2 main ones relevant to dark sites are the presence of a near full moon (produces about 0.1 lux illuminance at maximum), and in particular for this site, the presence of twilight sky.

4.1.1.7 The presence of a near full moon (roughly full +/- 5 days) is significant because of the contrast issue discussed in paragraph 3.1.1.4. The sky brightness given by the moon varies by about a factor of 15 between full and +/- 7 days and is not significant outside that period. The location of the setting moon varies considerably throughout the year, but can be within the field of view of the night-time viewpoints when looking at the Offshore Project.

Plate 4-1 Night-time satellite image of the region of Lewis nearest to the proposed Spiorad na Mara Offshore Wind Farm



The image shown here is a composite of 2 cloud and moon free nights from January 2025. Images are typically acquired between 1 and 3am local time and therefore do not capture most rural streetlights in the area which turn off at 10pm. Note the satellite images are only sensitive to wavelengths of light beyond 500 nanometres, which will capture most of the output of warm white LEDs, but not cool white ones. A selection of all settlements in the area is indicated by name. Major roads are shown in red, and the coastline in green. The boundary of the NSA is shown in orange. Viewpoints considered are shown in yellow. The turbines with aviation lighting are shows as sky blue (60 turbine option) or mauve (44 turbine option).

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4.1.1.8 Twilight is important to the appearance of the Offshore Project at different times of year. Twilight falls into 3 phases: civil, when the sky is still bright; nautical, named for the fact that landforms are still visible, but the stars are now present in the sky; and astronomical which is the final phase before full night, when the sky is still brighter in the direction of sunset/sunrise but otherwise the sky largely appears dark (see Section 9.3 for greater detail). Following this comes full night. For the Isle of Lewis/*Eilean Leòdhais*, full night never occurs from near the end of April until mid-August. Nearer mid-summer, from mid-May until the last week in July, even astronomical twilight does not occur. Landforms are always visible, and the sky in the direction of the Sun remains bright. Therefore, for anyone looking northwest through north, the sky is bright throughout the night, and the apparent brightness of the lights is greatly suppressed due to the contrast effect. In mid-winter, although civil twilight is long, the setting sun is well away from the line between the viewpoints and the Offshore Project, so the effect is lessened considerably. At that time of year the sky is also essentially dark enough to see most stars for more than twelve hours. Times for sunrise, sun set and twilight are provided in **Table 4-1**.

Table 4-1 Times of sunrise, sunset, and the starts and ends of civil, nautical and astronomical twilight for the given dates

	Sunrise	**Sunset**	**Civil Twilight start**	**Civil Twilight end**	**Nautical Twilight start**	**Nautical Twilight end**	**Astronomical Twilight start**	**Astronomical Twilight end**
Spring equinox*	06:24	18:42	05:44	19:22	20:09	04:57	04:06	21:00
Midsummer	04:20	22:34	03:02	23:52	Rest of Night			
Midwinter	09:11	15:35	08:19	17:21	07:26	17:21	06:37	18:10

*The autumn equinox times (not shown) are +1 hour on the spring equinox times due to the BST/GMT time difference. Before astronomical twilight starts, or after it ends, is full night (defined as the Sun being more than 18 degrees below the horizon). Civil twilight is sufficiently bright that it is possible to read large print text without assistance. Nautical twilight is named for the fact that navigators could still see landforms during this period. In midsummer, nautical twilight is as dark as the sky becomes. The sky in the direction of the setting/rising sun is always notably brighter than in the opposite direction. At midsummer the sun sets/rises 40 degrees NW/NE of north, and so the entire northern horizon remains light.

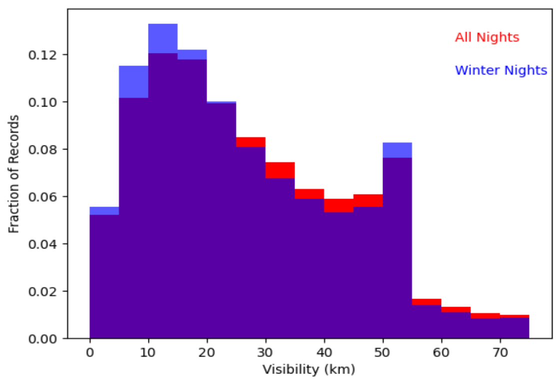
4.1.1.9 Finally, one aspect of the night-sky background is a key attraction for visitors. The northern lights are generally most easily visible looking near the north magnetic pole (which moves, unlike the geographic pole, and is currently in far northern Canada, so a few degrees northwest when looking from Lewis/*Eilean Leòdhais*). The actual lights typically form an oval pattern (when looked at from above), centred on, but about 20 degrees south of, this pole, which usually means that only stronger events are easily visible in northern Scotland/*Alba*. Stronger events shift this pattern to larger angular deflections away from magnetic north, and are therefore more visible, and higher in the sky. Weaker events will potentially be visible closer to the horizon, though the opacity of the atmosphere is significantly larger when looking at small angles of elevation, than when looking nearer to overhead. The stronger, higher elevation events are the ones that typically will be recognised by visitors as aurorae.

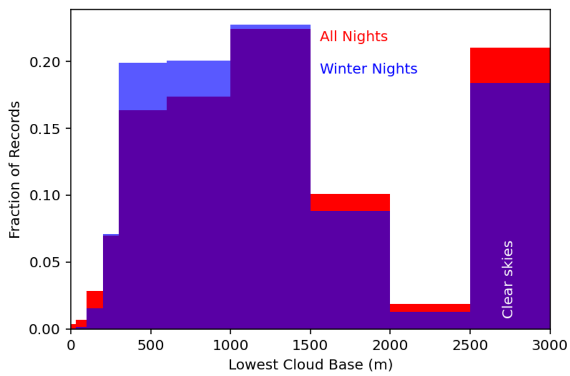
5 METEOROLOGICAL CHARACTERISTICS

5.1.1.1 There are no detailed meteorological records for the Offshore Project site itself. There is a Meteorological Office synoptic weather station at Stornoway/*Steòrnabhagh* however. The station lies at the airport, 15 m above ordnance datum so is a reasonable match to many of the night-time viewpoints. This station has modern automatic visibility sensors that measure the particulate concentration in the air along a path of only about 1-2 m. The sensor is the same as those used on wind farm sites to trigger the increase in brightness of the aviation warning lights. They are not sensitive to direction and obviously do not measure what is happening to the visibility further away. The particle concentration is extrapolated to a defined "visibility" according to regulations. These automated Met Office sites also measure the altitude of the lowest level of the cloud base using LIDAR. The cloud base height informs the likelihood that elevated structures such as at the wind farm is within cloud.

5.1.1.2 The Met Office MIDAS Land and Marine Surface Stations Data are publicly available under v3.0 of the Open Government Licence, and provide measures of visibility and cloud base height. Hourly data were considered from 2014 onwards, as that period covers full automated measurements. It should be noted that the data for visibilities and cloud base heights are given as binned ranges rather than discrete data, and these are what have been used here. The cloud base heights are presented as-is, but the visibilities have been rebinned into equal 5 km intervals for clarity. The data can be sub-divided by season and time of day. Only the relevant night-time results are shown here, and in particular winter nights given the discussion in Section 4.

Plate 5-1 Visibility records (left) and lowest cloud base height (right) for Stornoway/*Steòrnabhagh*





"Clear skies" can mean there are still clouds above 2,500 m, which is the limit the LIDAR can reach, as comparison of satellite and LIDAR data demonstrates.

5.1.1.3 Stornoway/*Steòrnabhagh* shows little difference between winter and all year records for visibility. The median winter night visibility is 23 km (27 km in summer). However, the cloud base does lower slightly in winter, as expected given cooler air. Only 5% of night-time records have visibility less than 5 km when the lights would switch up to 2,000 candela (this value is relatively constant throughout the year).

5.1.1.4 The cloud base data show that 8% of records have a cloud base below 200 m in winter nights. Unusually this rises to 19% in summer nights. As **Plate 5-1** shows, there are more records overall with a lower cloud base in winter, but this shifts into the slightly higher altitude bins. However, 200 m corresponds to the approximate WTG hub heights for the Offshore Project, so best reflects the fraction of time that the WTG lights are above the cloud base.

5.1.1.5 It should be emphasised that if the WTG hubs are above the cloud base they will essentially be equivalent to being viewed through thick fog at ground level. The effective visibility in this case is much less than 5 km. Therefore, although the lights may be operating at 2,000 candela, they will largely be invisible to most receptors (see also the figures in Section 6).

5.1.1.6 A better estimate of the time when the lights may be visible below the cloud base whilst operating at 2,000 candela is to examine the number of records which have cloud base above hub height, but visibility below 5 km. This is a small number – 1% of all winter night records for Stornoway/*Steòrnabhagh* have a cloud base above 200 m but visibility below 5 km.

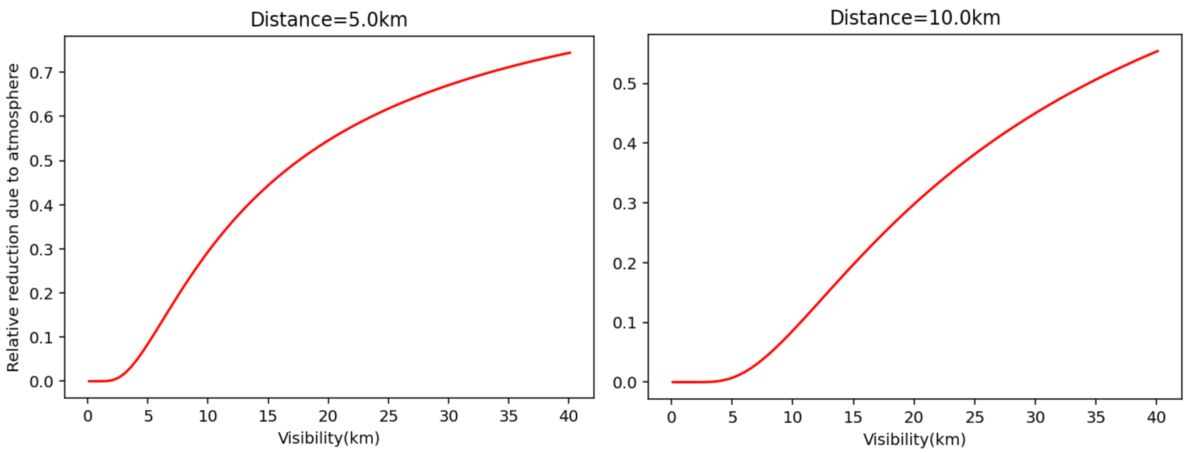
5.1.1.7 Overall it seems likely that most of the time when the lights will operate at 2,000 candela will be in conditions where they will not be seen much beyond 5 km, as demonstrated in **Plate 6-3** and **Plate 6-4**. Further consideration requires the use of numerical models to quantify the extent of any attenuation.

6 ATTENUATION OF LIGHT

6.1.1.1 Aerosols are small particles in suspension in the atmosphere. These include such diverse sources as sea spray to tree pollen to wind-blown soil. Any aerosol present attenuates light as it propagates through the atmosphere. In a vacuum, the light would diminish only through geometry as it spreads out, diminishing by 1/(distance^2). Adding aerosols will reduce this further. Examples of how the aerosols themselves reduce light are shown in **Plate 6-1**. For simplicity, the aerosol density is assumed to vary with altitude only in accordance with the expected atmospheric scale height. This is a very good approximation.

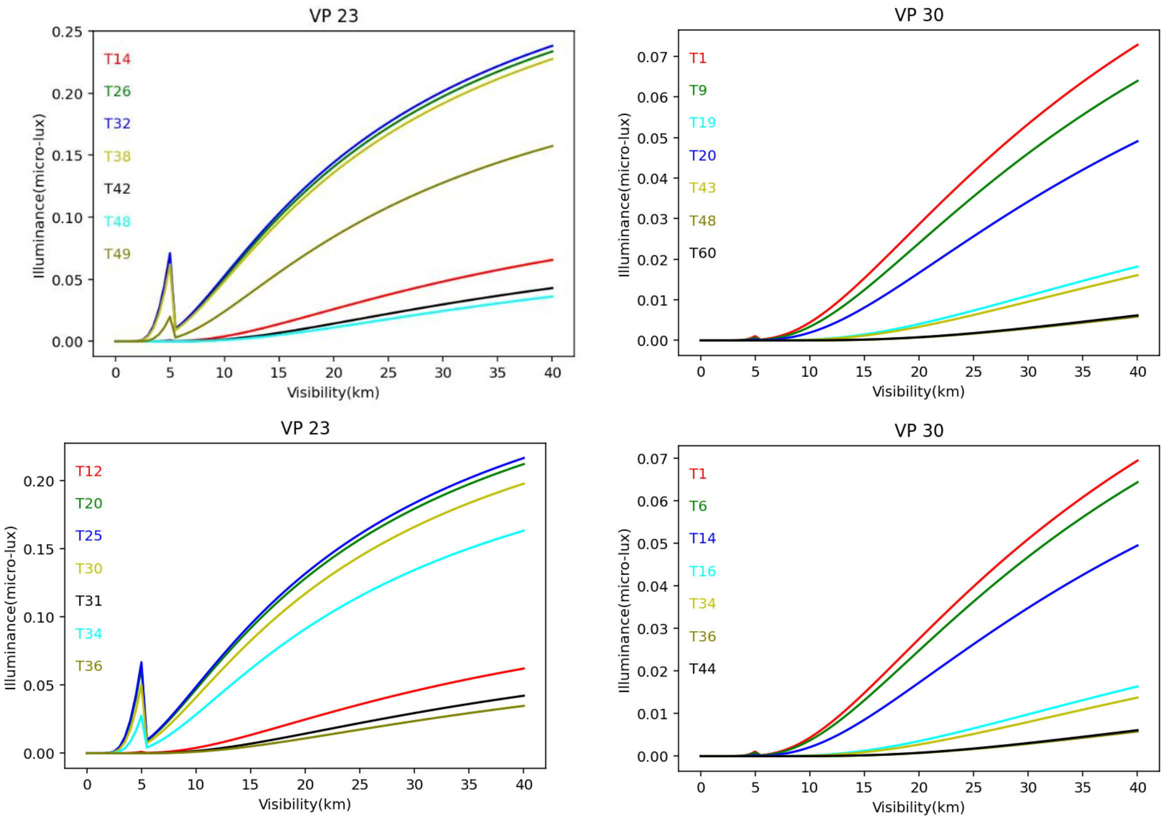
6.1.1.2 Even good visibility leads to a notable reduction in the brightness as also shown by **Plate 6-2**.

Plate 6-1 Examples of how aerosols can reduce light



The panels show how much the light is attenuated for an observer as a function of visibility. Only the attenuation due to the atmosphere is shown – the reduction due to distance is not included. In both cases it is assumed that the hub height is 200 m and the observer at 2 m, typical of values for both the taller turbine option and typical viewpoints. The curves change little for modest changes in these values. The attenuation is exponential, so drops rapidly at poorer visibilities, which is difficult to see on the linear y-axis shown. Very poor visibility (less than 1 km as might be expected when the hubs are above the cloud base) reduces the apparent brightness significantly.

Plate 6-2 Comparison of the expected brightness of the lights given different visibility conditions for VP23, Shawbost, and VP30, Gallan Head, for the 60 WTG layout (top) and 44 WTG layout (bottom).

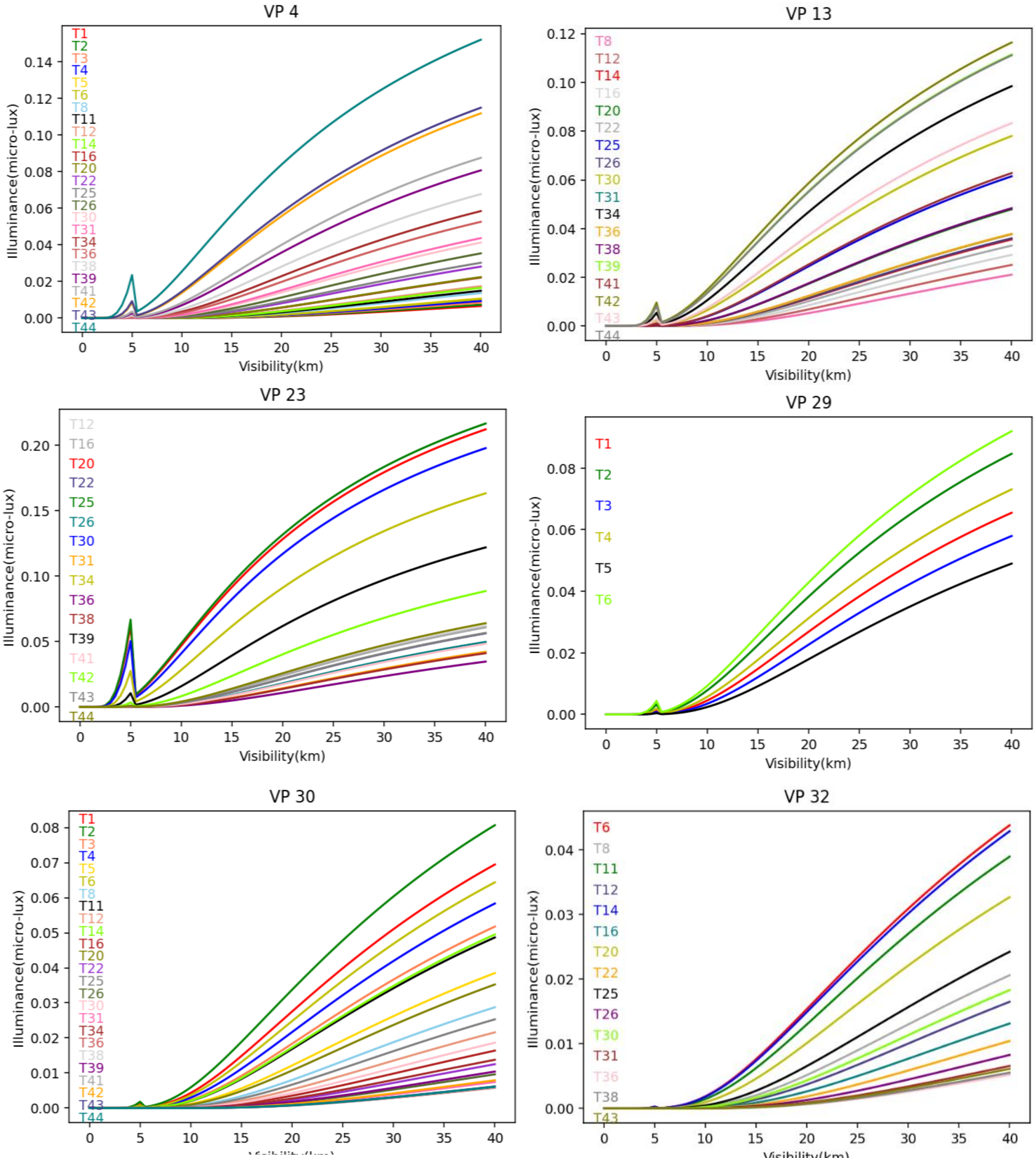


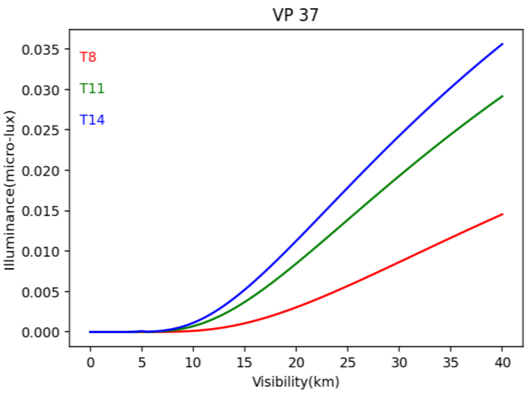
6.1.1.3 Combining the attenuation due to the atmosphere with that due to geometric dilution gives the actual illuminances for the aviation lights as shown in **Plate 6-3**. Two specific locations, VP23, Shawbost/*Siabost*, the closest to the Offshore Project and VP 30, Gallan Head, which is both representative of the NSA as a whole but also has the most "end-on" view of the Offshore Project are shown to demonstrate the similarity of the 2 layout options, even though the exact WTG locations do not match between the layouts. The 44 WTG layout is marginally closer to Gallan Head for example, but the extra height of the hub means the elevation angle is more negative, which makes the light fainter at the source.

6.1.1.4 The other feature in these plots is the change when the light is switched up to 2,000 candela. This is almost not visible as a change when the lights lie at larger distance from the viewpoint, but for smaller distances, as for VP 23 at 8 km, with the given choice of WTG lights, the effect is noticeable. This only becomes significant for locations within about 5 km however – the lights basically appear brighter than when in 10% setting when the distance is less than the visibility, and none of the WTGs lie within this distance.

6.1.1.5 **Plate 6-3** shows the expected brightness of all visible aviation warning lights for the 7 night-time viewpoints. The 44 WTG layout results are shown.

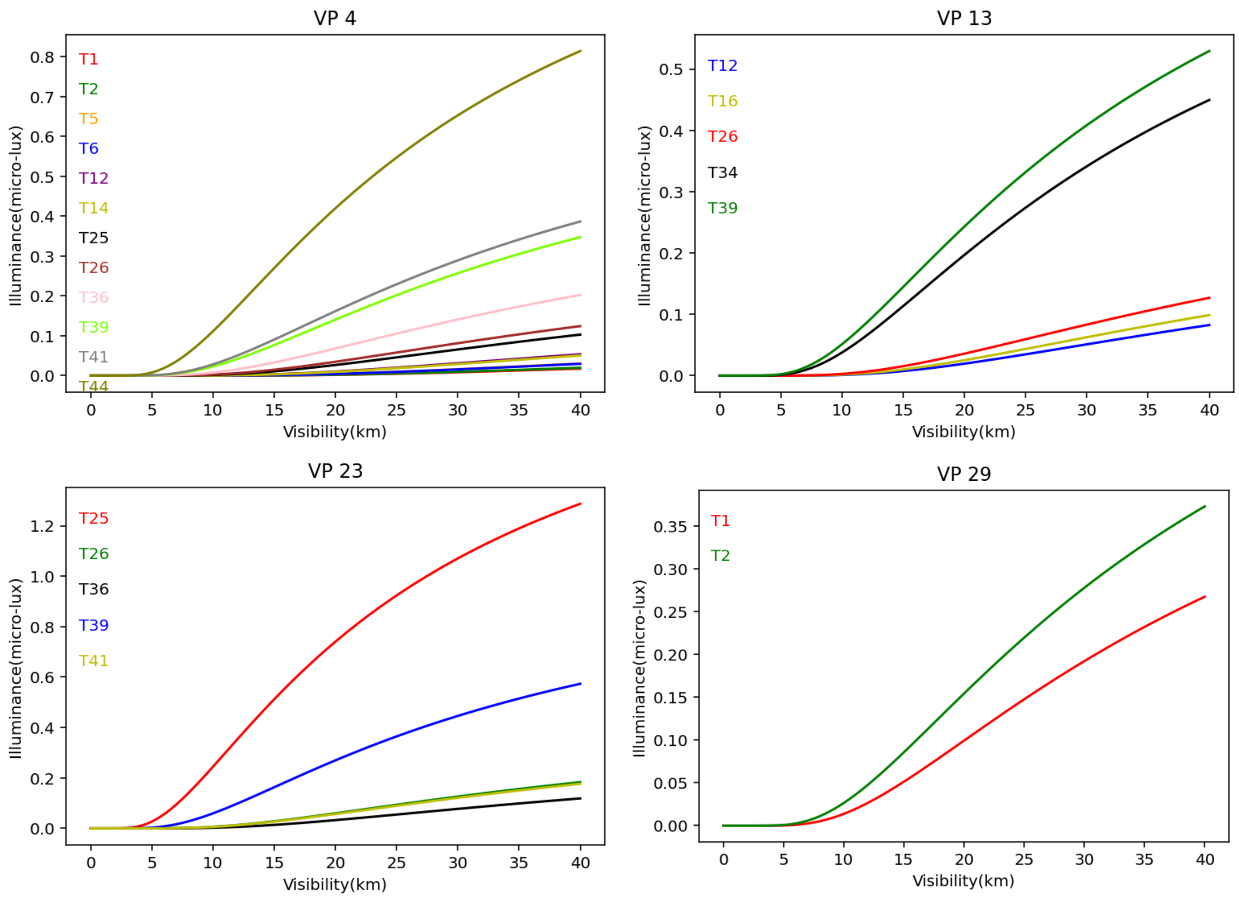
Plate 6-3 Predicted brightnesses of the aviation lights for all viewpoints

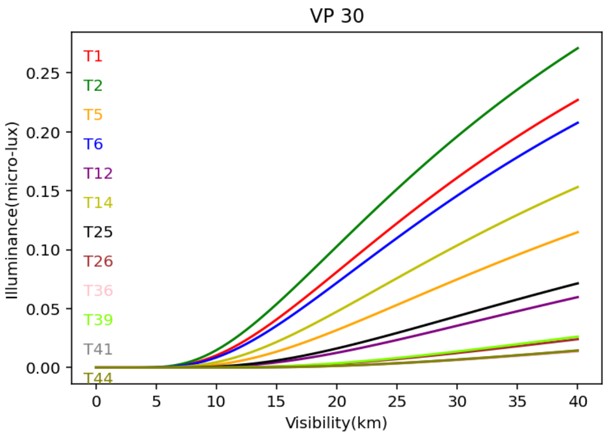




Only those WTGs with visible hubs unobscured by local landforms are shown. The 44 WTG layout is assumed. Only the closest viewpoints to the lights show any significant effect when the lights switch from 200 to 2,000 candela (when the visibility is 5 km), which is modelled for all viewpoints here.

Plate 6-4 Predicted brightness of the yellow navigation lights for all viewpoints with visibility of the navigation lights





No navigation lights are visible from VPs 32 and 37. All turbines indicated to have lights not obscured by local landforms are shown. All lights are assumed to be SPS lights for these calculations. The dominant effect for any viewpoint is from the nearest lights. The 44 WTG layout is shown, but the results are essentially identical for the 60 WTG layout given the lights are at the same height above sea level in both cases.

6.1.1.6 The effect of the yellow navigation lights can be considered using similar methods. **Plate 6-4** shows results for all indicative WTG locations currently assumed to require lighting. The 44 WTG layout results are shown. The nearest WTGs will be dominant for these yellow navigation lights. For each example shown, the brightest lights are simply the nearest. This is because these lights emit horizontally, and with a large beam, so virtually all locations see the same part of the light. Reduction in some of this lighting would be beneficial, if feasible, given these lights are brighter than the aviation warning lights simply because they are typically viewed closer to maximum intensity. This is true for all viewpoints.

6.1.1.7 We can compare these predictions with astronomical sources. Orion is the most prominent winter constellation, sitting about 30 degrees above the southern horizon, shaped approximately like an H. The upper left and lower right stars in this pattern are amongst the brightest in the sky, with an illuminance between 1.5 and 2 micro-lux. The 3 stars that form Orion's belt, i.e. the bar of the H, are typical middling stars. These would appear as approximately 0.3 micro-lux. Such stars are relatively easy to see but not particularly prominent. The individual red aviation warning lights are fainter than this even in very good visibility. The faintest red light someone can see is somewhat dependent on the individual, but with full dark adaptation, 0.01 micro-lux is a reasonably conservative estimate without aids such as binoculars. Because yellow lights emit closer to the maximum sensitivity of the eye, the limit for them is about a factor of 10 smaller. For this scheme, that limit is only reached for the closest SPS navigation lights to the coastal viewpoints when the visibility is below about 3 km.

6.1.1.8 The cumulative effect of the lights will be considered further in Section 7.

7 INDIVIDUAL VIEWPOINTS

7.1.1.1 The range in individual light brightness will vary from viewpoint to viewpoint. The data shown in **Plate 6-3** and **Plate 6-4** can be interpreted for individual viewpoints as follows. For any viewpoint, select a "typical" visibility using the meteorological data from Section 5. Follow this visibility value up the graphs shown to see what illuminances are present for each of the lit WTGs, and each of the yellow or red lights. These can then be compared to the values for stars, to give a rough approximation of how bright the lights can be expected to be, though the colour of the lights will be significant in making the warning lights appear different.

7.1.1.2 Cumulatively the main effect is from those brighter lights. These will appear roughly as 2 patterns – from the viewpoints on the coast adjacent to the Offshore Project, they will appear stretched out along horizon; for those at the extremes they will be compressed into a narrower arc. For example, from VP 30, the lights span about 30 degrees, whilst from VP 23 they cover almost 60 degrees. Local landforms mask at least some of the lights in most locations. The fullest visibility of all lights, both aviation and navigation, will be from the most westerly points of the shoreline along the coast. Any location away from the coast tends to see fewer lights, and in the case of VP 37 Callanish, none of the navigation lights and few of the aviation warning lights. The brightness of the red light at source depends on the angle it is viewed at. Given the limits that the human eye can detect in the red, lights that lie below about 0.01 micro-lux even at best visibility, assumed here to be 60 km (see **Plate 5-1**), are unlikely to be seen without aids such as binoculars. The discussion on individual viewpoints below assume the 44-WTG layout, and the red lights emitting at 10% in good visibility.

7.1.1.3 All the yellow lights by comparison are likely to be seen in good visibility. The yellow lights are all viewed close to the horizon, and at a near horizontal angle (deviating by less than 0.3 degrees). Again the discussion assumes the 44 WTG layout. All of the navigation lights lie on WTGs that also have aviation lights, so the discussion of distances to lights below applies to both.

7.2 VP 4

7.2.1.1 The lit WTGs that can potentially be seen from this viewpoint range from 9.6 to 31.6 km. 19 of the aviation warning lights have predicted brightness even at best visibility greater than the threshold for the eye discussed in Section 3.1.1.4. The nearest red lights are at negative viewing angles relative to the horizontal plane at the WTG hub, only approaching the horizontal for the furthest lights. For the adopted model shown in **Plate 9-1**, this corresponds to a range between approximately 25 and 45 candela at 10% output. The actual range in brightness to an observer at the viewpoint is between a middling star and those stars which a typical individual would only just be able to see when fully dark adapted. This is one of only 2 viewpoints where all lights, both aviation and navigation, are potentially visible. The yellow lights are most visible from the nearest WTGs (T44, T41 and T39 in that order). T44 is essentially the same as the brightest stars, the other 2 are like the belt stars in Orion. For the aviation lights, they are slightly fainter than the Orion belt stars for the nearer lights, and although some of the more distant ones will be at the lower end of what the human eye can see, a significant number of both red and yellow lights will be visible to someone with good dark adaptation.

7.3 VP 13

7.3.1.1 The lights range from 11.0 to 26.8 km. 18 red lights are expected to be detectable by the eye in best visibility. The overall brightnesses are similar to, but very slightly fainter than, VP 4, though the lights will spread out more along the horizon.

7.3.1.2 VP 23 is the nearest location to any of the lit WTGs. The lit WTGs range from 8.0 to 18.7 km. However, the nearness of the red lights also means the angles they are viewed at are more negative. At 8 km, the lights are seen at -1.1 degrees so the intrinsic output is < 25 candela; the more distant aviation lights are seen nearer the horizontal plane, but the extra 10 km distance significantly reduces the brightness to the actual observer. As a result, the aviation warning lights only appear similar to the brightness of the Orion belt stars at most. In best visibility, 16 are likely to be visible. By comparison the yellow nautical lights, albeit a reduced number due to blocking from local landforms, appear the brightest here of any viewpoint, similar to the brightest stars in the sky.

7.4 VP 29

7.4.1.1 The lights range from 11.9 to 28.3 km. This location is on the edge of the NSA. Many of the lit WTGs are masked by local landforms. 2 yellow lights are visible at about the level of Orion belt stars. The red lights appear similar to fainter stars. 6 are above the threshold of the eye in best visibility.

7.5 VP 30

7.5.1.1 Gallan Head is a site which advertises its dark skies, and lies within the NSA. Although it has no official "dark skies" status, the Gallan Head Community Trust are involved in the regular Hebridean Dark Skies Festival. The lit WTGs range from 14.6 to 34.1 km. This viewpoint, because of its elevated nature and westerly location, can see all of the lights present. However, only 16 are likely to be detectable even in best visibility because of the distance to the northern half of the Offshore Project. The added distance helps reduce the apparent brightness of even the detectable red lights to that of fainter stars. The yellow lights however remain similar to Orion belt stars.

7.6 VP 32

7.6.1.1 The distances are from 16.2 to 33.7 km, and the angle at which the Offshore Project is viewed is similar to Gallan Head, and it also lies within the NSA. The current layout for the 44 WTG option places the navigation lights behind local landforms. As a result, none are expected to be visible, though this may change with relatively small WTG shifts. For comparison, the brightness of any such lights would be expected to be similar to VP 30. The aviation lights appear fainter than for VP 30 however, since the lower altitude of the viewpoint results in a slightly more negative angle at which the aviation lights are viewed. These are all in the regime of faint stars, and only 9 are expected to be above the threshold of the human eye in the best visibility.

7.7 VP 37

7.7.1.1 This location is particularly sensitive as it contains the Callanish stone circle. It is also the most distant from the Offshore Project on average, ranging between 18.6 and 32.6 km, and most of the lights, including all of the navigation lights, are screened by the local hills. The distance helps reduce the apparent brightness of the red lights to that of the faintest visible stars. All 3 of those are however detectable in best visibility. The BASF factor will also be in the line of sight towards the Offshore Project, as previously noted, and its lighting will make the aviation warning lights more difficult to see due to the contrast effect discussed in Section 3.1.1.4.

8 DISCUSSION

8.1.1.1 Another way to compare the lights is to compare the emitted candela as seen at each location with other known sources of lighting that are typically visible at night. The simplest of these examples for red lights are car rear brake lights, which on average are about 80 candela. This is somewhat brighter than the apparent output of any of the WTG lights from any of the viewpoints. The colour is similar to the aviation warning lights as well, making the comparison easier. Although it may be difficult to imagine, a car brake light at slightly greater distance than the distances to the WTGs will be a good match with what to expect. There is unfortunately no such easy directly comparable light source for the nautical navigation lights.

8.1.1.2 A brighter comparison (about 400 candela) are modern LED traffic lights. The red and amber lights there are a good match to the colour of the different warning lights. The Offshore Project safety lights are typically a factor of 3-10 times fainter than the comparative modern LED traffic lights (see Section 2). So, the equivalent distance to view LED traffic lights at are roughly 2-3 times more distant than the actual lights, which is obviously impractical. Equally to be avoided as a comparison of brightness are onshore WTG lights. These by regulation emit much more light on the horizontal plane, so will always appear brighter.

8.1.1.3 For all viewpoints, lights more distant than 15 km are at a level where they can be thought of as very faint even in fully dark conditions and excellent visibility. Beyond 25 km, all of the aviation lights are expected to lie below the threshold of human vision. The main effect is generally from the lights nearer than about 10 km. The same is true for flashing lights. The atmosphere scintillates, making more distant lights appear variable even if actually steady, but it is a random flicker that is less noticeable than a steady pattern. The flashing patterns for the nearby lights will be more evident and will actually stand out more to a typical observer than steady lights.

8.1.1.4 In summary, the yellow nautical navigation lights appear brighter than the red aviation warning lights for those viewpoints where they can be seen. Any mitigation to reduce this would be beneficial. Replacing SPS lights with IPS lights for those nearest the coast and facing inland would reduce the predicted values by a factor of 6, as outlined in paragraph 2.1.1.6. From **Plate 6-4**, this would reduce the apparent illuminance of the yellow navigation lights to be similar to the red aviation warning lights. Such a reduction would be particularly beneficial for those viewpoints along the northwest coast road. The aviation lights themselves are typically similar to middling stars at brightest. Many of the aviation lights from any given viewpoint will likely fall below typical limiting values for the human eye. So even when considered as a cumulative source (flashing or otherwise), the aviation lights are less likely to stand out. The greatest effect (brightest lights for both red and yellow) is seen at VP 23, followed by VP 4 and VP 13. The least is for VP 37 (Callanish) where no yellow lights are visible, and the 3 red lights are faint even in excellent visibility.

9 SUPPLEMENTARY MATERIAL

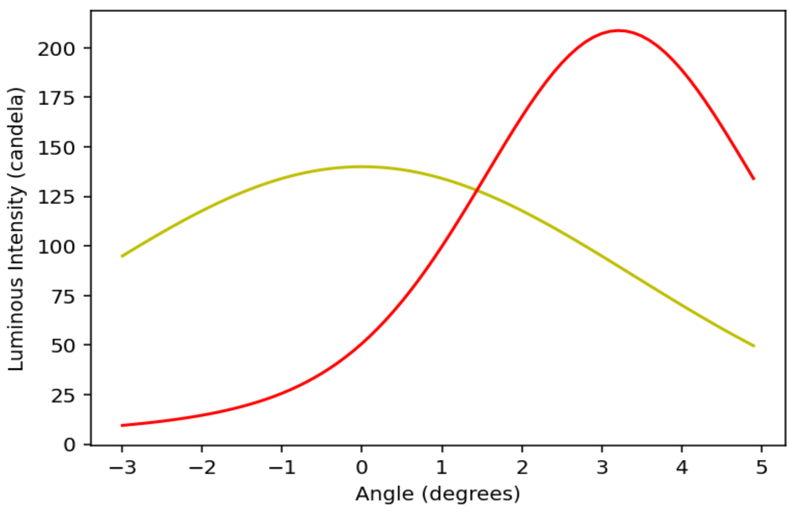
9.1 STATEMENT OF EXPERIENCE

9.1.1.1 Dr Stuart Lumsden is an Associate Professor in the School of Physics and Astronomy at the University of Leeds. He worked for the professional optical observatory based near Coonabarabran, NSW, the (then) Anglo-Australian Observatory for 6 years, working on optical and infrared instrumentation for astronomy, and is therefore familiar with issues related to light pollution, and the propagation of light, at night. He has acted as an expert on such matters for wind farm developments in Scotland/*Alba* over the past 10 years, with particular regard to the use of infrared lighting on WTGs with tip height of less than 150 m near the Dark Sky Park in Galloway/*Gall-Ghàidhealaibh*, and visible red aviation lighting for the WTGs exceeding 150 m at developments across Scotland/*Alba,* including most recently the public inquiries for Crystal Rig IV, and Clash Gour, and the hearing session at Scoop Hill. He was a member of the Scottish Government Aviation Lighting Guidance Working Group.

9.2 MODEL LIGHT OUTPUTS

9.2.1.1 The actual expected brightness of both the aviation and navigation lights is subject to final confirmation. shows examples for both, as used in the modelling, which satisfy the appropriate regulations. The actual legal requirements are given in paragraph 2.1.1.3 (aviation lights) and paragraph 2.1.1.5 (navigation lights).

Plate 9-1 Intensity versus elevation angle for the aviation warning light used in the modelling (red curve).



The model satisfies the limits placed by the CAA, and has a realistic profile based on other LEDs. The curve shown is for good visibility when the luminous intensity is reduced to 10% of the nominal values. The light emits at 625 nanometres. The yellow curve shows the output from the yellow nautical navigation lights, which emit at 590 nanometres. These data are based on an available model of light.

9.3 TWILIGHT

9.3.1.1 Sunset occurs when the full disc of the sun falls below the horizon. Sunrise is when the disc first emerges above the horizon. Twilight is the period that follows/precedes sunset/sunrise.

9.3.1.2 Twilight is defined as civil (sun at angles 0 degrees to −6 degrees), nautical (sun at angles −6 degrees to −12 degrees) and astronomical (sun at angles −12 degrees to −18 degrees). Full night follows thereafter. No stars are visible until the end of civil twilight, though brighter objects like Venus can be seen. The brightest stars appear at the start of nautical twilight, and gradually the fainter ones appear from thereon.

9.3.1.3 This is essentially just a contrast issue, as the sky is still brighter than the stars.

9.3.1.4 The length of twilight varies with location and time of year. Representative times for the shortest day, the spring equinox and the longest day are given in **Table 4-1**.

9.3.1.5 The twilight sky varies widely in brightness and colour (if clear). At the zenith, the sky appears very blue when still lit. On the horizon it is much redder by comparison, as more scattering occurs (both Rayleigh and Mie, and significant multiple scattering). When looking towards the setting sun, the difference in brightness from zenith to horizon is over a factor of 10. At 90 degrees away from the setting sun around the horizon, it is nearer a factor of 3. However, these values will change with the season, and with the location, so it is not trivial to derive a "typical" value that can be used when determining whether a light can be seen in twilight or not. Instead, it is best to rely on observations of the actual scene, noting that even this will just be a snapshot.

9.3.1.6 The sky brightness changes through twilight approximately as a power-law, of form $\log E = -a * time + b$ for the illuminance, E, where a and b are positive constants that would need to be measured for a specific site, and time is the time after sunset in appropriate units. Unfortunately, there are few calibrated measurements of the twilight sky brightness in candela/m^2, even at the zenith, for any site anywhere in the world.

10 GLOSSARY OF TERMS AND ABBREVIATIONS

10.1.1.1 A list of key terms and acronyms used in this appendix are provided in **Table 10-1** and **Table 10-2**.

Table 10-1 Acronyms and abbreviations

Term	Definition
EIAR	Environmental Impact Assessment Report
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IPS	Intermediate peripheral structures
MHWS	Mean High Water Springs
MIDAS	Met Office Integrated Data Archive System
NLB	Northern Lighthouse Board
NSA	National Scenic Area
OCAS	Offshore Cable Area of Search
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
SPS	Significant peripheral structures
WTG	Wind Turbine Generator

Table 10-2 Glossary

Term	Meaning
absorption	In the context of atmospheric physics, light that is completely removed when interacting with a molecule or particle is said to be absorbed.
aerosol	Any particle, man-made or natural, in suspension in the atmosphere.
aerosol optical thickness	The attenuation of light when looking directly upwards, measures the total aerosol content. This is less than the attenuation that would be seen horizontally given the rapid decrease of atmospheric and aerosol density with altitude.
candela	SI unit of luminous intensity – see below.
contrast	In the context of atmospheric physics and vision, generally defined as the difference in brightness of 2 objects divided by the average of the 2 brightnesses.
dark adaptation	The process by which our eyes switch from photopic (cone mediated) vision to scotopic (rod mediated) vision after moving from a lit area to a dark one. The switch over “zone” is known as mesopic vision.
elevation angle	The warning lights appear as different brightness according to the angle of elevation they are viewed at. Here, the horizontal plane is defined as 0 degrees, and below the plane is negative. At increasingly negative values, the lights are correspondingly fainter. See **Plate 9-1**. An observer below the height of lights is at a negative elevation angle.
illuminance	How bright a light appears per unit area to a distant observer. Typically defined in terms of lumens/m^2 which is also denoted as lux. For a distant observer looking up at the aviation warning lights, the illuminance they see in the case is set by the

	angle of elevation (which is negative because although they are looking up the light is propagating downwards from the horizontal), the distance and the atmospheric clarity. The navigation lights are seen close to the horizontal plane and hence their maximum output, so this factor is less important for them.
lumens	SI unit of luminous flux – see below.
luminance	Like luminous intensity, but for a source that is extended as far as the observer is concerned. It is defined in terms of brightness per unit area (e.g. as the light output from a TV screen is defined in terms of its luminance). This is not typically used for warning lights except very close to the source but is relevant for factors such as the brightness of the twilight sky.
luminous flux	This is how bright a light is at the source but summed up over all the angles it emits at, so different from the luminous intensity (candela) value. For a uniform source this is equivalent to multiplying the candela value by 4π, the angular area of the surface of a sphere. A standard domestic light bulb, which typically emits across a wide angular spread, is usually defined in terms of its luminous flux. Measured in lumens.
luminous intensity	This is the brightness of a light as a function of the viewing angle at the light source itself. For a uniform angular illumination this is easily related to the luminous flux. For the aviation lights this is not true. Measured in candela.
lux	SI unit of illuminance. Equivalent to lumens/m^2.
nanometres	nanometres = 10^{-9} m.
opacity	The attenuation of light due to intervening material.
optical depth	The opacity along a given line-of-sight.
photopic	The term denoting human vision in daytime. This is dominated by the colour sensitive cones, which also give us the best acuity in our vision. The cones become inactive at low light levels.
resolution	For an optical system, the angular separation of 2 objects before they appear to merge into 1.
scale height	The height in the atmosphere below which most of a given material exists. For example, most of the aerosol component in the atmosphere is under the aerosol scale height of approximately 1.5 km.
scattering	In the context of atmospheric physics, light that is scattered is reflected from a molecule or particle, at an angle that depends on the process. Back-scatter is reflected back to the source, and forward-scatter is actually light that largely tracks its original path for example.
scotopic	The term denoting human vision in night-time. This is dominated by the monochromatic rods. The rods are more sensitive to blue than red light. The rods "switch-off" in daytime.
solid angle	The angular area of a surface. For example, a circle seen as having an angular extent of 1 degree in radius has an angular area of π square degrees.
steradians	1 square radian, or 3282.9 square degrees.
subtends	An object at a distance from a viewer is seen to be a certain angular size – that is it subtends that angle. Also used to describe angular areas.
visibility	How far away an object can be seen and still have a distinctive 5% contrast with its surroundings. For example, in hazy conditions you might see a distant building but

	not the individual windows on its facade, when in clear conditions you can. The 5% contrast is defined by regulation.
wavelength	The wavelength of light is the physical unit that defines its colour. For visible light, given in units of nanometres (1 billionth of a metre). Human vision operates approximately between 400 and 750 nanometres.

11 REFERENCES

Civil Aviation Authority, 2016. “Policy and Guidance on Wind Turbines”. Available at https://www.caa.co.uk/our-work/publications/documents/content/cap-764/ [Accessed 14 February 2026].

Civil Aviation Authority, 2016. “Air Navigation Order 2016”. Available at https://www.caa.co.uk/general-aviation/the-ga-unit/air-navigation-order-2016/ [Accessed 14 February 2026].

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), 2017. “R0202 Marine Signal Lights-Calculation, Definition and Notation of Luminous Range (E200-2)”. Available at https://www.iala.int/product/r0202/ [Accessed 14 February 2026].

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), 2021. “G1162 The Marking of Offshore Man-Made Structures (Edition 1.1)”. Available at https://www.iala.int/product/g1162/ [Accessed 14 February 2026].

Lamb, T. (2016). Why Rods and Cones? Eye, 30, 179-185.

Maritime and Coastguard Agency, 2022. “MGN 372 Amendment 1 (M+F) Safety of Navigation: Guidance to Mariners Operating in the Vicinity of UK Offshore Renewable Energy Installations (OREIs)”. Available at https://www.gov.uk/government/publications/mgn-372-amendment-1-mf-guidance-to-mariners-operating-in-vicinity-of-uk-oreis/mgn-372-amendment-1-mf-safety-of-navigation-guidance-to-mariners-operating-in-the-vicinity-of-uk-offshore-renewable-energy-installations-oreis [Accessed 14 February 2026].

Met Office, 2024. “MIDAS Open: UK hourly weather observation data, v202407. NERC EDS Centre for Environmental Data Analysis, 06 August 2024”. Available at https://dx.doi.org/10.5285/c50776e4903942cdb329589da70b83fe [Accessed 14 February 2026].

Sabik Marine, 2026. Available at: https://sabik.com/wp-content/uploads/2024/10/sabik_marine_datasheet_led_160_2020.pdf [Accessed 14 February 2025].

Singh, A., Bloss, W., and Pope, F. (2017). 60 years of UK visibility measurements: impact of meteorology and atmospheric pollutants on visibility. Atmospheric Chemistry and Physics, 17(3), 2085-2101.

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