PAGERPOWER
Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Arcus Ltd

Sweetbriar Solar Farm

November 2021

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from a solar photovoltaic (PV) development located near North Killingholme, Lincolnshire, England. The assessment pertains to the possible impact upon surrounding road users, dwellings, railway operations and infrastructure, and aviation activity associated with Humberside Airport, in accordance with industry best practice.

Pager Power

Pager Power has undertaken over 750 glint and glare assessments in the UK, Europe and internationally. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Conclusions

No significant impacts are predicted upon dwellings, road users, railway operations and infrastructure or aviation activity at Humberside Airport, surrounding the proposed development, and no further mitigation is recommended.

Guidance and Studies

Guidelines exist in the UK (produced by the Civil Aviation Authority) and in the USA (produced by the Federal Aviation Administration) with respect to solar developments and aviation activity. The UK CAA guidance is relatively high-level and does not prescribe a formal methodology. There is no existing planning guidance for the assessment of solar reflections from solar panels towards roads, rail and nearby dwellings. Pager Power has however produced guidance for glint and glare and solar photovoltaic developments, which was published in early 2017, with the third edition originally published in 2020[1]. The guidance document sets out the methodology for assessing roads, dwellings, and aviation activity with respect to solar reflections from solar panels.

Pager Power's approach is to undertake geometric reflection calculations and, where a solar reflection is predicted, consider the screening (existing and/or proposed) between the receptor and the reflecting solar panels. For aviation activity, where a solar reflection is predicted, solar intensity calculations are undertaken in line with the Sandia National Laboratories' FAA methodology[2]. The scenario in which a solar reflection can occur for all receptors is then identified and discussed, and a comparison is made against the available solar panel reflection studies to determine the overall impact.

The available studies have measured the intensity of reflections from solar panels with respect to other naturally occurring and manmade surfaces. The results show that the reflections produced are

[1] Pager Power Glint and Glare Guidance, Third Edition (3.1), April 2021.

[2] Formerly mandatory for on-airfield solar developments in the USA under the FAA's interim policy, superseded in 2021 with a policy that effectively requires individual airports to sign off on their on-airfield development as they see fit.

of intensity similar to or less than those produced from still water and significantly less than reflections from glass and steel[3].

Assessment Results – Dwellings

The results of the analysis have shown that for eight of the 14 assessed dwellings, visibility of glare that is predicted by the modelling output, to last for more than three months per year and less than 60 minutes per day will be removed by the existing and proposed screening. Therefore, no impact is predicted and further mitigation is not required. Where solar reflections are geometrically possible towards the remaining dwellings, no further mitigation is necessary due to the maximum duration of effects being sufficiently low.

Assessment Results – Roads

The roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

Assessment Results – Aviation

Solar reflections are not geometrically possible towards the ATC tower nor the approaches for runways 02, 20, 08 and 26. No impacts upon aircraft on these runway approaches nor the ATC tower are predicted and no mitigation is required.

Assessment Results – Railway

The results of the modelling indicate that solar reflections are geometrically possible towards all 12 of the assessed train driver receptors along a 1.1km section of railway track. However, solar reflections are removed by existing and proposed screening. If the screening were to be removed the impact would remain low due to the reflections occurring outside the train drivers' primary field of view (30 degrees either side of the direction of travel); therefore, mitigation is not required.

[3] SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy, 2010).

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 51 countries within Europe, Africa, America, Asia and Australasia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially, the company focus was on modelling the impact of wind turbines on radar systems. Over the years, the company has expanded into numerous fields including:

- Renewable energy projects.
- Building developments.
- Aviation and telecommunication systems.

Pager Power prides itself on providing comprehensive, understandable, and accurate assessments of complex issues in line with national and international standards. This is underpinned by its custom software, longstanding relationships with stakeholders and active role in conferences and research efforts around the world.

Pager Power's assessments withstand legal scrutiny and the company can provide support for a project at any stage.

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from a solar photovoltaic (PV) development located near North Killingholme, Lincolnshire, England. The assessment pertains to the possible impact upon surrounding road users, dwellings, railway operations and infrastructure, and aviation activity associate with Humberside airport, in accordance with industry best practice.

This report contains the following:

- Solar development details.
- Explanation of glint and glare.
- Overview of relevant guidance.
- Overview of relevant studies.
- Overview of Sun movement.
- Assessment methodology.
- Identification of receptors.
- Glint and glare assessment for identified receptors.
- Results discussion.

1.2 Pager Power's Experience

Pager Power has undertaken over 750 Glint and Glare assessments in the UK and internationally. The studies have included assessment of civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Glint and Glare Definition

The definition of glint and glare is as follows[4]:

- Glint – a momentary flash of bright light typically received by moving receptors or from moving reflectors.
- Glare – a continuous source of bright light typically received by static receptors or from large reflective surfaces.

The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

[4] These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Site Plan

Figure 1 below[5] shows the site layout plan. The blue lines denote the solar panel locations.

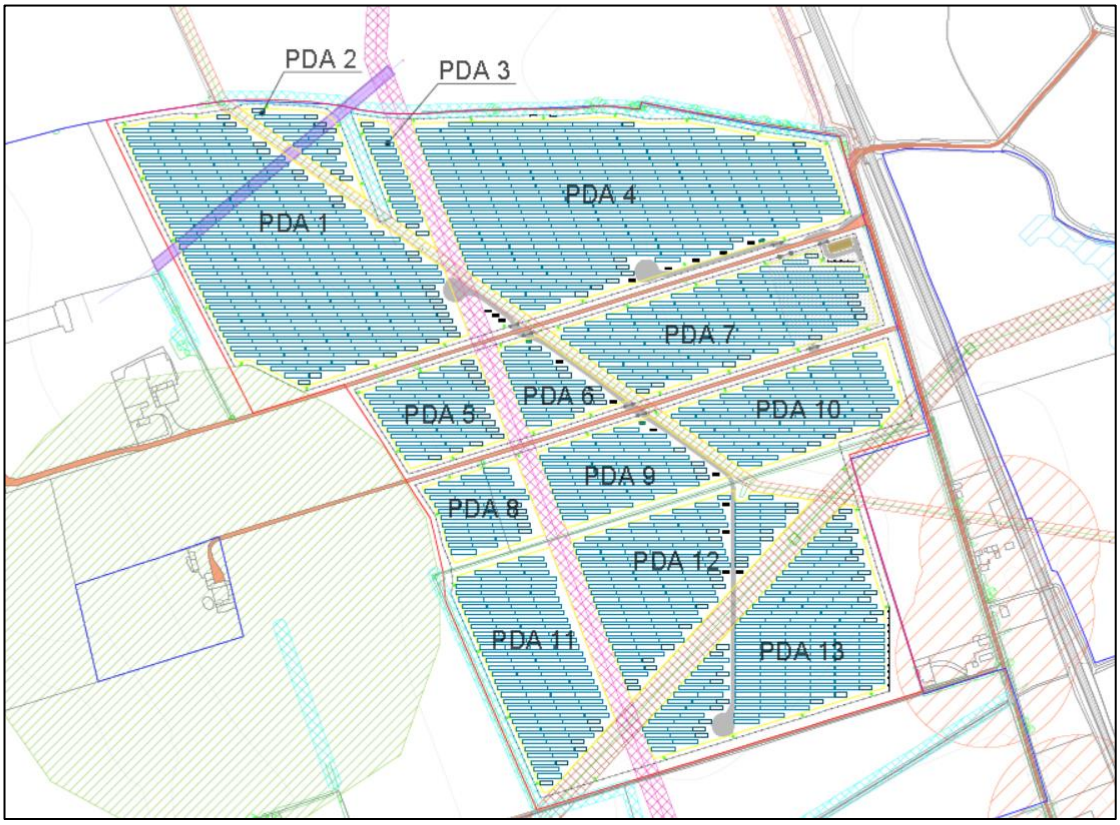


Figure 1 *Proposed development site plan*

[5] Provided to Pager Power by the developer, Arcus Ltd.

2.2 Proposed Mitigation

Figure 2[5] below shows the proposed mitigation.

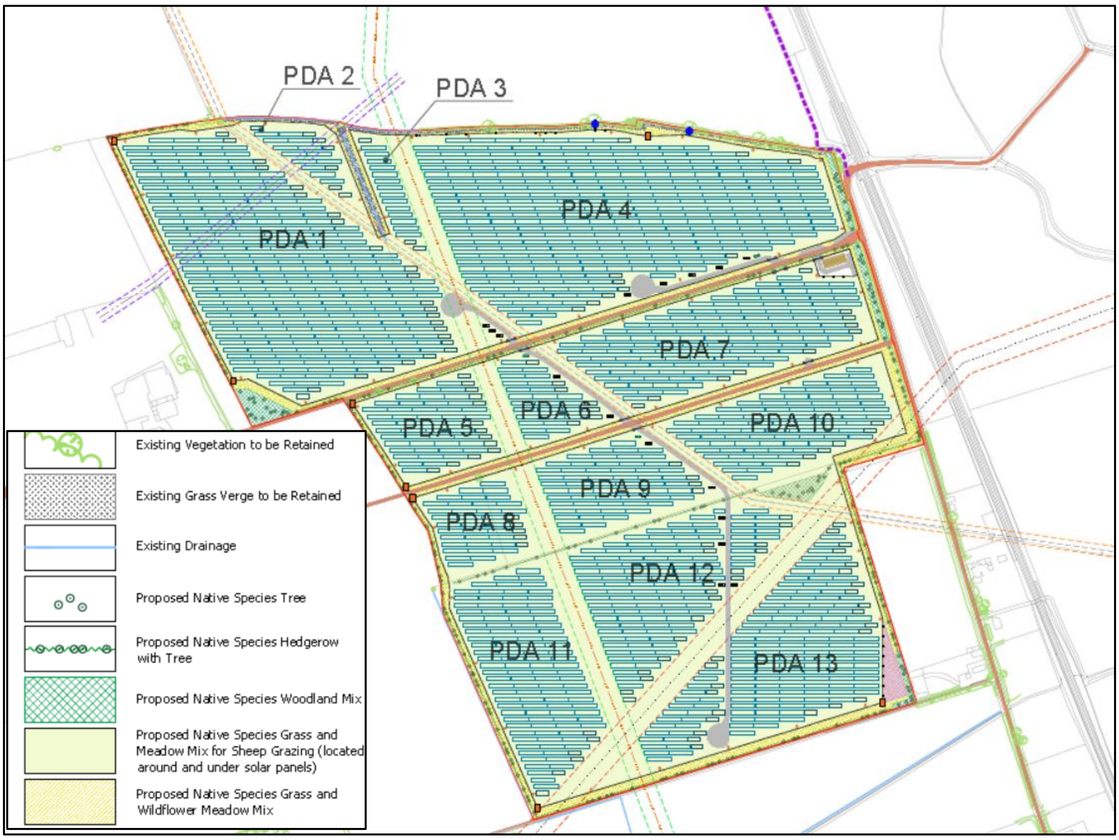


Figure 2 *Proposed mitigation*

2.3 Proposed Development Location – Aerial Image

Figure 3 below[6] shows the panel area overlaid onto aerial imagery (blue polygons).

Figure 3 *Proposed development location – aerial image*

2.4 Photovoltaic Panel Mounting Arrangements and Orientation

The solar panel dimensions as assessed within this report are as follows:

- The maximum height of the solar panels is 2.8m above ground level (agl), the minimum height is 0.8m agl - assessed at a panel midpoint of 1.8m agl;
- Tilt: 20 degrees above the horizontal;
- Orientation: 180 degrees (south facing).

[6] Copyright © 2021 Google.

3 HUMBERSIDE AIRPORT DETAILS

3.1 Overview

The following section presents general details regarding Humberside Airport.

3.2 Airport Information

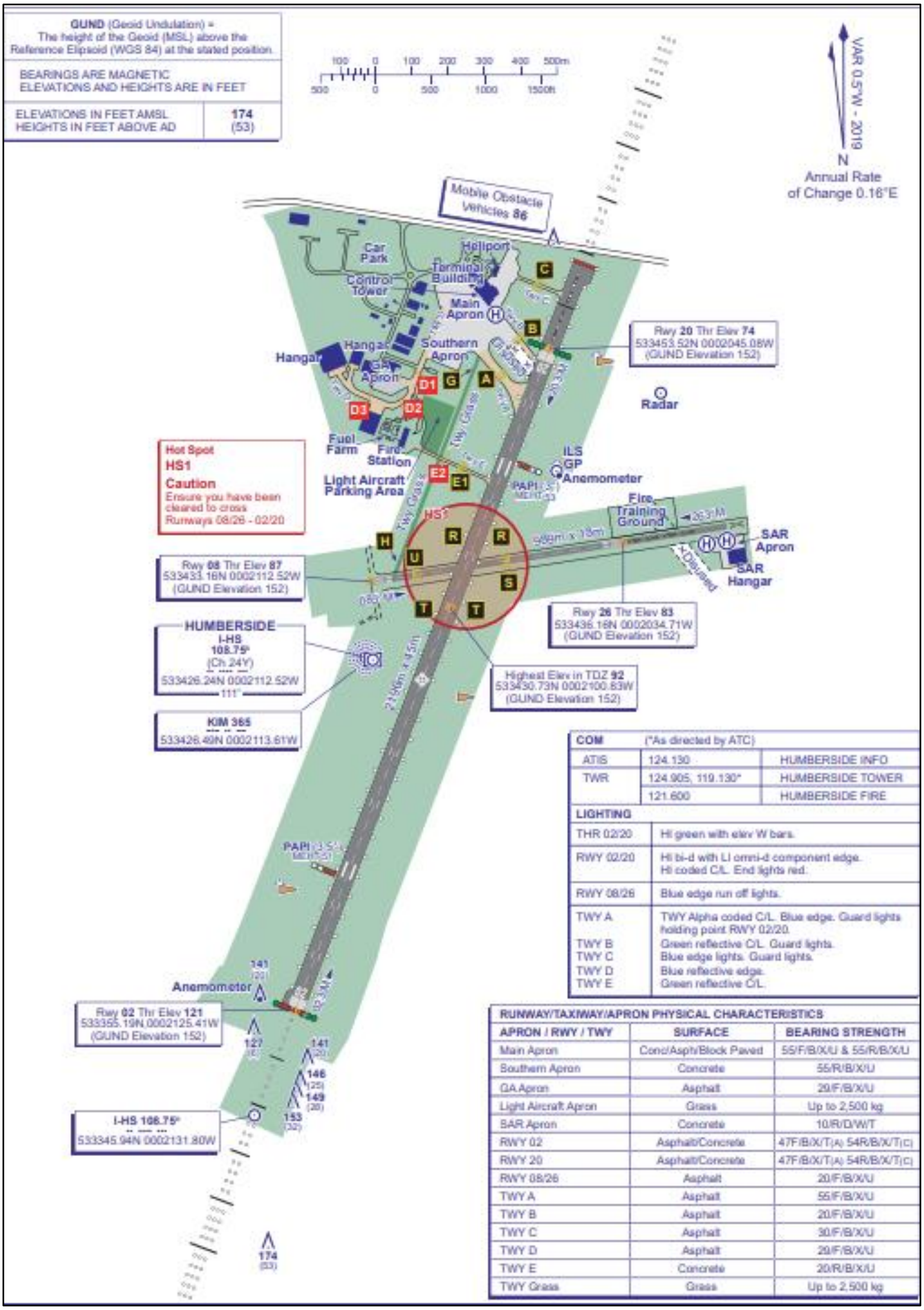
Humberside Airport is a privately owned airport for public use, operating international and domestic flights.

3.3 Runway Details

Humberside has two runways:

- 02/20 – 2,196m by 45m.
- 08/26 – 989m by 18m.

The runway is shown in Figure 4[6] (aerodrome chart) on the following page.



COM	(*As directed by ATC)	
ATIS	124.130	HUMBERSIDE INFO
TWR	124.905, 119.130*	HUMBERSIDE TOWER
	121.600	HUMBERSIDE FIRE

LIGHTING	
THR 02/20	HI green with elev W bars.
RWY 02/20	HI bi-d with LI omni-d component edge. HI coded C/L. End lights red.
RWY 08/26	Blue edge run off lights.
TWY A	TWY Alpha coded C/L. Blue edge. Guard lights holding point RWY 02/20.
TWY B	Green reflective C/L. Guard lights.
TWY C	Blue edge lights. Guard lights.
TWY D	Blue reflective edge.
TWY E	Green reflective C/L.

RUNWAY/TAXIWAY/APRON PHYSICAL CHARACTERISTICS

APRON / RWY / TWY	SURFACE	BEARING STRENGTH
Main Apron	Conc/Asph/Block Paved	55/F/B/X/U & 55/R/B/X/U
Southern Apron	Concrete	55/R/B/X/U
GA Apron	Asphalt	29/F/B/X/U
Light Aircraft Apron	Grass	Up to 2,500 kg
SAR Apron	Concrete	10/R/D/W/T
RWY 02	Asphalt/Concrete	47F/B/X/T(A) 54R/B/X/T(C)
RWY 20	Asphalt/Concrete	47F/B/X/T(A) 54R/B/X/T(C)
RWY 08/26	Asphalt	20/F/B/X/U
TWY A	Asphalt	55/F/B/X/U
TWY B	Asphalt	20/F/B/X/U
TWY C	Asphalt	30/F/B/X/U
TWY D	Asphalt	29/F/B/X/U
TWY E	Concrete	20/R/B/X/U
TWY Grass	Grass	Up to 2,500 kg

Figure 4 *Humberside Airport Aerodrome Chart*

3.4 Air Traffic Control Tower

Humberside Airport has an Air Traffic Control (ATC) Tower located approximately 750m to the north northwest of the centre of runway 08/26 and is highlighted in Figure 5[6] below.

Figure 5 *Location of the proposed development relative to Humberside Airport*

4 GLINT AND GLARE ASSESSMENT METHODOLOGY

4.1 Guidance and Studies

Appendices A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels are possible.
- The measured intensity of a reflection from solar panels can vary from 2% to 30% depending on the angle of incidence.
- Published guidance shows that the intensity of solar reflections from solar panels are equal to or less than those from water. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

4.2 Background

Details of the Sun's movements and solar reflections are presented in Appendix C.

4.3 Pager Power's Methodology

4.3.1 Pager Power's Methodology

The glint and glare assessment methodology has been derived from the information provided to Pager Power through consultation with stakeholders and by reviewing the available guidance and studies. The methodology for a glint and glare assessments is as follows:

- Identify receptors in the area surrounding the solar development.
- Consider direct solar reflections from the solar development towards the identified receptors by undertaking geometric calculations.
- Consider the visibility of the panels from the receptor's location. If the panels are not visible from the receptor then no reflection can occur.
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur.
- Consider both the solar reflection from the solar development and the location of the direct sunlight with respect to the receptor's position.
- Consider the solar reflection with respect to the published studies and guidance - including intensity calculations where appropriate.
- Determine whether a significant detrimental impact is expected in line with the process presented in Appendix D.

4.3.2 Sandia National Laboratories' Methodology

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer available. Whilst strictly applicable in the USA and to solar photovoltaic developments only, the methodology and associated guidance is widely used by UK aviation stakeholders. The following text is taken from the SGHAT model methodology.

'This tool determines when and where solar glare can occur throughout the year from a user-specified PV array as viewed from user-prescribed observation points. The potential ocular impact from the observed glare is also determined, along with a prediction of the annual energy production.'

The result was a chart that states whether a reflection can occur, the duration and predicted intensity for aviation receptors.

Pager Power has undertaken many aviation glint and glare assessments with both models (SGHAT and Pager Power's) producing similar results. Intensity calculations in line with Sandia National Laboratories' methodology has been completed[7]. Where required, cross checks have been completed.

4.4 Assessment Methodology and Limitations

Further technical details regarding the methodology of the geometric calculations and limitations are presented in Appendix E and F.

[7] Currently using the Forge Solar model, based on the Sandia methodology.

5 IDENTIFICATION OF RECEPTORS

5.1 Ground-Based Receptors – Overview

There is no formal guidance with regard to the maximum distance at which glint and glare should be assessed. From a technical perspective, there is no maximum distance for potential reflections. The significance of a reflection however decreases with distance because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases. Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances.

The above parameters and extensive experience over a significant number of glint and glare assessments undertaken, shows that a 1km assessment area from the proposed panel area is appropriate for glint and glare effects on ground-based receptors and 500m is considered appropriate for railway receptors. Reflections towards ground-based receptors located further north than any proposed panel are highly unlikely[8]. Therefore, receptors north of the panel areas have been excluded from the assessment area.

Potential receptors within the assessment areas are identified based on mapping and aerial photography of the region. The initial judgement is made based on high-level consideration of aerial photography and mapping i.e. receptors are excluded if it is clear from the outset that no visibility would be possible. A more detailed assessment is made if the modelling reveals a reflection would be geometrically possible.

Terrain elevation heights have been interpolated based on Ordnance Survey of Great Britain (OSGB) 50m Panorama data. Receptor details can be found in Appendix G.

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[8] For fixed, south-facing panels at this latitude.

5.2 Dwelling Receptors

The analysis has considered dwellings that:

- Are within the 1km assessment area; and
- Have a potential view of the panels.

The assessed dwelling receptors are shown in Figure 6[6], below, along with the 1km assessment area (the green outlined polygon). A total of 14 dwelling locations have been assessed.

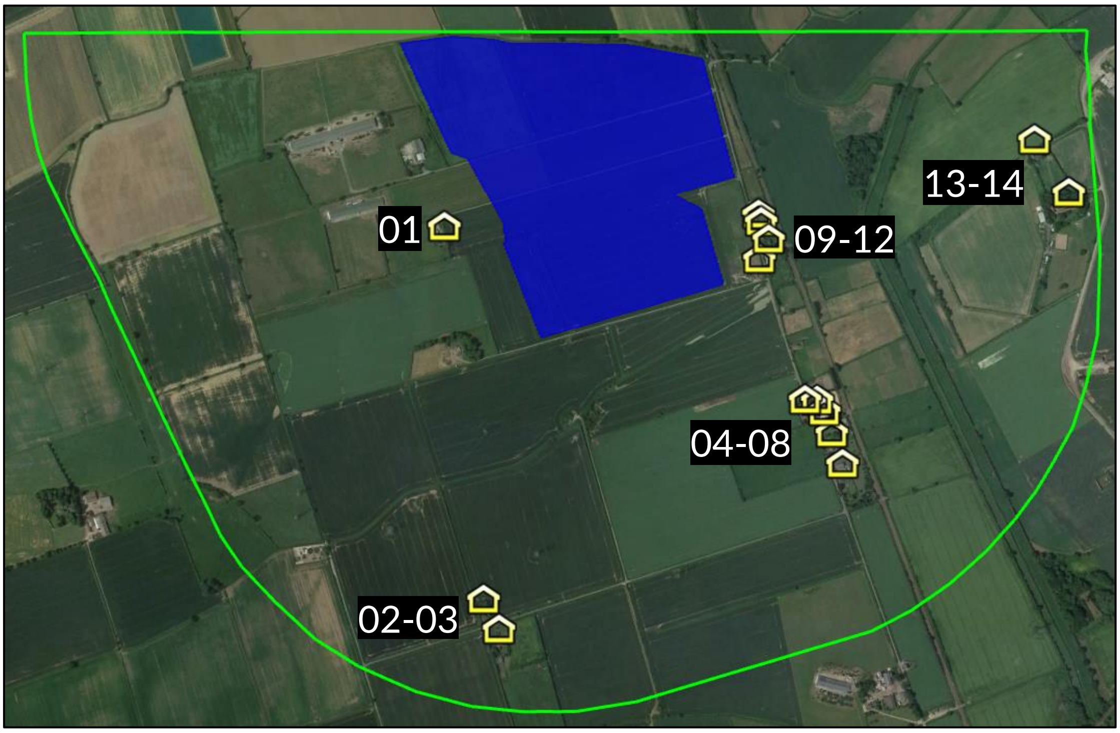

Figure 6 *Assessed dwelling receptors*

For the dwellings, a height of 1.8 metres above ground level has been taken as typical eye level for an observer on the ground floor of the dwelling[9].

Close-up images to illustrate the dwelling receptors are presented in Figures 7-11[6], on the following pages.

[9] This height is used for modelling purposes and all floors are considered in the results discussion.

Figure 7 *Dwelling 01*

Figure 8 *Dwellings 02-03*

Figure 9 *Dwellings 04-08*

Figure 10 *Dwellings 09-12*

Figure 11 *Dwellings 13-14*

5.3 Road Receptors

Road types can generally be categorised as:

- Major National – Typically a road with a minimum of two carriageways with a maximum speed limit of up to 70mph. These roads typically have fast moving vehicles with busy traffic;
- National – Typically a road with a one or more carriageways with a maximum speed limit of up to 60mph or 70mph. These roads typically have fast moving vehicles with moderate to busy traffic density;
- Regional – Typically a single carriageway with a maximum speed limit of up to 60mph. The speed of vehicles will vary with a typical traffic density of low to moderate; and
- Local – Typically roads and lanes with the lowest traffic densities. Speed limits vary.

The roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

The nearest significant road is the A160, which is south of the panel area and outside of the 1km assessment area. The location of the A160 relative to the proposed development is shown in Figure 12[6] below.

Considering all of the above, none of the surrounding roads have therefore been taken forward for detailed modelling. No significant impacts upon road users are predicted and no mitigation is required.

Figure 12 *Nearest significant road relative to the proposed development*

5.4 Aviation Receptors

5.4.1 Airborne Receptors – Approaching Aircraft

Humberside Airport has two operational runways, with four associated approach paths, one for each bearing. It is Pager Power's methodology to assess whether a solar reflection can be experienced on the approach paths for the associated runways. This is considered to be the most critical stage of the flight.

A geometric glint and glare assessment has been undertaken for both aircraft approach paths for the runway. The Pager Power approach for determining receptor (aircraft) locations on the approach path is to select locations along the extended runway centre line from 50ft above the runway threshold out to a distance of 2 miles. The height of the aircraft is determined by using a 3-degree descent path relative to the runway threshold height. The receptor details for each runway approach are presented in Appendix G. Figure 13[6] below shows the assessed aircraft approach paths.

Figure 13 *Runway approach paths – aerial image*

5.4.2 ATC Tower

It is standard practice to determine whether a solar reflection can be experienced by personnel within the ATC Tower. The detailed receptor details are presented in Appendix G.

Figure 14[6] on the following page shows the location of the ATC Tower.

Figure 14 *ATC Tower location – aerial image*

5.5 Railway Receptors

Typical reasons stated by a railway stakeholder for requesting a glint and glare assessment often relate to the following:

1. The development producing solar reflections towards train drivers;
2. The development producing solar reflections, which causes a train driver to take action; and
3. The development producing solar reflections that affect railway signals.

With respect to point 1, a reflective panel could produce solar reflections towards a train driver. If this reflection occurs where a railway signal, crossing etc., is present, or where the driver's workload is particularly high, the solar reflection may affect operations. This is deemed to be the most concern with respect to solar reflections.

Following from point 1, point 2 identifies whether a modelled solar reflection could be significant by determining its intensity. Only where a solar reflection occurs under certain conditions and is of a particular intensity may it cause a reaction from a train driver and thus potentially affect safe operations. Therefore, intensity calculations are undertaken where a solar reflection is identified and where its presence could potentially affect the safety of operations. Points 1 and 2 are completed in a 2-step approach.

With respect to all points, railway lines use light signals to manage trains on approach towards particular sections of track. If a signal is passed when not permitted, a SPAD (Signal Passed At Danger) is issued. The concerns will relate specifically to the possibility of the reflections appearing to illuminate signals that are not switched on (known as a phantom aspect illusion) or a distraction caused by the glare itself, both of which could lead to a SPAD. The definition is presented below:

'Light emitted from a Signal lens assembly that has originated from an external source (usually the sun) and has been internally reflected within the Signal Head in such a way that the lens assembly gives the appearance of being lit.[10]*'*

5.5.1 Glint and Glare Definition

As well as the glint and glare definition presented in Section 1.3, glare can also be categorised as causing visual discomfort whereby an observer would instinctively look away, or cause disability whereby objects become difficult to see. The guidance produced by the Commission Internationale de L'Eclairage (CIE) describes disability glare as[11]:

'Disability glare is glare that impairs vision. It is caused by scattering of light inside the eye…The veiling luminance of scattered light will have a significant effect on visibility when intense light sources are present in the peripheral visual field and contrast of objects is seen to be low.'

'Disability glare is most often of importance at night when contrast sensitivity is low and there may well be one or more bright light sources near to the line of sight, such as car headlights, streetlights or

[10] Source: Glossary of Signalling Terms, Railway Group Guidance Note GK/GN0802. Issue One. Date April 2004.
[11] CIE 146:2002 & CIE 147:2002 Collection on glare (2002).

floodlights. But even in daylight conditions disability glare may be of practical significance: think of traffic lights when the sun is close to them, or the difficulty viewing paintings hanging next to windows.'

These types of glare are of particular importance in the context of railway operations as they may cause a distraction to a train driver (discomfort) or may cause railway signals to be difficult to see (disability).

5.5.2 Railway Signal Receptors

The analysis has considered railway signal receptors that:

- Are within the 500m assessment area;
- Have a potential view of the panels.

No railway signals were identified following an initial review of the available imagery. Network Rail have been contacted with request for railway signal information; however, no response has been received to date. This report can be updated if railway signals are identified by Network Rail.

5.5.3 Train Driver Receptors

The analysis has considered train driver receptors that:

- Are within the 500m assessment area;
- Have a potential view of the panels.

Figure 15[6] on the following page shows the section of railway identified within 500m of the proposed development (green outlined polygon); 12 railway receptors were identified.

Receptor details can be found in Appendix A.

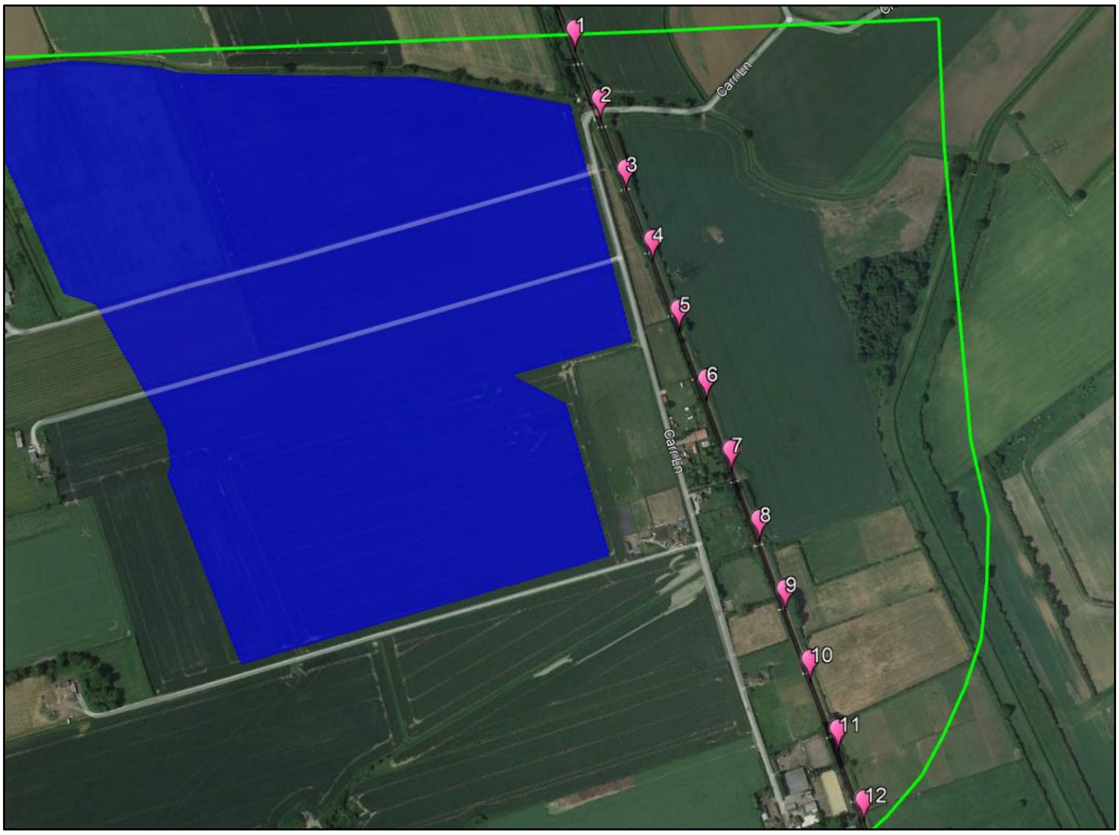

Figure 15 *Railway receptors - aerial image*

6 ASSESSED REFLECTORS

6.1 Reflector Area

A resolution of 10m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor from a point every 10m from within the defined areas. This resolution is sufficiently high to maximise the accuracy of the results, increasing the resolution further would not significantly change the modelling output. The number of modelled reflector points are determined by the size of the reflector area and the assessment resolution.

The bounding co-ordinates for the proposed solar development have been extrapolated from the site plans. The data can be found in Appendix G. The assessed panel areas are shown in Section 2 of this report.

7 GLINT AND GLARE ASSESSMENT – TECHNICAL RESULTS

7.1 Evaluation of Effects

The tables in the following subsections present the results of the technical analysis. The final column summarises the predicted impact considering the level of identified screening based on a desk-based review of the available imagery.

The significance of the predicted effects has been evaluated in accordance with Pager Power's published guidance document[12].

The flowcharts setting out the impact characterisation and presented in Appendix D[13]. The list of assumptions and limitations are presented in Appendix F. The modelling output for key receptors can be found in Appendix H.

When evaluating visibility in the context of glint and glare, it is only the *reflecting* panel area that must be considered. For example, if the western half of the development is visible, but reflections would only be possible from the eastern half, it can be concluded that the reflecting area is not visible and no impacts are predicted. This is why there can be instances where visibility of the development is predicted, but glint and glare issues are screened.

Receptors are included within the assessment based on the potential visibility of the development as a whole, among other factors. Once the modelling output has been generated, the assessment can be refined to evaluate the visibility of the reflecting area specifically.

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[12] Solar Photovoltaic Development – Glint and Glare Guidance Issue 3.1, April 2021.

[13] There is no standard methodology for evaluating effects on ground-based receptors beyond a kilometre. These receptors have been considered based on first principles and the general methodology for ground-based receptors, keeping in mind the relative safety/amenity implications for differing receptor types.

7.2 Geometric Calculation Results – Dwelling Receptors

Refer to Section 8.1 for a discussion of the following results.

Dwelling(s)	Are Solar Reflections Geometrically Possible? (GMT)		Comment
	am	pm	
01	Yes.	No.	The model output shows potential effects would last for more than three months per year and less than 60 minutes per day. The worst-case impact is moderate; however, sufficient existing and proposed screening is present so further mitigation is not recommended.
02-04	No.	No.	No solar reflections geometrically possible. No impact predicted.
05-06	No.	Yes.	The model output shows potential effects would last for less than three months per year and less than 60 minutes per day. The worst-case impact is low, which does not require further consideration.
07-12	No.	Yes.	The model output shows potential effects would last for more than three months per year and less than 60 minutes per day. The worst-case impact is moderate; however, sufficient existing and proposed screening is present so further mitigation is not recommended.
13	Yes.	No.	The model output shows potential effects would last for less than three months per year and less than 60 minutes per day. The worst-case impact is low, which does not require further consideration.
14	No.	Yes.	The model output shows potential effects would last for more than three months per year and less than 60 minutes per day. The worst-case impact is moderate; however, sufficient existing screening is present so further mitigation is not recommended.

Table 1 *Geometric analysis results for dwelling receptors*

7.3 Geometric Calculation Results – Aviation Receptors

7.3.1 Overview

The Pager Power and Forge model have been used to determine whether reflections are geometrically possible, when assessing aviation receptors. Intensity calculations (Forge Model) in line with the Sandia National Laboratories methodology have been undertaken. These calculations are routinely required for solar photovoltaic developments on or near aerodromes. The intensity model calculates the expected intensity of a reflection with respect to the potential for an after-image (or worse) occurring. The designation used by the model is presented in Table 3 below along with the associated colour coding.

Coding Used	Intensity Key
Glare beyond 50°	Glare beyond 50 deg from pilot line-of-sight
Low potential	Low potential for temporary after-image
Potential	Potential for temporary after-image
Potential for permanent eye damage	Potential for permanent eye damage

Table 2 *Glare intensity designation*

This coding has been used in the table where a reflection has been calculated and is in accordance with Sandia National Laboratories' methodology.

In addition, the intensity model allows for the assessment of a variety of solar panel surface materials. In the first instance, a surface material of 'smooth glass without an anti-reflective coating' is assessed. This is the most reflective surface and allows for a 'worst case' assessment. Other surfaces that could be modelled include:

- Smooth glass with an anti-reflective coating;
- Light textured glass without an anti-reflective coating;
- Light textured glass with an anti-reflective coating; or
- Deeply textured glass.

If significant glare is predicted, modelling of less reflective surfaces could be undertaken.

The tables in the following subsections summarise the time (am or pm) and intensity for a solar reflection that could be experienced by a receptor. Appendix H presents the results charts.

7.3.2 ATC Tower

Receptor	Reflection possible toward the ATC Tower? (GMT)		Glare Type	Comment
	AM	PM		
ATC Tower	No.	No.	N/A	No solar reflections geometrically possible. No impact predicted.

Table 3 *Geometric analysis results for the ATC tower*

7.3.3 Approach for Runway 02

Receptor	Reflection possible toward the runway 02 approach path? (GMT)		Glare Type	Comment
	AM	PM		
Threshold – 2 miles	No.	No.	N/A	No solar reflections geometrically possible. No impact predicted.

Table 4 *Geometric analysis results for the Runway 02 Approach*

7.3.4 Approach for Runway 20

Receptor	Reflection possible toward the runway 20 approach path? (GMT)		Glare Type	Comment
	AM	PM		
Threshold – 2 miles	No.	No.	N/A	No solar reflections geometrically possible. No impact predicted.

Table 5 *Geometric analysis results for the Runway 20 Approach*

7.3.5 Approach for Runway 08

Receptor	Reflection possible toward the runway 08 approach path? (GMT)		Glare Type	Comment
	AM	PM		
Threshold – 2 miles	No.	No.	N/A	No solar reflections geometrically possible. No impact predicted.

Table 6 *Geometric analysis results for the Runway 08 Approach*

7.3.6 Approach for Runway 26

Receptor	Reflection possible toward the runway 26 approach path?? (GMT)		Glare Type	Comment
	AM	PM		
Threshold – 2 miles	No.	No.	N/A	No solar reflections geometrically possible. No impact predicted.

Table 7 *Geometric analysis results for the Runway 26 Approach*

7.4 Geometric Calculation Results – Train Driver Receptors

Receptor	Reflection Possible Towards Receptor? (GMT)		Comments
	am	pm	
1	No.	No.	No solar reflections geometrically possible. No impact predicted.
2-12	No.	Yes.	Predicted solar reflections occur outside the train driver's primary field of view (30 degrees either side of the direction of travel). Therefore a low impact is predicted and further mitigation is not recommended.

Table 8 *Geometric analysis results for the identified train driver receptors*

8 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

8.1 Dwelling Results

The process for quantifying impact significance is defined in the report appendices. For dwelling receptors, the key considerations are:

- Whether a significant reflection is predicted to be experienced in practice.
- The duration of the predicted effects, relative to thresholds of:
    - Three months per year.
    - 60 minutes per day.

Where reflections are predicted to be experienced for less than three months per year and less than 60 minutes per day or where the separation distance to the nearest visible reflecting panel is over 1km, the impact significance is low, and mitigation is not required.

Where reflections are predicted to be experienced for more than three months per year or for more than 60 minutes per day, the impact significance is moderate and expert assessment of the following mitigating factors is required to determine the mitigation requirement:

- The separation distance to the panel area. Larger separation distances reduce the proportion of an observer's field of view that is affected by glare.
- The position of the Sun. Effects that coincide with direct sunlight appear less prominent than those that do not. The Sun is a far more significant source of light.
- Whether solar reflections will be experienced from all storeys. The ground floor is typically considered the main living space and therefore has a greater significance with respect to residential amenity.
- Whether the dwelling appears to have windows facing the reflecting areas. An observer may need to look at an acute angle to observe the reflecting areas.

Where reflections are predicted to be experienced for more than three months per year and more than 60 minutes per day, the impact significance is high, and mitigation is required.

A conservative review of the available imagery has been undertaken within the desk-based assessment, whereby it is assumed views of the panels are possible if it cannot be reliably determined that existing screening will remove effects.

Solar reflections lasting for more than three months per year and less than 60 minutes on any one day have been predicted for dwellings 01, 07-12 and 14. However, due to sufficient existing and proposed screening, there is no predicted impact from the reflecting area. Therefore, no further mitigation is recommended. These dwellings are shown in Figure 16[6] on the following page for completeness.

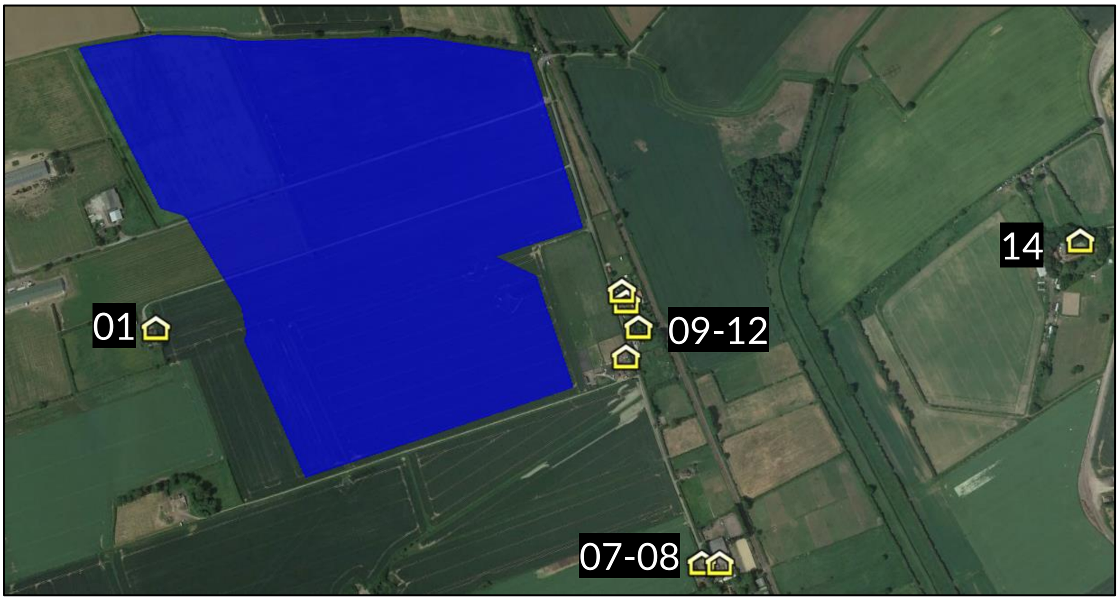

Figure 16 *Dwellings 01, 07-12 and 14*

Figure 17[6] below depicts the reflector area (yellow area) in relation to dwellings 01 and 07-08 and any proposed mitigation that will remove views of the reflecting area (green lines). This is the total area accounting for potential reflections throughout March-October.

Figure 17 *Aerial image depicting dwellings 01 and 07-08, in relation to the cumulative reflector area*

Figure 18[6] on the following page depicts the cumulative reflector area in relation to dwellings 09-12 and 14 and any proposed mitigation that will remove views of the reflecting area (green line). This is the total area accounting for potential reflections throughout March-September.

Figure 18 *Aerial image depicting dwellings 09-12 and 14, in relation to the reflector area*

Figures 17 and 18 are representative of the reflector areas for the potentially affected dwellings (01, 07-12 and 14) in terms of the relative position of the reflecting area and the overall timing/duration of effects[14]. After undertaking a conservative analysis of these dwellings, it is evident that the existing and proposed screening will inhibit visibility of the reflecting solar panel area; thus, further mitigation is not required.

For dwellings 05-06 and 13, a reflection is geometrically possible; however, the predicted impact of the reflecting solar panel is of low significance due to the duration of effects. Therefore, no further consideration is required and no mitigation is required. In addition, for dwellings 02-04, no reflections are geometrically possible. Therefore, no impact is predicted, and no mitigation is required.

8.1.1 Dwelling Assessment Conclusions

Overall, solar reflections lasting for more than three months of the year and less than 60 minutes are deemed possible towards receptor locations 01, 07-12, and 14 considering baseline conditions. Following a review of the available imagery, it has been concluded that no visibility of the reflecting panel areas is considered possible due to the existing and proposed screening. Therefore, no impact is precited, and no further mitigation is required.

Dwellings 05-06 and 13 could experience solar reflections for less than three months of the year and less than 60 minutes. In accordance with the methodology set out in Section 3 and Appendix D, the worst-case resulting impact significance is low and, subsequently, no further mitigation is required.

The remaining dwellings are expected to have no impact, where no reflections are geometrically possible (dwellings 02-04), therefore no further mitigation is required.

[14] The more detailed breakdown of effect times/dates is presented in Section 6 and in Appendix H.

8.2 Aviation Results

The assessment results and discussion for Humberside Airport receptors are presented in the following sub-sections.

8.2.1 ATC Tower

The results of the geometric modelling have shown that solar reflections towards the ATC tower from the proposed solar development are not geometrically possible. Therefore, no impacts are predicted, and no mitigation is required.

8.2.2 Runway 02 Approaches

The results of the geometric modelling have shown that solar reflections are not geometrically possible towards the runway 02 approach path. Therefore, no impacts are predicted, and no mitigation is required.

8.2.3 Runway 20 Approaches

The results of the geometric modelling have shown that solar reflections are not geometrically possible towards the runway 20 approach path. Therefore, no impacts are predicted, and no mitigation is required.

8.2.4 Runway 08 Approaches

The results of the geometric modelling have shown that solar reflections are not geometrically possible towards the runway 08 approach path. Therefore, no impacts are predicted, and no mitigation is required.

8.2.5 Runway 26 Approaches

The results of the geometric modelling have shown that solar reflections are not geometrically possible towards the runway 26 approach path. Therefore, no impacts are predicted, and no mitigation is required.

8.2.6 Aviation Assessment Conclusions

In accordance with the methodology presented in Section 4 and Appendix D, no significant impact upon aircraft on these runway approaches nor the ATC tower are predicted and no mitigation is required.

8.3 Train Driver Receptors

The results of the modelling indicate that solar reflections are geometrically possible towards 9 of the 12 assessed train driver receptors along the 1.1km section of railway track. The section of railway track where solar reflections are geometrically possible is shown in Figure 19[6] below.

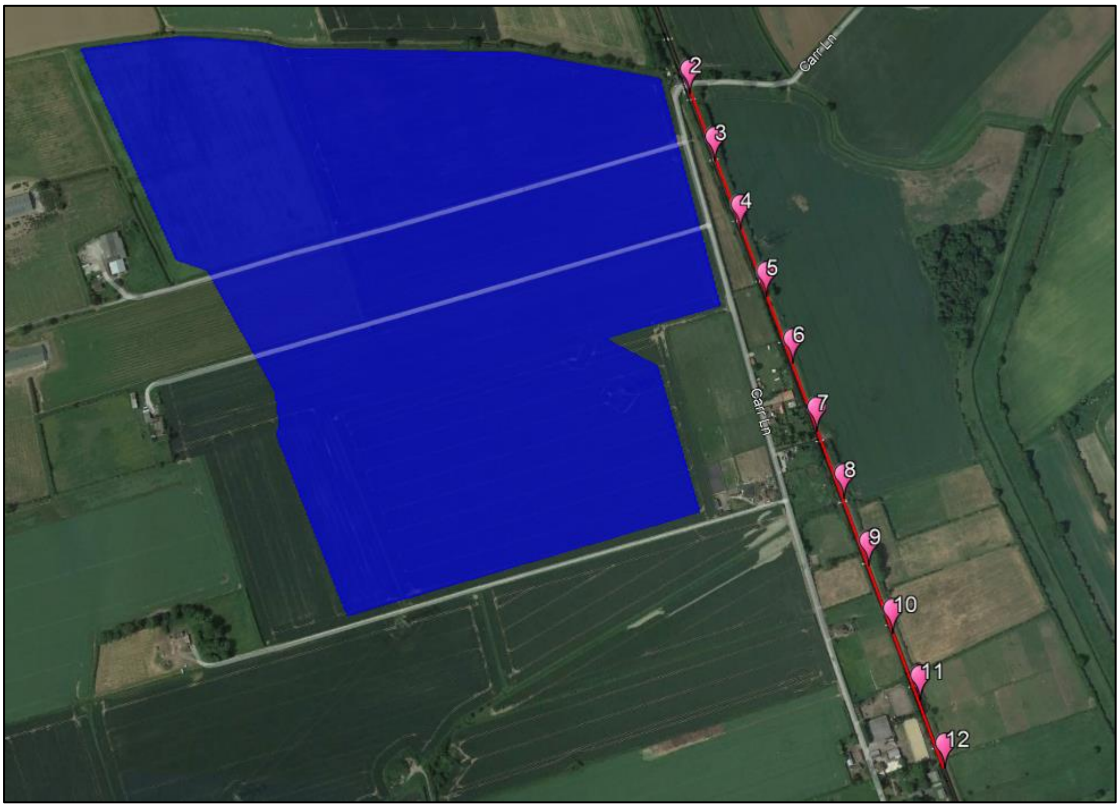

Figure 19 *Section of assessed railway where solar reflections are possible*

The key considerations for quantifying impact significance for train driver receptors are:

- Whether a reflection is predicted to be experienced in practice.
- The location of the reflecting panel relative to a train driver's direction of travel.
- The workload of a train driver experiencing a solar reflection.

Where reflections originate from outside of a train driver's field of view (30 degrees either side of the direction of travel), the impact significance is low, and mitigation is not required.

Where reflections originate from inside of a train driver's field of view but there are mitigating circumstances, the impact significance is moderate and expert assessment of the mitigating factors is required to determine the mitigation requirement (if any). Of particular relevance is whether the solar reflection originates from directly in front of a train driver and the workload of the train driver along the section of railway line.

Where reflections originate from directly in front of a train driver and there are no further mitigating circumstances, the impact significance is high, and mitigation is required.

There would be no impact to the train driver due to the existing screening, removing views of the reflecting solar panel area. In the absence of screening vegetation the impact would be low where the reflections fall outside the train driver's primary field of view (30 degrees either side of the direction of travel). The existing vegetation is shown in Figure 20[6] below by the blue line.

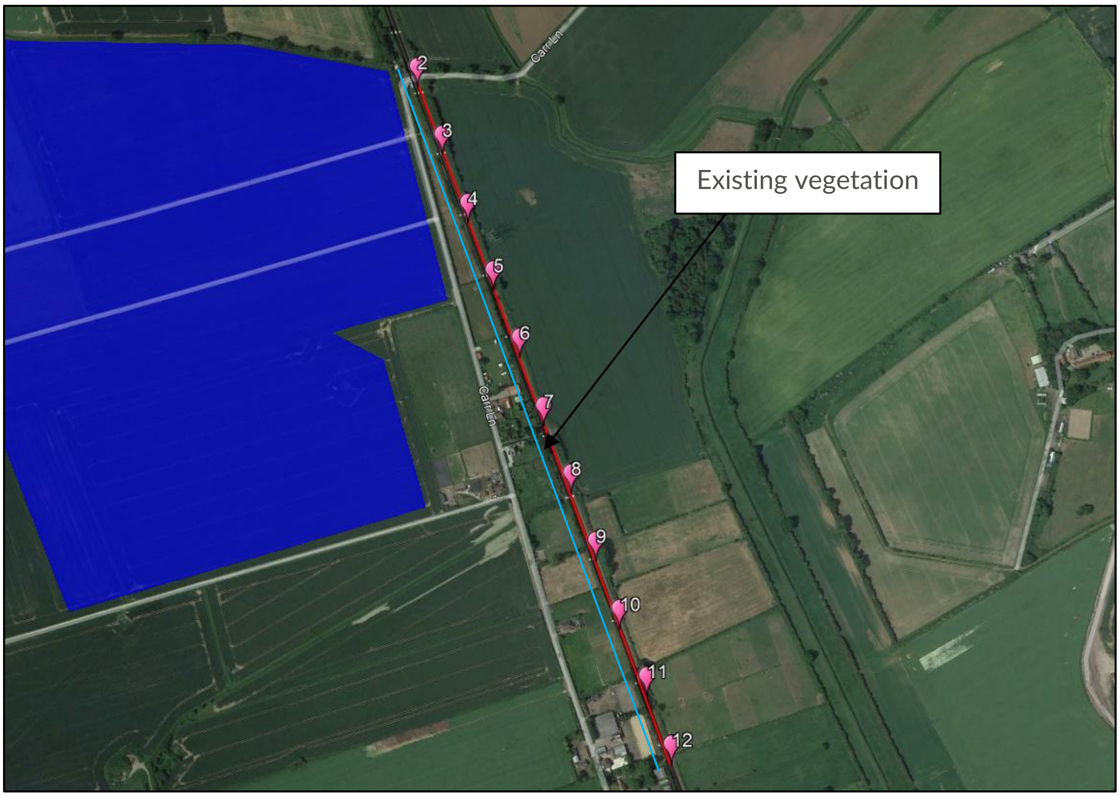

Figure 20 *Existing vegetation adjacent railway track – aerial image*

9 OVERALL CONCLUSIONS

9.1 Dwelling Receptors

The results of the analysis have shown that for eight of the 14 assessed dwellings, visibility of glare that is predicted to last for more than three months per year and less than 60 minutes per day will be removed by the existing and proposed screening. Therefore, no impact is predicted and further mitigation is not required. Where solar reflections are geometrically possible towards the remaining receptors, no further mitigation is necessary due to the maximum duration of effects being sufficiently low.

9.2 Road Receptors

The roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Assessment is not recommended for local roads as any solar reflections from the proposed development that are experienced by a road user would be considered 'low' impact in accordance with the guidance presented in Appendix D.

9.3 Aviation Receptors

Solar reflections are not geometrically possible towards the ATC tower nor the approaches for runways 02, 20, 08 and 26. No impacts upon aircraft on these runway approaches nor the ATC tower are predicted and no mitigation is required.

9.4 Train Driver Receptors

The results of the modelling indicate that solar reflections are geometrically possible towards all 12 of the assessed train driver receptors along a 1.1km section of railway track. However, solar reflections are removed by existing and proposed screening. If the screening were to be removed the impact would remain low due to the reflections occurring outside the train drivers' primary field of view (30 degrees either side of the direction of travel); therefore, mitigation is not required.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

This section presents details regarding the relevant guidance and studies with respect to the considerations and effects of solar reflections from solar panels, known as 'Glint and Glare'.

This is not a comprehensive review of the data sources, rather it is intended to give an overview of the important parameters and considerations that have informed this assessment.

UK Planning Policy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[15] (specifically regarding the consideration of solar farms, paragraph 013) states:

'What are the particular planning considerations that relate to large scale ground-mounted solar photovoltaic Farms?

The deployment of large-scale solar farms can have a negative impact on the rural environment, particularly in undulating landscapes. However, the visual impact of a well-planned and well-screened solar farm can be properly addressed within the landscape if planned sensitively.

Particular factors a local planning authority will need to consider include:

…

- *the proposal's visual impact, the effect on landscape of glint and glare (see guidance on landscape assessment) and on* ***neighbouring uses and aircraft safety****;*
- *the extent to which there may be additional impacts if solar arrays follow the daily movement of the sun;*

…

The approach to assessing cumulative landscape and visual impact of large scale solar farms is likely to be the same as assessing the impact of wind turbines. However, in the case of ground-mounted solar panels it should be noted that with effective screening and appropriate land topography the area of a zone of visual influence could be zero.'

[15] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 17/06/2020

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare are, however, provided for assessing the impact of solar reflections upon surrounding roads and dwellings. Therefore, the Pager Power approach is to determine whether a reflection from the proposed solar development is geometrically possible and then to compare the results against the relevant guidance/studies to determine whether the reflection is significant. The Pager Power approach has been informed by the policy presented above, current studies (presented in Appendix B) and stakeholder consultation. Further information can be found in Pager Power's Glint and Glare Guidance document[16] which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

Railway Assessment Guidelines

The following section provides an overview of the relevant railway guidance with respect to the siting of signals on railway lines. Network Rail is the stakeholder of the UK's railway infrastructure. Whilst the guidance is not strictly applicable in Ireland, the general principles within the guidance is expected to apply.

A railway operator's concerns would likely to relate to the following:

1. The development producing solar glare that affects train drivers; and
2. The development producing solar reflections that affect railway signals and create a risk of a phantom aspect signal.

Railway guidelines are presented below. These relate specifically to the sighting distance for railway signals.

Reflections and Glare

The extract below is taken from Section A5 – Reflections and glare (pages 64-65) of the 'Signal Sighting Assessment Requirements'[17] which details the requirement for assessing glare towards railway signals.

Reflections and glare

Rationale

Reflections can alter the appearance of a display so that it appears to be something else.

Guidance

A5 is present if direct glare or reflected light is directed into the eyes or into the lineside signalling asset that could make the asset appear to show a different aspect or indication to the one presented.

A5 is relevant to any lineside signalling asset that is capable of presenting a lit signal aspect or indication.

The extent to which excessive illumination could make an asset appear to show a different signal aspect or indication to the one being presented can be influenced by the product being used.

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[16] Solar Photovoltaic Development – Glint and Glare Guidance, Edition 3.1, April 2021. Pager Power.

[17] Source: Signal Sighting Assessment Requirements, June 2016. Railway Group Guidance Note. Last accessed 18.10.2016.

Requirements for assessing the phantom display performance of signalling products are set out in GKRT0057 section 4.1.

Problems arising from reflection and glare occur when there is a very large range of luminance, that is, where there are some objects that are far brighter than others. The following types of glare are relevant:

a) *Disability glare, caused by scattering of light in the eye, can make it difficult to read a lit display.*
b) *Discomfort glare, which is often associated with disability glare. While being unpleasant, it does not affect the signal reading time directly, but may lead to distraction and fatigue.*

Examples of the adverse effect of disability glare include:

a) *When a colour light signal presenting a lit yellow aspect is viewed at night but the driver is unable to determine whether the aspect is a single yellow or a double yellow.*
b) *Where a colour light signal is positioned beneath a platform roof painted white and the light reflecting off the roof can make the signal difficult to read.*

Options for militating against A5 include:

a) *Using a product that is specified to achieve high light source: phantom ratio values.*
b) *Alteration to the features causing the glare or reflection.*
c) *Provision of screening.*

Glare is possible and should be assessed when the luminance is much brighter than other light sources. Glare may be unpleasant and therefore cause distraction and fatigue, or may make the signal difficult to read and increase the reading time.

Determining the Field of Focus

The extract below is taken from Appendix F - Guidance on Field of Vision (pages 98-101) of the 'Signal Sighting Assessment Requirements'18 which details the visibility of signals, train drivers' field of vision and the implications with regard to signal positioning.

Asset visibility

The effectiveness of an observer's visual system in detecting the existence of a target asset will depend upon its:

a) *Position in the observer's visual field.*
b) *Contrast with its background.*
c) *Luminance properties.*
d) *The observer's adaptation to the illumination level of the environment.*

It is also influenced by the processes relating to colour vision, visual accommodation, and visual acuity. Each of these issues is described in the following sections.

[18] Source: Signal Sighting Assessment Requirements, June 2016. Railway Group Guidance Note. Last accessed 28.08.2020.

Field of vision

The field of vision, or visual field, is the area of the visual environment that is registered by the eyes when both eyes and head are held still. The normal extent of the visual field is approximately 135o in the vertical plane and 200o in the horizontal plane.

The visual field is usually described in terms of central and peripheral regions: the central field being the area that provides detailed information. This extends from the central point (0^{o}) to approximately 30^{o} at each eye. The peripheral field extends from 30o out to the edge of the visual field.

F.6.3 Objects positioned towards the centre of the observer's field of vision are seen more quickly and identified more accurately because this is where our sensitivity to contrast is the highest. Peripheral vision is particularly sensitive to movement and light.

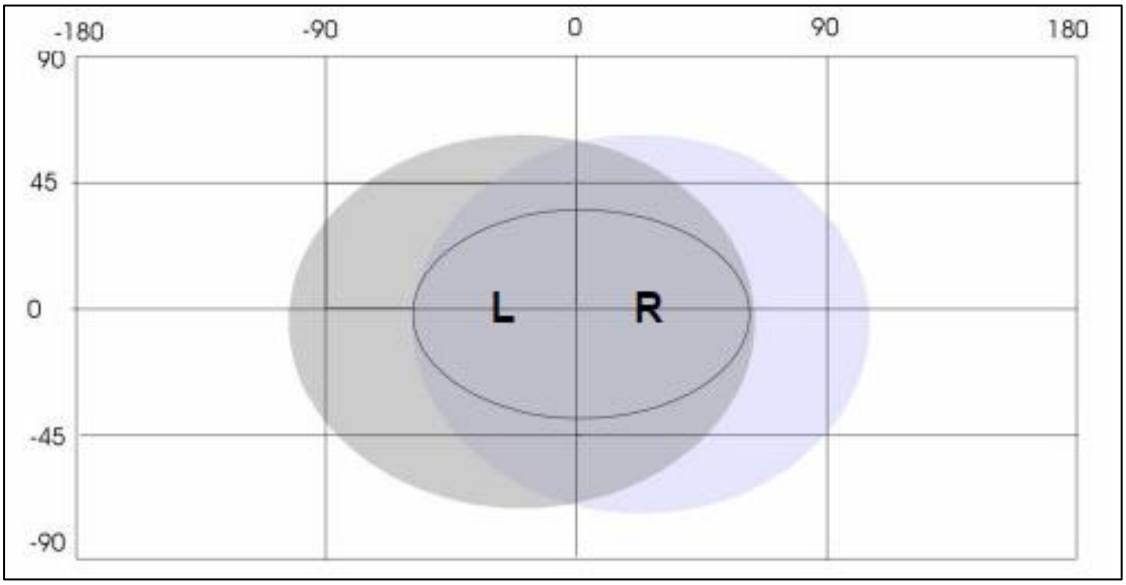

Figure G 21 - Field of view

In Figure G 21, the two shaded regions represent the view from the left eye (L) and the right eye (R) respectively. The darker shaded region represents the region of binocular overlap. The oval in the centre represents the central field of vision.

Research has shown that drivers search for signs or signals towards the centre of the field of vision. Signals, indicators and signs should be positioned at a height and distance from the running line that permits them to be viewed towards the centre of the field of vision. This is because:

a) As train speed increases, drivers become increasingly dependent on central vision for asset detection. At high speeds, drivers demonstrate a tunnel vision effect and focus only on objects in a field of + 8^{o} from the direction of travel.

b) Sensitivity to movement in the peripheral field, even minor distractions can reduce the visibility of the asset if it is viewed towards the peripheral field of vision. The presence of clutter to the sides of the running line can be highly distracting (for example, fence posts, lamp-posts, traffic, or non-signal lights, such as house, compatibility factors or security lights).

Figure G 22 and Table G 5 identify the radius of an 8o cone at a range of close-up viewing distances from the driver's eye. This shows that, depending on the lateral position of a stop signal, the optimal *(normal) train stopping point could be as far as 25 m back from the signal to ensure that it is sufficiently prominent.*

The dimensions quoted in Table G 5 assume that the driver is looking straight ahead. Where driver-only operation (DOO) applies, the drivers' line of sight at the time of starting the train is influenced by the location of DOO monitors and mirrors. In this case it may be appropriate to provide supplementary information alongside the monitors or mirrors using one of the following:

- *a) A co-acting signal.*
- *b) A miniature banner repeater indicator.*
- *c) A right away indicator.*
- *d) A sign to remind the driver to check the signal aspect.*

In order to prevent misreading by trains on adjacent lines, the co-acting signal or miniature banner repeater may be configured so that the aspect or indication is presented only when a train is at the platform to which it applies.

'Car stop' signs should be positioned so that the relevant platform starting signals and / or indicators can be seen in the driver's central field of vision.

If possible, clutter and non-signal lights in a driver's field of view should be screened off or removed so that they do not cause distraction.

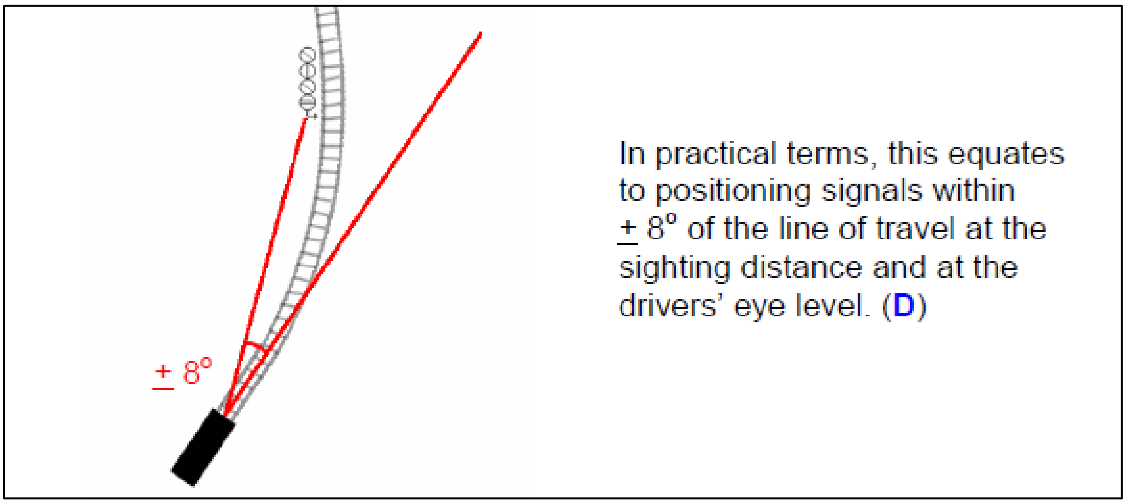

Figure G 22 - Signal positioning

'A' (m)	'B' (m)	Typical display positions
5	*0.70*	-
6	*0.84*	-
7	*0.98*	-
8	*1.12*	-
9	*1.26*	-
10	*1.41*	-
11	*1.55*	-
12	*1.69*	-
13	*1.83*	-
14	*1.97*	-
15	*2.11*	*A stop aspect positioned 3.3 m above rail level and 2.1 m from the left hand rail is within the 8° cone at 15.44 m in front of the driver*
16	*2.25*	-
17	*2.39*	-
18	*2.53*	*A stop aspect positioned 5.1 m above rail level and 0.9 m from the left hand rail is within the 8° cone at 17.93 m in front of the driver*
19	*2.67*	-
20	*2.81*	-
21	*2.95*	-
22	*3.09*	-
23	*3.23*	-
24	*3.37*	-
25	*3.51*	*A stop aspect positioned 3.3 m above rail level and 2.1 m from the right hand rail is within the 8° cone at 25.46 m in front of the driver*

Table G 5 – 8° cone angle co-ordinates for close-up viewing

The distance at which the 8° cone along the track is initiated is dependent on the minimum reading time and distance which is associated to the speed of trains along the track. This is discussed below.

Determining the Assessed Minimum Reading Time

The extract below is taken from section B5 (pages 8-9) of the 'Guidance on Signal Positioning and Visibility' which details the required minimum reading time for a train driver when approaching a signal.

'B5.2.2 Determining the assessed minimum reading time

GE/RT8037

The assessed minimum reading time shall be no less than eight seconds travelling time before the signal.

The assessed minimum reading time shall be greater than eight seconds where there is an increased likelihood of misread or failure to observe. Circumstances where this applies include, but are not necessarily limited to, the following:

a) the time taken to identify the signal is longer (for example, because the signal being viewed is one of a number of signals on a gantry, or because the signal is viewed against a complex background)

b) the time taken to interpret the information presented by the signal is longer (for example, because the signal is capable of presenting route information for a complex layout ahead)

c) there is a risk that the need to perform other duties could cause distraction from viewing the signal correctly (for example, the observance of lineside signs, a station stop between the caution and stop signals, or DOO (P) duties)

d) the control of the train speed is influenced by other factors (for example, anticipation of the signal aspect changing).

The assessed minimum reading time shall be determined using a structured format approved by the infrastructure controller.'

The distance at which a signal should be clearly viewable is determined by the maximum speed of the trains along the track. If there are multiple signals present at a location then an additional 0.2 seconds reading time is added to the overall viewing time.

Signal Design and Lighting System

Many railway signals are now LED lights and not filament (incandescent) bulbs. The benefits of an LED signal over a filament bulb signal with respect to possible phantom aspect illuminations are as follows:

- An LED railway signal produces a more intense light making them more visible to approaching trains when compared to the traditional filament bulb technology[19];
- No reflective mirror is present within the LED signal itself unlike a filament bulb. The presence of the reflective surfaces greatly increases the likelihood of incoming light being reflecting out making the signal appear illuminated.

[19] Source: Wayside LED Signals – Why it's Harder than it Looks, Bill Petit.

Many LED signal manufacturers[20,21,22] claim that LED signal lights significantly reduce or completely remove the likelihood of a phantom aspect illumination occurring.

Aviation Assessment Guidance

The UK Civil Aviation Authority (CAA) issued interim guidance relating to Solar Photovoltaic Systems (SPV) on 17 December 2010 and was subject to a CAA information alert 2010/53. The formal policy was cancelled on September 7th, 2012[23] however the advice is still applicable[24] until a formal policy is developed. The relevant aviation guidance from the CAA is presented in the section below.

CAA Interim Guidance

This interim guidance makes the following recommendations (p.2-3):

'8. It is recommended that, as part of a planning application, the SPV developer provide safety assurance documentation (including risk assessment) regarding the full potential impact of the SPV installation on aviation interests.

9. Guidance on safeguarding procedures at CAA licensed aerodromes is published within CAP 738 Safeguarding of Aerodromes and advice for unlicensed aerodromes is contained within CAP 793 Safe Operating Practices at Unlicensed Aerodromes.

10. Where proposed developments in the vicinity of aerodromes require an application for planning permission the relevant LPA normally consults aerodrome operators or NATS when aeronautical interests might be affected. This consultation procedure is a statutory obligation in the case of certain major airports, and may include military establishments and certain air traffic surveillance technical sites. These arrangements are explained in Department for Transport Circular 1/2003 and for Scotland, Scottish Government Circular 2/2003.

11. In the event of SPV developments proposed under the Electricity Act, the relevant government department should routinely consult with the CAA. There is therefore no requirement for the CAA to be separately consulted for such proposed SPV installations or developments.

12. If an installation of SPV systems is planned on-aerodrome (i.e. within its licensed boundary) then it is recommended that data on the reflectivity of the solar panel material should be included in any assessment before installation approval can be granted. Although approval for installation is the responsibility of the ALH[25], as part of a condition of a CAA Aerodrome Licence, the ALH is required to obtain prior consent from CAA Aerodrome Standards Department before any work is begun or approval to the developer or LPA is granted, in accordance with the procedures set out in CAP 791 Procedures for Changes to Aerodrome Infrastructure.

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[20] Source: http://www.unipartdorman.co.uk/assets/unipart_dorman_rail_brochure.pdf. (Last accessed 21.02.18).
[21] Source: http://www.vmstech.co.uk/downloads/Rail.pdf. (Last accessed 21.02.18).
[22] Source: Siemens, Sigmaguard LED Tri-Colour L Signal – LED Signal Technology at Incandescent Prices. Datasheet 1A-23. (Last accessed 22.02.18).
[23] Archived at Pager Power
[24] Reference email from the CAA dated 19/05/2014.
[25] Aerodrome Licence Holder.

13. During the installation and associated construction of SPV systems there may also be a need to liaise with nearby aerodromes if cranes are to be used; CAA notification and permission is not required.

14. The CAA aims to replace this informal guidance with formal policy in due course and reserves the right to cancel, amend or alter the guidance provided in this document at its discretion upon receipt of new information.

15. Further guidance may be obtained from CAA's Aerodrome Standards Department via aerodromes@caa.co.uk.'

FAA Guidance

The most comprehensive guidelines available for the assessment of solar developments near aerodromes were produced initially in November 2010 by the United States Federal Aviation Administration (FAA) and updated in 2013.

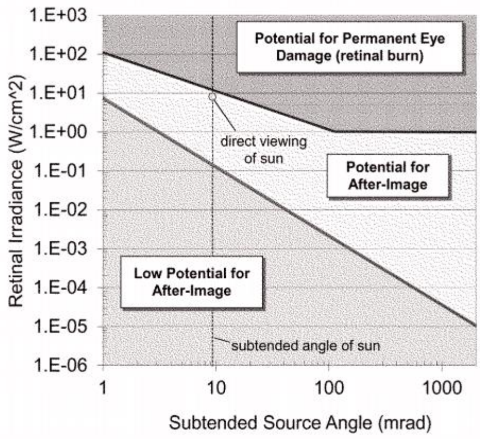
The 2010 document is entitled '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[26] and the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'*[27]. In April 2018 the FAA released a new version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[28].

An overview of the methodology presented within the 2013 interim guidance and adopted by the FAA is presented below. This methodology is not presented within the 2018 guidance.

- *Solar energy systems located on an airport that is not federally-obligated or located outside the property of a federally-obligated airport are not subject to this policy.*
- *Proponents of solar energy systems located off-airport property or on non-federally-obligated airports are strongly encouraged to consider the requirements of this policy when siting such system.*
- *FAA adopts the Solar Glare Hazard Analysis Plot…. as the standard for measuring the ocular impact of any proposed solar energy system on a federally-obligated airport. This is shown in the figure below.*

[26] Archived at Pager Power
[27] Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports, Department of Transportation, Federal Aviation Administration (FAA), date: 10/2013, accessed on: 20/03/2019
[28] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019

Figure 1



Solar Glare Ocular Hazard Plot: The potential ocular hazard from solar glare is a function of retinal irradiance and the subtended angle (size/distance) of the glare source. It should be noted that the ratio of spectrally weighted solar illuminance to solar irradiance at the earth's surface yields a conversion factor of ~100 lumens/W. Plot adapted from Ho et al., 2011.

Chart References: Ho, C.K., C.M. Ghanbari, and R.B. Diver, 2011, Methodology to Assess Potential Glint and Glare Hazards from Concentrating Solar Power Plants: Analytical Models and Experimental Validation, J. Solar Energy Engineering, August 2011, Vol. 133, 031021-1 – 031021-9.

Solar Glare Hazard Analysis Plot (FAA)

- *To obtain FAA approval to revise an airport layout plan to depict a solar installation and/or a "no objection" … the airport sponsor will be required to demonstrate that the proposed solar energy system meets the following standards:*
- *No potential for glint or glare in the existing or planned Airport Traffic Control Tower (ATC) cab, and*
- *No potential for glare or "low potential for after-image" … along the final approach path for any existing landing threshold or future landing thresholds (including any planned interim phases of the landing thresholds) as shown on the current FAA-approved Airport Layout Plan (ALP). The final approach path is defined as two (2) miles from fifty (50) feet above the landing threshold using a standard three (3) degree glidepath.*
- *Ocular impact must be analysed over the entire calendar year in one (1) minute intervals from when the sun rises above the horizon until the sun sets below the horizon.*

The bullets highlighted above state there should be 'no potential for glare' at that ATC Tower and 'no' or 'low potential for glare' on the approach paths.
Key points from the 2018 FAA guidance are presented below.

- *Reflectivity refers to light that is reflected off surfaces. The potential effects of reflectivity are glint (a momentary flash of bright light) and glare (a continuous source of bright light). These two effects are referred to hereinafter as "glare," which can cause a brief loss of vision, also known as flash blindness[29].*

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[29] Flash Blindness, as described in the FAA guidelines, can be described as a temporary visual interference effect that persists after the source of illumination has ceased. This occurs from many reflective materials in the ambient environment.

- *The amount of light reflected off a solar panel surface depends on the amount of sunlight hitting the surface, its surface reflectivity, geographic location, time of year, cloud cover, and solar panel orientation.*
- *As illustrated on Figure 16*[30]*, flat, smooth surfaces reflect a more concentrated amount of sunlight back to the receiver, which is referred to as specular reflection. The more a surface is polished, the more it shines. Rough or uneven surfaces reflect light in a diffused or scattered manner and, therefore, the light will not be received as bright.*
- *Because the FAA has no specific standards for airport solar facilities and potential glare, the type of glare analysis may vary. Depending on site specifics (e.g., existing land uses, location and size of the project) an acceptable evaluation could involve one or more of the following levels of assessment:*
    - *A qualitative analysis of potential impact in consultation with the Control Tower, pilots and airport officials;*
    - *A demonstration field test with solar panels at the proposed site in coordination with FAA Tower personnel;*
    - *A geometric analysis to determine days and times when an impact is predicted.*
- *The extent of reflectivity analysis required to assess potential impacts will depend on the specific project site and system design.*
- ***1. Assessing Baseline Reflectivity Conditions** – Reflection in the form of glare is present in current aviation operations. The existing sources of glare come from glass windows, auto surface parking, rooftops, and water bodies. At airports, existing reflecting surfaces may include hangar roofs, surface parking, and glassy office buildings. To minimize unexpected glare, windows of air traffic control towers and airplane cockpits are coated with anti-reflective glazing. Operators also wear polarized eye wear. Potential glare from solar panels should be viewed in this context. Any airport considering a solar PV project should first review existing sources of glare at the airport and the effectiveness of measures used to mitigate that glare.*
- ***2. Tests in the Field** – Potential glare from solar panels can easily be viewed at the airport through a field test. A few airports have coordinated these tests with FAA Air Traffic Controllers to assess the significance of glare impacts. To conduct such a test, a sponsor can take a solar panel out to proposed location of the solar project, and tilt the panel in different directions to evaluate the potential for glare onto the air traffic control tower. For the two known cases where a field test was conducted, tower personnel determined the glare was not significant. If there is a significant glare impact, the project can be modified by ensuring panels are not directed in that direction.*
- ***3. Geometric Analysis** – Geometric studies are the most technical approach for reflectivity issues. They are conducted when glare is difficult to assess through other methods. Studies of glare can employ geometry and the known path of the sun to predict when sunlight will reflect off of a fixed surface (like a solar panel) and contact a fixed receptor (e.g., control*

[30] First figure in Appendix B.

tower). At any given site, the sun moves across the sky every day and its path in the sky changes throughout year. This in turn alters the destination of the resultant reflections since the angle of reflection for the solar panels will be the same as the angle at which the sun hits the panels. The larger the reflective surface, the greater the likelihood of glare impacts.

- *Facilities placed in remote locations, like the desert, will be far from receptors and therefore potential impacts are limited to passing aircraft. Because the intensity of the light reflected from the solar panel decreases with increasing distance, an appropriate question is how far you need to be from a solar reflected surface to avoid flash blindness. It is known that this distance is directly proportional to the size of the array in question*31 *but still requires further research to definitively answer.*
- ***Experiences of Existing Airport Solar Projects** – Solar installations are presently operating at a number of airports, including megawatt-sized solar facilities covering multiple acres. Air traffic control towers have expressed concern about glint and glare from a small number of solar installations. These were often instances when solar installations were sited between the tower and airfield, or for installations with inadequate or no reflectivity analysis. Adequate reflectivity analysis and alternative siting addressed initial issues at those installations.*

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[31] Ho, Clifford, Cheryl Ghanbari, and Richard Diver. 2009. Hazard Analysis of Glint and Glare From Concentrating Solar Power Plants. SolarPACES 2009, Berlin Germany. Sandia National Laboratories.

Air Navigation Order (ANO) 2009

In some instances, an aviation stakeholder can refer to the ANO 2009 with regard to safeguarding. Key points from the document are presented below.

Endangering safety of an aircraft

137. A person must not recklessly or negligently act in a manner likely to endanger an aircraft, or any person in an aircraft.

Lights liable to endanger

221.

(1) A person must not exhibit in the United Kingdom any light which—

(a) by reason of its glare is liable to endanger aircraft taking off from or landing at an aerodrome; or

(b) by reason of its liability to be mistaken for an aeronautical ground light is liable to endanger aircraft.

(2) If any light which appears to the CAA to be a light described in paragraph (1) is exhibited, the CAA may direct the person who is the occupier of the place where the light is exhibited or who has charge of the light, to take such steps within a reasonable time as are specified in the direction—

(a) to extinguish or screen the light; and

(b) to prevent in the future the exhibition of any other light which may similarly endanger aircraft.

(3) The direction may be served either personally or by post, or by affixing it in some conspicuous place near to the light to which it relates.

(4) In the case of a light which is or may be visible from any waters within the area of a general lighthouse authority, the power of the CAA under this article must not be exercised except with the consent of that authority.

Lights which dazzle or distract

222. A person must not in the United Kingdom direct or shine any light at any aircraft in flight so as to dazzle or distract the pilot of the aircraft.'

The document states that no 'light', 'dazzle' or 'glare' should be produced which will create a detrimental impact upon aircraft safety.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

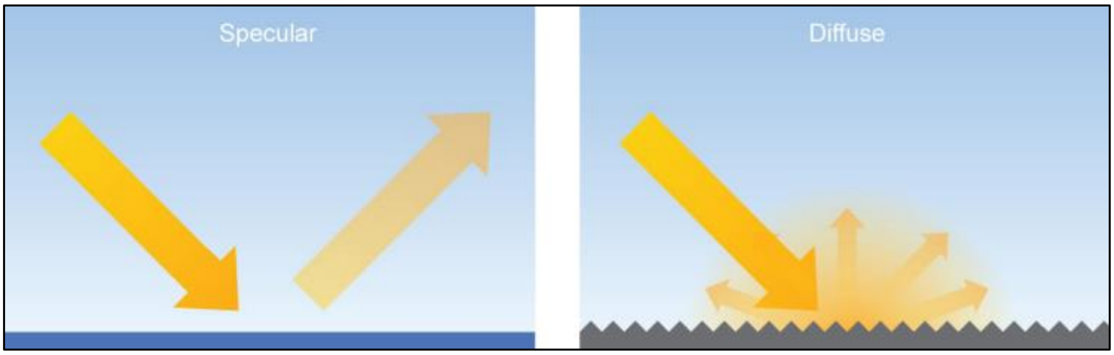
Overview

Studies have been undertaken assessing the type and intensity of solar reflections from various surfaces including solar panels and glass. An overview of these studies is presented below.

The guidelines presented are related to aviation safety. The results are applicable for the purpose of this analysis.

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance[32], illustrates the difference between the two types of reflections. Because solar panels are flat and have a smooth surface most of the light reflected is specular, which means that incident light from a specific direction is reradiated in a specific direction.



Specular and diffuse reflections

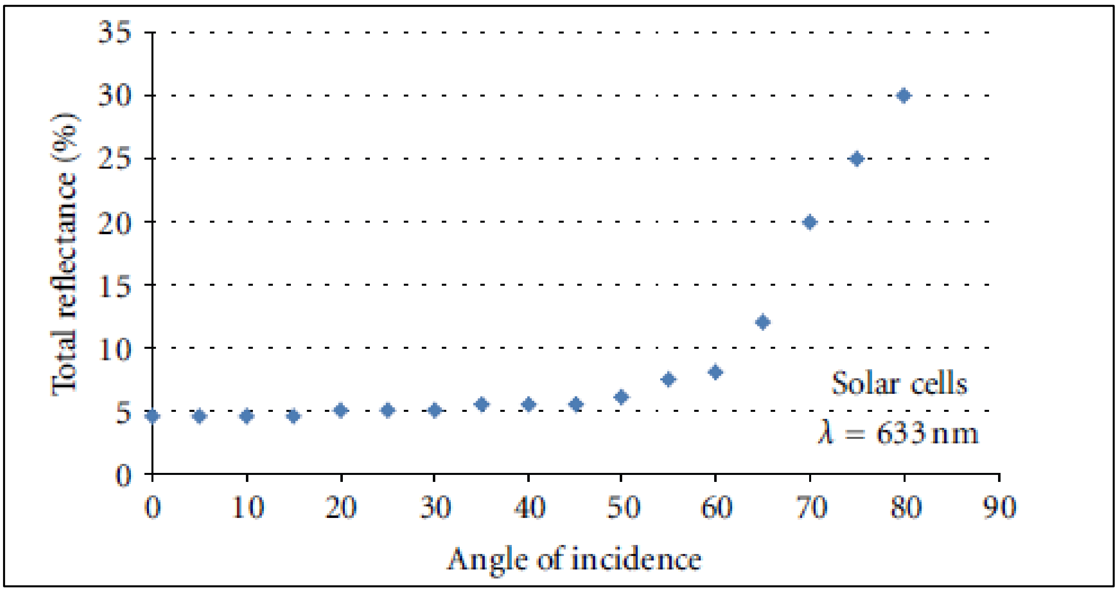
[32] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

Solar Reflection Studies

An overview of content from identified solar panel reflectivity studies is presented in the subsections below.

Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems"

Evan Riley and Scott Olson published in 2011 their study titled: *A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems*[33]". They researched the potential glare that a pilot could experience from a 25 degree fixed tilt PV system located outside of Las Vegas, Nevada. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image caused by smooth water. The study demonstrated that the reflectance of the solar cell varied with angle of incidence, with maximum values occurring at angles close to 90 degrees. The reflectance values varied from approximately 5% to 30%. This is shown on the figure below.



Total reflectance % when compared to angle of incidence

The conclusions of the research study were:

- The potential for hazardous glare from flat-plate PV systems is similar to that of smooth water;
- Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have a reflectivity greater than water and flat plate PV modules.

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33 Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems," ISRN Renewable Energy, vol. 2011, Article ID 651857, 6 pages, 2011. doi:10.5402/2011/651857

FAA Guidance – "Technical Guidance for Evaluating Selected Solar Technologies on Airports"[34]

The 2010 FAA Guidance included a diagram which illustrates the relative reflectance of solar panels compared to other surfaces. The figure shows the relative reflectance of solar panels compared to other surfaces. Surfaces in this figure produce reflections which are specular and diffuse. A specular reflection (those made by most solar panels) has a reflection characteristic similar to that of a mirror. A diffuse reflection will reflect the incoming light and scatter it in many directions. A table of reflectivity values, sourced from the figure within the FAA guidance, is presented below.

Surface	Approximate Percentage of Light Reflected[35]
Snow	80
White Concrete	77
Bare Aluminium	74
Vegetation	50
Bare Soil	30
Wood Shingle	17
Water	5
Solar Panels	5
Black Asphalt	2

Relative reflectivity of various surfaces

Note that the data above does not appear to consider the reflection type (specular or diffuse).

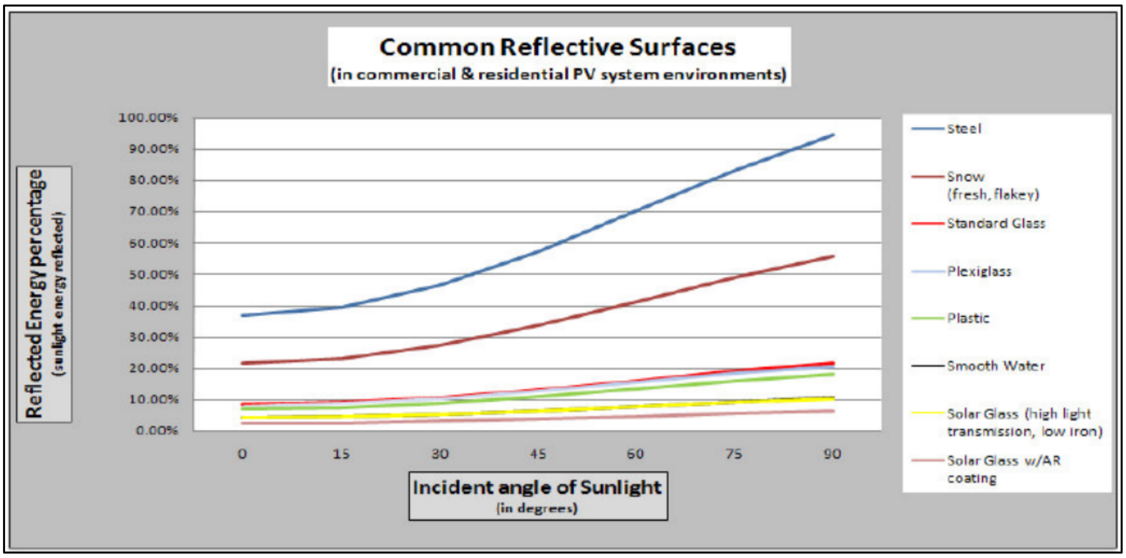
An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

[34] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.
[35] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[36] to '*increase awareness concerning the possible glare and reflectance impact of PV Systems on their surrounding environment*'.

The figure presented below shows the relative reflectivity of solar panels compared to other natural and manmade materials including smooth water, standard glass and steel.



Common reflective surfaces

The results, similarly to those from Riley and Olsen study (2011) and the FAA (2010), show that solar panels produce a reflection that is less intense than those of '*standard glass and other common reflective surfaces*'.

With respect to aviation and solar reflections observed from the air, SunPower has developed several large installations near airports or on Air Force bases. It is stated that these developments have all passed FAA or Air Force standards with all developments considered "No Hazard to Air Navigation". The note suggests that developers discuss any possible concerns with stakeholders near proposed solar farms.

[36] Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

The Sun's position in the sky can be accurately described by its azimuth and elevation. Azimuth is a direction relative to true north (horizontal angle i.e. from left to right) and elevation describes the Sun's angle relative to the horizon (vertical angle i.e. up and down).

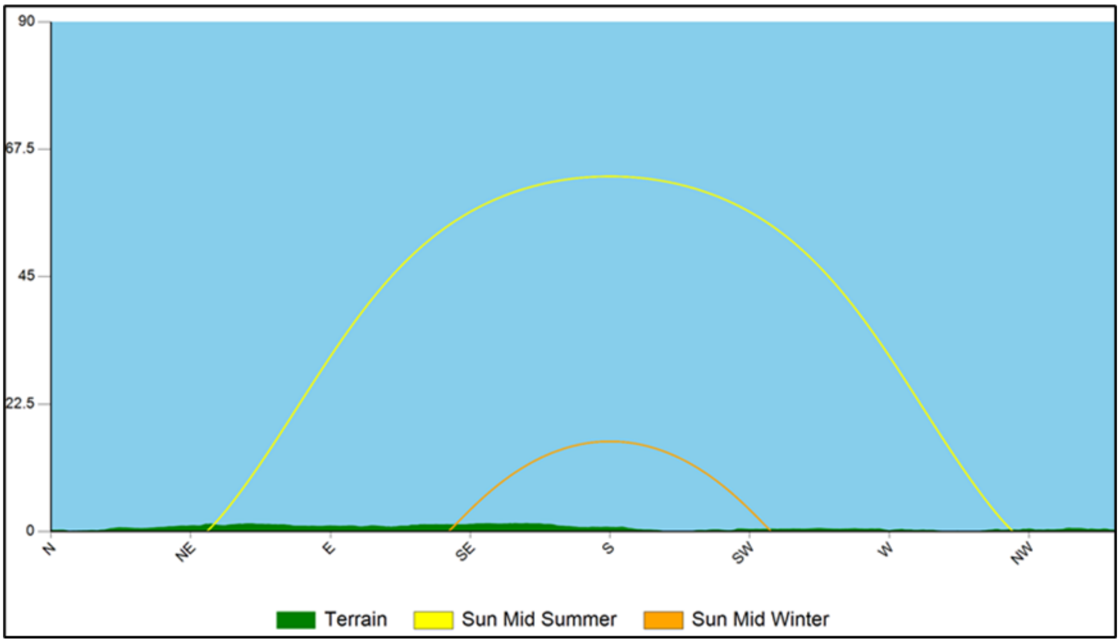
The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

- Time.
- Date.
- Latitude.
- Longitude.

The following is true at the location of the solar development:

- The Sun is at its highest around midday and is to the south at this time.
- The Sun rises highest on 21 June (longest day).
- On 21 December, the maximum elevation reached by the Sun is at its lowest (shortest day).

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector. The figure below shows terrain at the horizon as well as the sunrise and sunset curves throughout the year. This is based on the location longitude: - 0.32076 and latitude: 53.639869.



Terrain at the visible horizon and Sun paths

APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

The significance of glint and glare will vary for different receptors. The following section presents a general overview of the significance criteria with respect to experiencing a solar reflection.

Impact Significance Definition

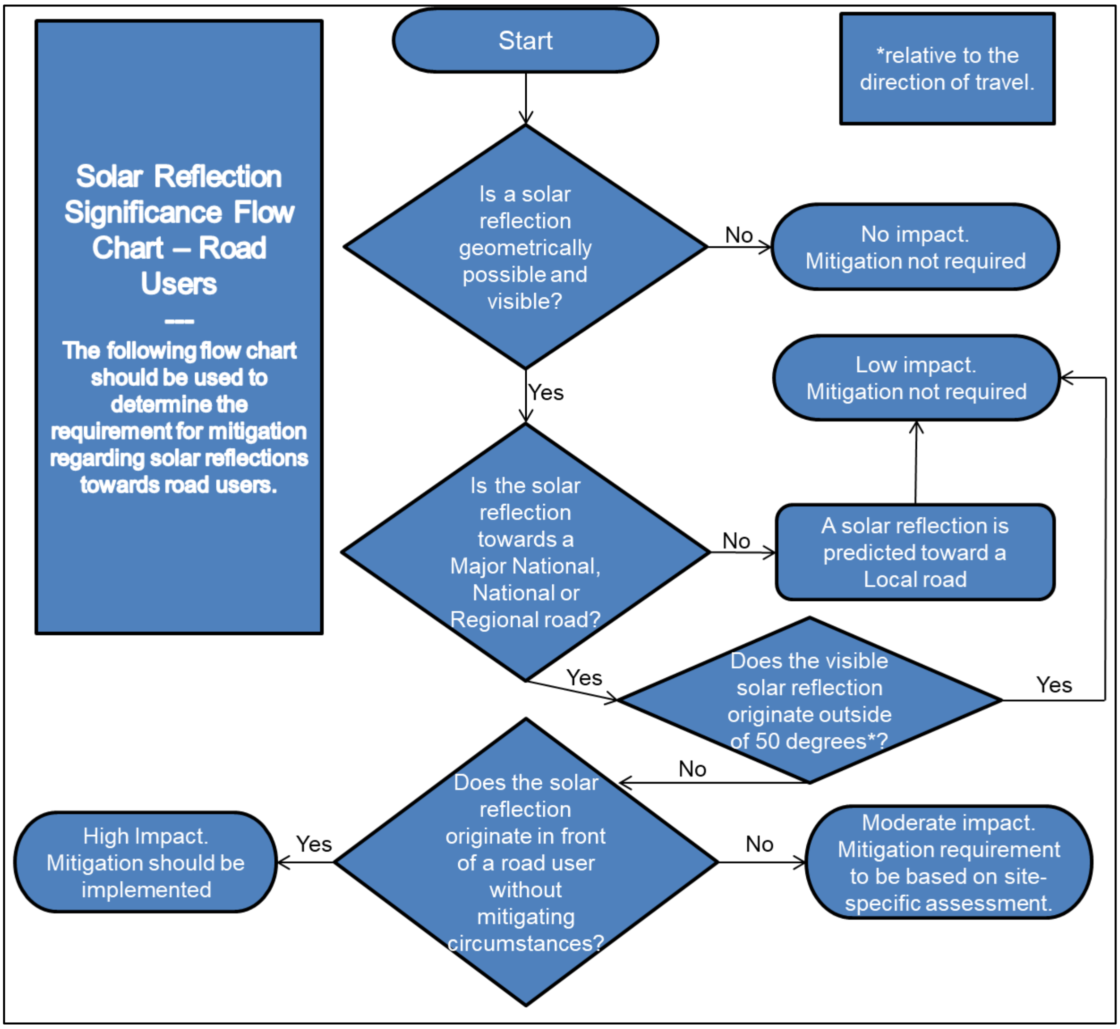
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation.
Major	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation and consultation is recommended.	Mitigation will be required if the proposed solar development is to proceed.

Impact significance definition

Assessment Process for Road Receptors

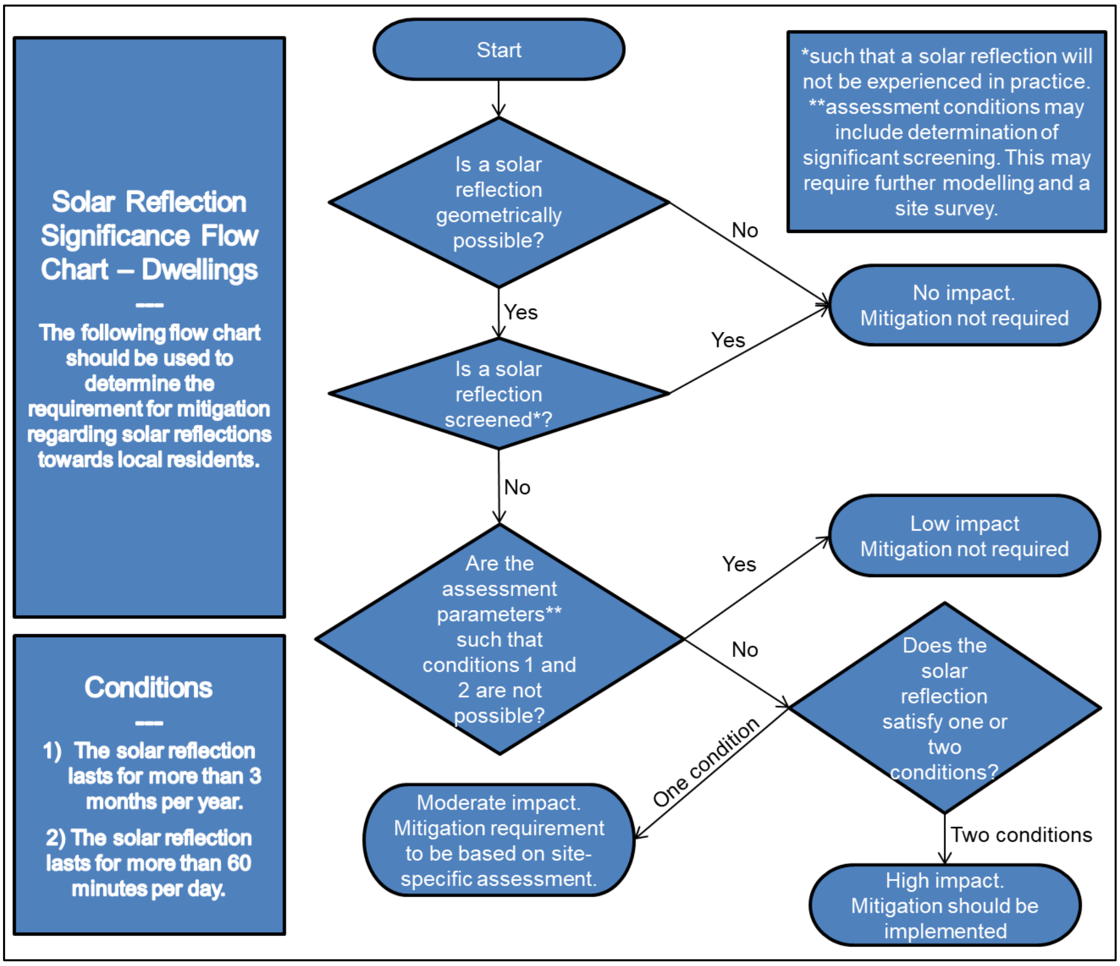
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Assessment Process for Dwelling Receptors

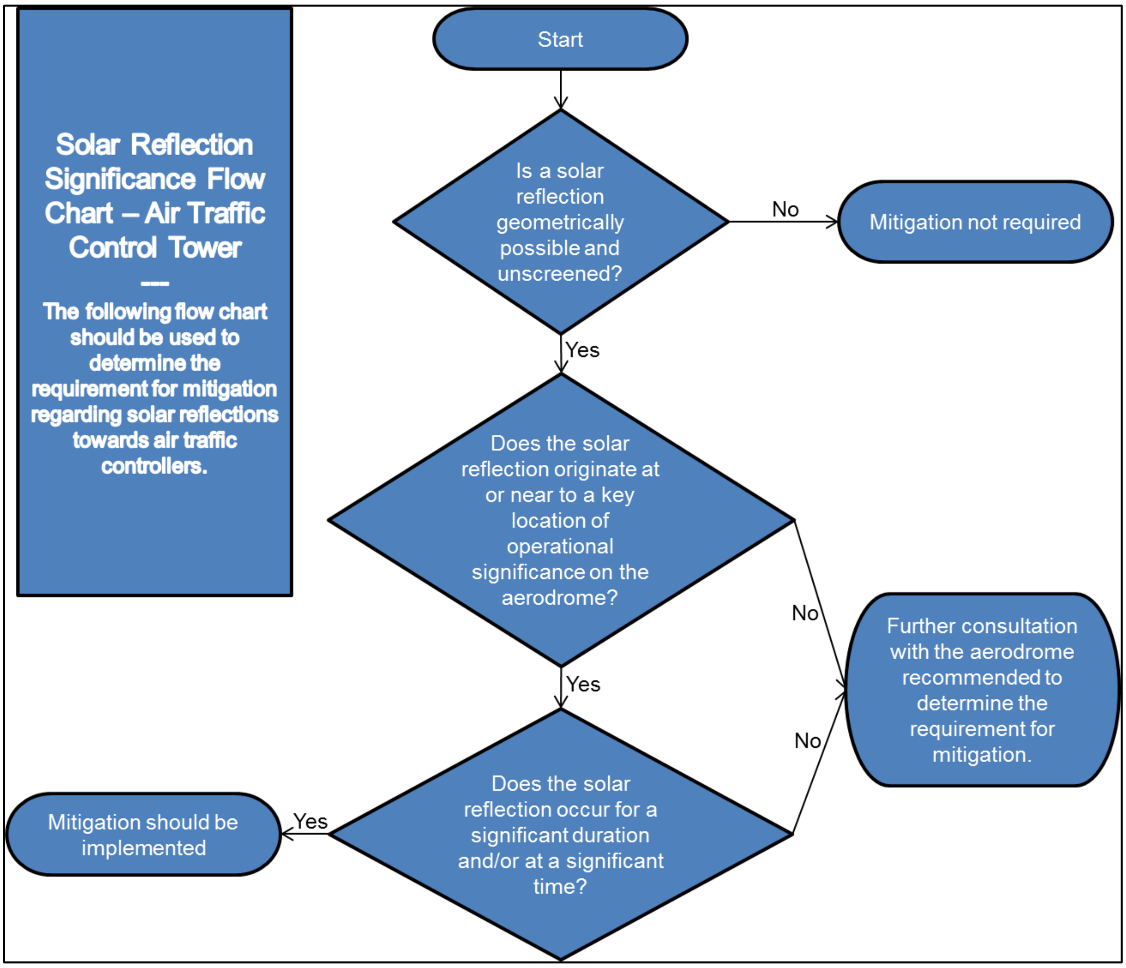
The flow chart presented below has been followed when determining the mitigation requirement for dwelling receptors.



Dwelling receptor mitigation requirement flow chart

Assessment Process – ATC Tower

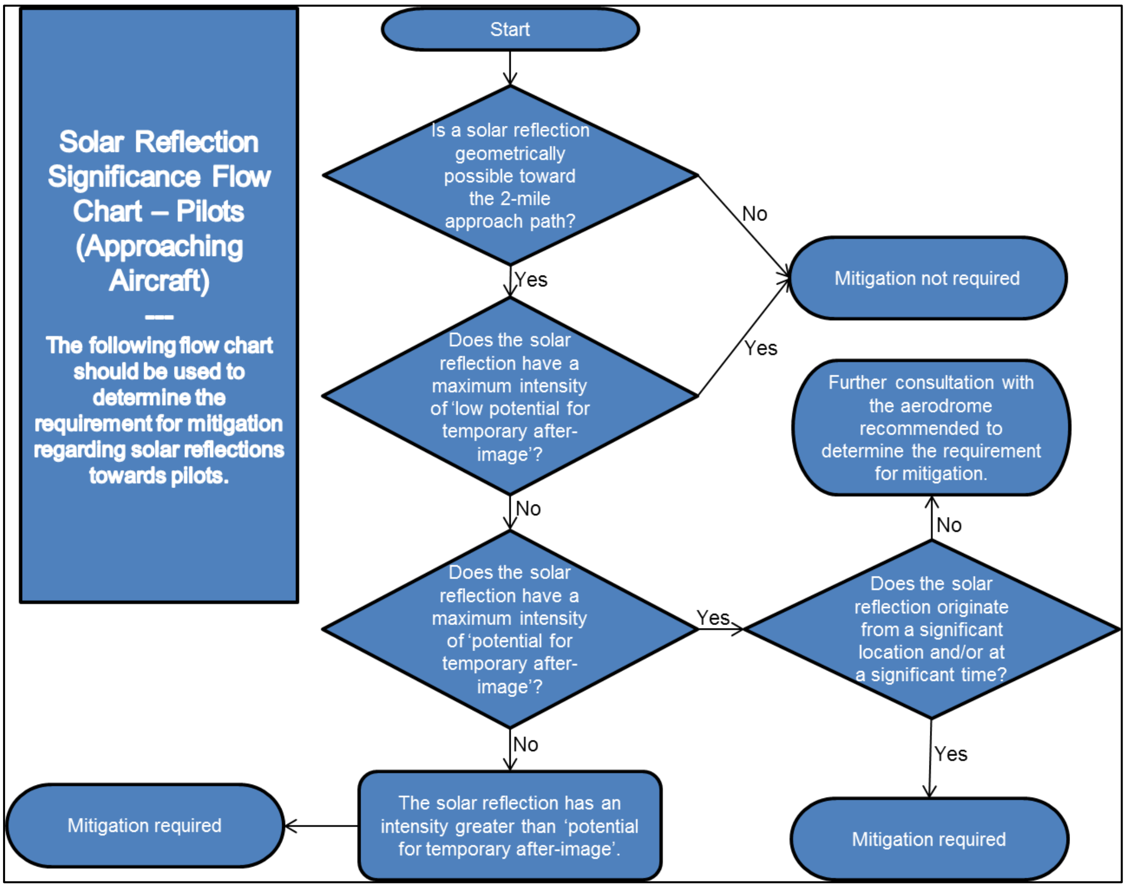
The charts relate to the determining the potential impact upon the ATC Tower.



ATC Tower mitigation requirement flow chart

Assessment Process – Approaching Aircraft

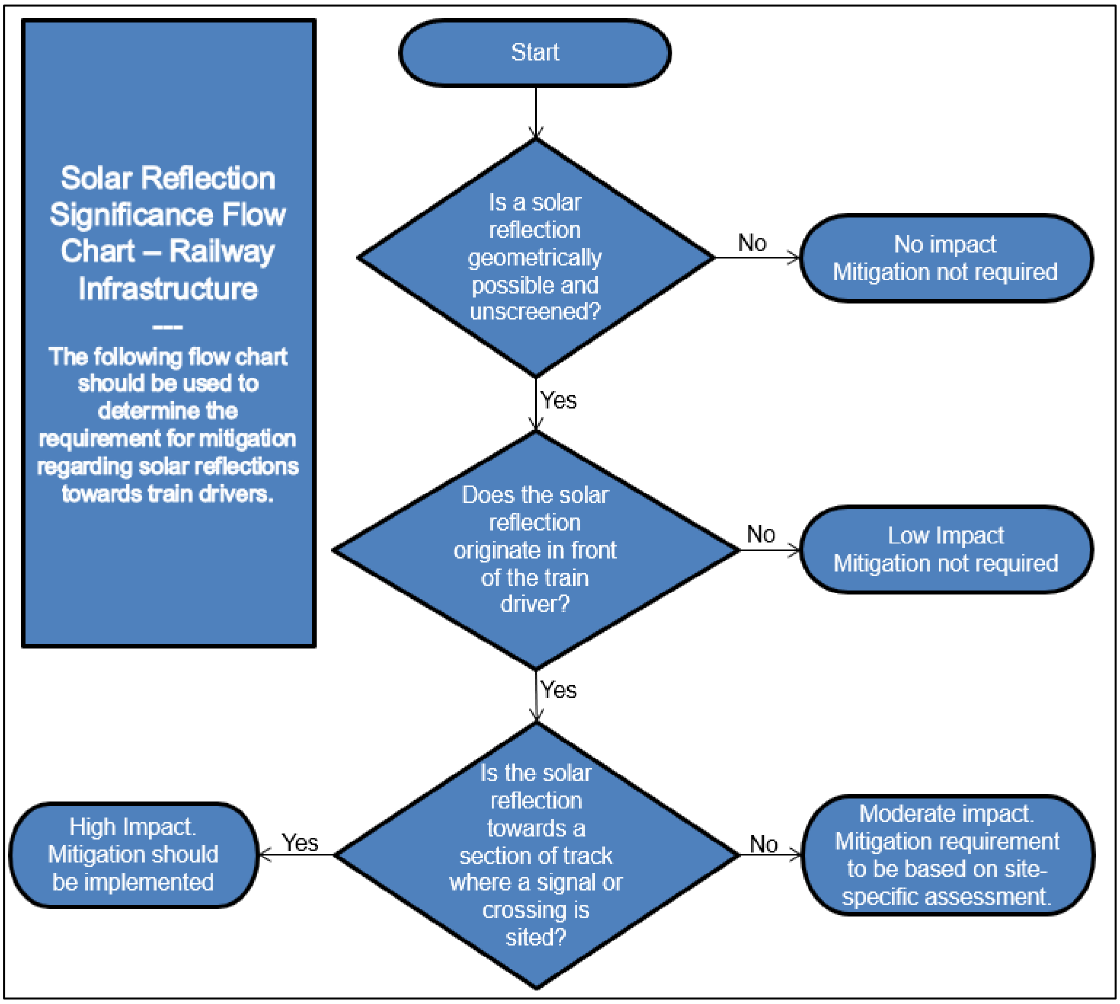
The charts relate to the determining the potential impact upon approaching aircraft.



Approaching aircraft receptor mitigation requirement flow chart

Assessment Process for Railway Receptors

The flow chart presented below has been followed when determining the mitigation requirement for railway receptors.



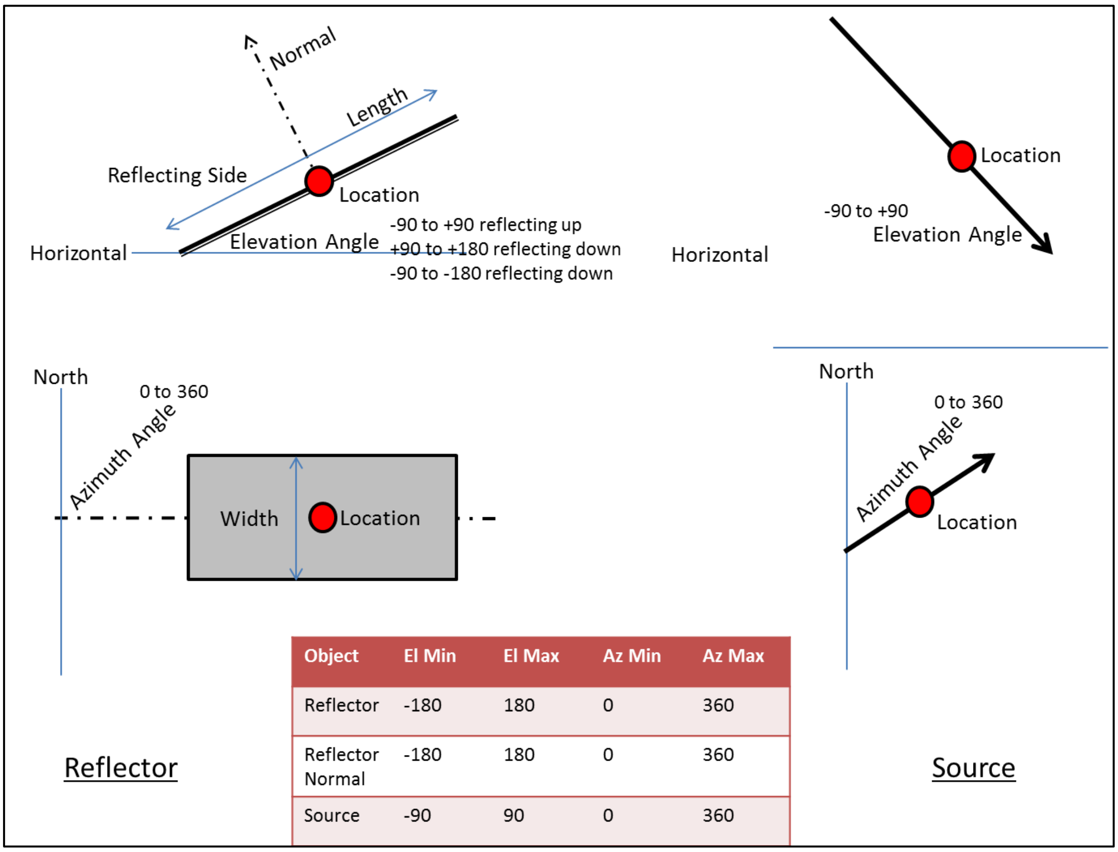
Train driver impact significance flow chart

APPENDIX E – PAGER POWER'S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

- The Earth's orbit around the Sun;
- The Earth's rotation;
- The Earth's orientation;
- The reflector's location;
- The reflector's 3D Orientation.

Reflections from a flat reflector are calculated by considering the normal which is an imaginary line that is perpendicular to the reflective surface and originates from it. The diagram below may be used to aid understanding of the reflection calculation process.



Object	El Min	El Max	Az Min	Az Max
Reflector	-180	180	0	360
Reflector Normal	-180	180	0	360
Source	-90	90	0	360

The following process is used to determine the 3D Azimuth and Elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;

- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
  - The angle between source and normal is equal to angle between normal and reflection;
  - Source, Normal and Reflection are in the same plane.

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

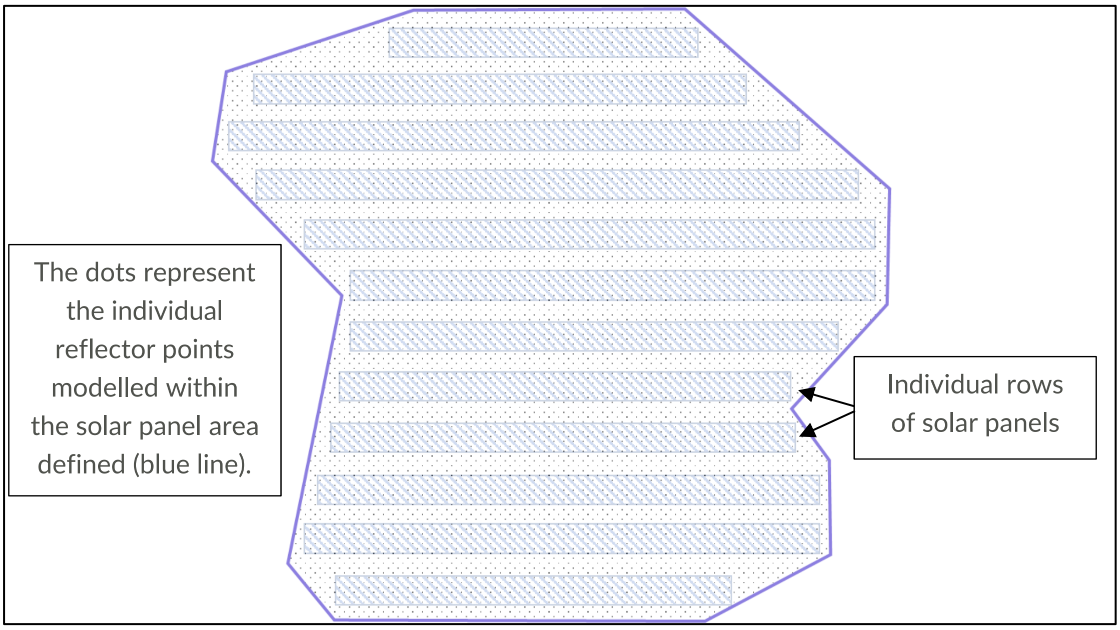
It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within each solar panel area defined.

It is assumed that the panel azimuth angle provided by the developer represents the azimuth angle for all of the panels within each solar panel area defined.

Only a reflection from the face of the panel has been considered. The frame or the reverse or frame of the solar panel has not been considered.

The model assumes that a receptor can view the face of every panel within the proposed development area whilst in reality this, in the majority of cases, will not occur. Therefore any predicted solar reflection from the face of a solar panel that is not visible to a receptor will not occur in practice.

A finite number of points within each solar panel area defined is chosen based on an assessment resolution so that a comprehensive understanding of the entire development can be formed. This determines whether a solar reflection could ever occur at a chosen receptor. The model does not consider the specific panel rows or the entire face of the solar panel within the development outline, rather a single point is defined every 'x' metres (based on the resolution) with the geometric characteristics of the panel. A panel area is however defined to encapsulate all possible panel locations. See the figure below which illustrates this process.



Solar panel area modelling overview

A single reflection point is chosen for the geometric calculations. This suitably determines whether a solar reflection can be experienced at a receptor location and the time of year and duration of the solar reflection. Increased accuracy could be achieved by increasing the number of heights assessed however this would only marginally change the results and is not considered significant.

The available street view imagery, satellite mapping, terrain and any site imagery provided by the developer has been used to assess line of sight from the assessed receptors to the modelled solar panel area, unless stated otherwise. In some cases, this imagery may not be up to date and may not give the full perspective of the installation from the location of the assessed receptor.

Any screening in the form of trees, buildings etc. that may obstruct the Sun from view of the solar panels is not within the modelling unless stated otherwise. The terrain profile at the horizon is considered if stated.

Forge's Sandia National Laboratories' (SGHAT) Model

The following text is taken from Forge[37] and is presented for reference.

Summary of assumptions and abstractions required by the SGHAT/ForgeSolar analysis methodology

1. Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
2. Result data files and plots are now retained for two years after analysis completion. Files should be downloaded and saved if additional persistence is required.
3. The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
4. Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects analyses of path receptors.
5. Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including ATCTs. Note that the SGHAT/ForgeSolar methodology has always relied on an analytical, qualitative approach to accurately determine the overall hazard (i.e. green vs. yellow) of expected glare on an annual basis.
6. The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
7. The algorithm assumes that the PV array is aligned with a plane defined by the total heights of the coordinates outlined in the Google map. For more accuracy, the user should perform runs using minimum and maximum values for the vertex heights to bound the height of the plane containing the solar array. Doing so will expand the range of observed solar glare when compared to results using a single height value.
8. The algorithm does not consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
9. The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
10. The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.
11. The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.
12. Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
13. Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
14. Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
15. PV array tracking assumes the modules move instantly when tracking the sun, and when reverting to the rest position.

[37] Source: https://www.forgesolar.com/help/#assumptions

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Terrain Height

All ground heights are interpolated based on OSGB data.

Dwelling Data

The table below presents the coordinate data for assessed dwelling receptors.

Dwelling	Longitude (°)	Latitude (°)	Dwelling	Longitude (°)	Latitude (°)
1	-0.32607	53.63767	15	-0.31163	53.63356
2	-0.32450	53.62883	16	-0.31346	53.63692
3	-0.32389	53.62812	17	-0.31309	53.63739
4	-0.31012	53.63204	18	-0.31339	53.63780
5	-0.31055	53.63277	19	-0.31350	53.63798
6	-0.31086	53.63329	20	-0.30241	53.63976
7	-0.31115	53.63355	21	-0.30104	53.63849

Dwelling data

ATC Receptor Details

The details are presented in the table below.

Longitude (°)	Latitude (°)	Ground Height (m amsl)	ATC Tower Height (m agl)	Overall Assessed Height (m amsl)
-0.34846	53.58315	22	8	30

ATC tower receptor details

The Approach Path for Aircraft Landing on Runway 02

The table below presents the data for the assessed locations for aircraft on approach to runway 02. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (36.9m/121ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	-0.35706	53.56533	Threshold	52.1
2	-0.35799	53.56399	160.9	60.5
3	-0.35891	53.56265	321.9	69.0
4	-0.35984	53.56131	482.8	77.4
5	-0.36077	53.55997	643.7	85.8
6	-0.36170	53.55863	804.7	94.2
7	-0.36262	53.55729	965.6	102.7
8	-0.36355	53.55595	1126.5	111.1
9	-0.36448	53.55462	1287.5	119.5
10	-0.36541	53.55328	1448.4	127.9
11	-0.36634	53.55194	1609.3	136.3
12	-0.36726	53.55060	1770.3	144.8
13	-0.36819	53.54926	1931.2	153.2
14	-0.36912	53.54792	2092.1	161.6

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
15	-0.37005	53.54658	2253.1	170.0
16	-0.37097	53.54524	2414.0	178.5
17	-0.37190	53.54390	2575.0	186.9
18	-0.37283	53.54256	2735.9	195.3
19	-0.37376	53.54122	2896.8	203.7
20	-0.37468	53.53988	3057.8	212.2
21	-0.37561	53.53854	2 miles	220.6

Assessed receptor (aircraft) locations on the approach path for runway 02

The Approach Path for Aircraft Landing on Runway 20

The table below presents the data for the assessed locations for aircraft on approach to runway 20. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (22.6m/74ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	-0.34586	53.58153	Threshold	37.8
2	-0.34493	53.58287	160.9	46.2
3	-0.34400	53.58421	321.9	54.6
4	-0.34307	53.58555	482.8	63.1
5	-0.34214	53.58689	643.7	71.5
6	-0.34121	53.58823	804.7	79.9
7	-0.34028	53.58957	965.6	88.3
8	-0.33936	53.59091	1126.5	96.8
9	-0.33843	53.59225	1287.5	105.2
10	-0.33750	53.59359	1448.4	113.6
11	-0.33657	53.59493	1609.3	122.0
12	-0.33564	53.59627	1770.3	130.4
13	-0.33471	53.59760	1931.2	138.9
14	-0.33379	53.59894	2092.1	147.3
15	-0.33286	53.60028	2253.1	155.7
16	-0.33193	53.60162	2414.0	164.1
17	-0.33100	53.60296	2575.0	172.6
18	-0.33007	53.60430	2735.9	181.0
19	-0.32914	53.60564	2896.8	189.4

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
20	-0.32822	53.60698	3057.8	197.8
21	-0.32729	53.60832	2 miles	206.2

Assessed receptor (aircraft) locations on the approach path for runway 20

The Approach Path for Aircraft Landing on Runway 08

The table below presents the data for the assessed locations for aircraft on approach to runway 08 The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (26.5m/87ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	-0.35348	53.57588	Threshold	41.8
2	-0.35590	53.57569	160.9	50.2
3	-0.35831	53.57550	321.9	58.6
4	-0.36073	53.57531	482.8	67.0
5	-0.36315	53.57511	643.7	75.4
6	-0.36557	53.57492	804.7	83.9
7	-0.36799	53.57473	965.6	92.3
8	-0.37040	53.57454	1126.5	100.7
9	-0.37282	53.57435	1287.5	109.1
10	-0.37524	53.57416	1448.4	117.6
11	-0.37766	53.57397	1609.3	126.0
12	-0.38008	53.57378	1770.3	134.4
13	-0.38249	53.57359	1931.2	142.8
14	-0.38491	53.57340	2092.1	151.3
15	-0.38733	53.57321	2253.1	159.7

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
16	-0.38975	53.57302	2414.0	168.1
17	-0.39216	53.57283	2575.0	176.5
18	-0.39458	53.57263	2735.9	184.9
19	-0.39700	53.57244	2896.8	193.4
20	-0.39942	53.57225	3057.8	201.8
21	-0.40184	53.57206	2 miles	210.2

Assessed receptor (aircraft) locations on the approach path for runway 08

The Approach Path for Aircraft Landing on Runway 26

The table below presents the data for the assessed locations for aircraft on approach to runway 26. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (25.4m/83.4ft amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	-0.34298	53.57671	Threshold	40.7
2	-0.34056	53.57690	160.9	49.1
3	-0.33814	53.57709	321.9	57.5
4	-0.33572	53.57728	482.8	65.9
5	-0.33330	53.57747	643.7	74.4
6	-0.33089	53.57767	804.7	82.8
7	-0.32847	53.57786	965.6	91.2
8	-0.32605	53.57805	1126.5	99.6
9	-0.32363	53.57824	1287.5	108.0
10	-0.32121	53.57843	1448.4	116.5
11	-0.31880	53.57862	1609.3	124.9

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
12	-0.31638	53.57881	1770.3	133.3
13	-0.31396	53.57900	1931.2	141.7
14	-0.31154	53.57919	2092.1	150.2
15	-0.30912	53.57938	2253.1	158.6
16	-0.30671	53.57957	2414.0	167.0
17	-0.30429	53.57976	2575.0	175.4
18	-0.30187	53.57995	2735.9	183.8
19	-0.29945	53.58015	2896.8	192.3
20	-0.29703	53.58034	3057.8	200.7
21	-0.29462	53.58053	2 miles	209.1

Assessed receptor (aircraft) locations on the approach path for runway 26

Train Driver Data

An additional height of 2.75m has been added to the ground height, this has been taken as typical eye level for a train driver.

No.	Longitude (°)	Latitude (°)	No.	Longitude (°)	Latitude (°)
1	-0.31564	53.64274	7	-0.31246	53.63770
2	-0.31512	53.64191	8	-0.31190	53.63688
3	-0.31460	53.64106	9	-0.31138	53.63605
4	-0.31406	53.64022	10	-0.31089	53.63522
5	-0.31352	53.63938	11	-0.31032	53.63440
6	-0.31296	53.63855	12	-0.30981	53.63357

Train driver data

Modelled Reflector Data

The table below presents the coordinate data for modelled reflector area used in the assessment.

Vertex number	Longitude (°)	Latitude (°)	Vertex number	Longitude (°)	Latitude (°)
1	-0.31873	53.64242	10	-0.32369	53.63766
2	-0.32351	53.64246	11	-0.32220	53.63544
3	-0.32415	53.64254	12	-0.31491	53.63671
4	-0.32576	53.64260	13	-0.31580	53.63852
5	-0.32784	53.64244	14	-0.31688	53.63886
6	-0.32579	53.63983	15	-0.31590	53.63903
7	-0.32515	53.63970	16	-0.31448	53.63926
8	-0.32373	53.63820	17	-0.31576	53.64210
9	-0.32363	53.63778			

Modelled reflector area

APPENDIX H – DETAILLED MODELLING RESULTS

Model Output Charts

The charts for the potentially affected receptors are shown on the following pages. Each chart shows:

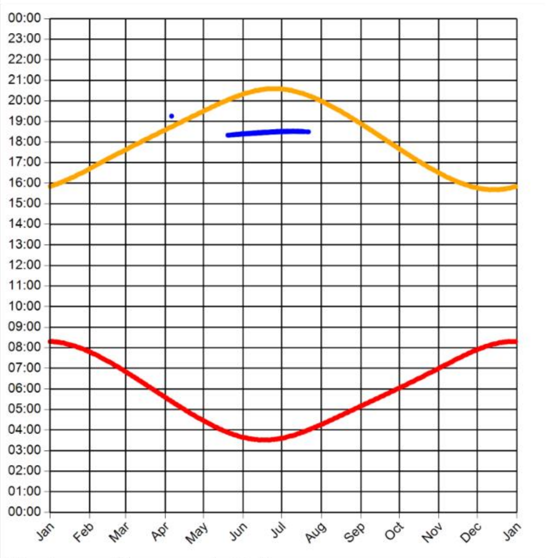
- The receptor (observer) location – top right image. This also shows the azimuth range of the Sun itself at times when reflections are possible. If sunlight is experienced from the same direction as the reflecting panels, the overall impact of the reflection is reduced as discussed within the body of the report.
- The reflecting panels – bottom right image. The reflecting area is shown in yellow. The orange areas denote panel locations that will not produce glare due to terrain screening at the horizon. If the yellow panels are not visible from the observer location, no issues will occur in practice. Additional obstructions which may obscure the panels from view are considered separately within the analysis.
- The reflection date/time graph – left hand side of the page. The blue line indicates the dates and times at which geometric reflections are possible. This relates to reflections from the yellow areas.
- The sunrise and sunset curves throughout the year (red and yellow lines).

Dwelling Receptors

The charts below relate to the dwelling receptors where low impacts have been predicted. Modelling output for the remaining receptors can be provided on request.

Observer 05 Results

Reflection Date/Time (GMT) Graph



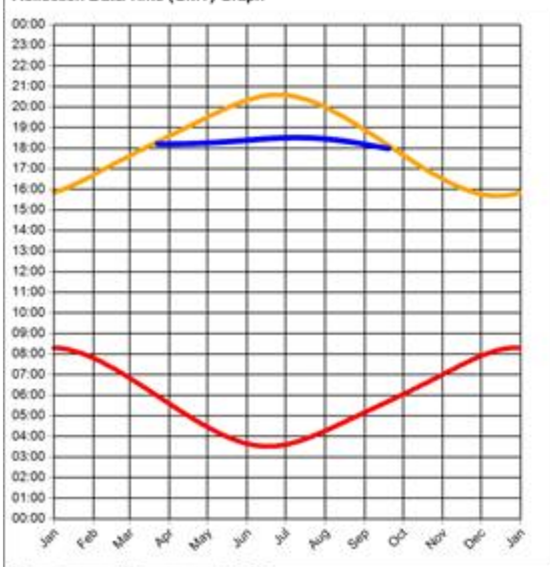
Min observer difference angle: 13.1°
Max observer difference angle: 15.5°

Observer Location Sun azimuth range is 286.6° - 289.4° (yellow)

Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

Observer 6 Results

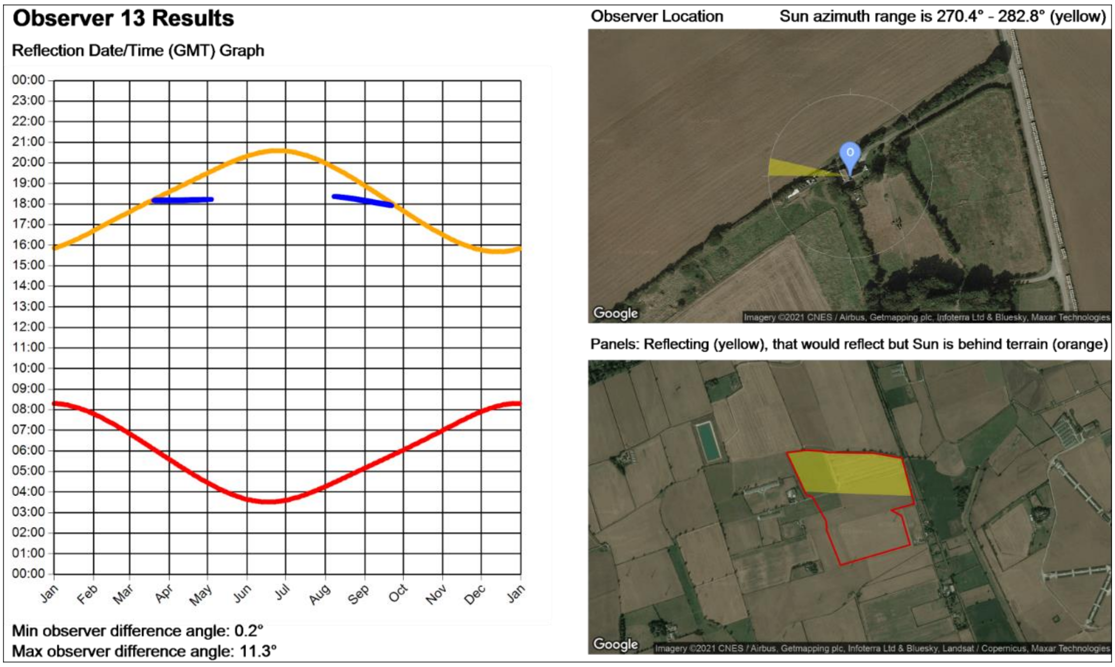
Reflection Date/Time (GMT) Graph



Min observer difference angle: 0.2°
Max observer difference angle: 15.9°

Observer Location Sun azimuth range is 271.4° - 289.5° (yellow)

Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)


Observer 13 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 0.2°
Max observer difference angle: 11.3°
Observer Location
Sun azimuth range is 270.4° - 282.8° (yellow)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google
Imagery ©2021 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies

Aviation Receptors

The modelling results for the aviation receptors have been included in this document below for completeness even though no significant impact is predicted.

PV & Receptor Analysis Results

Results for each PV array and receptor

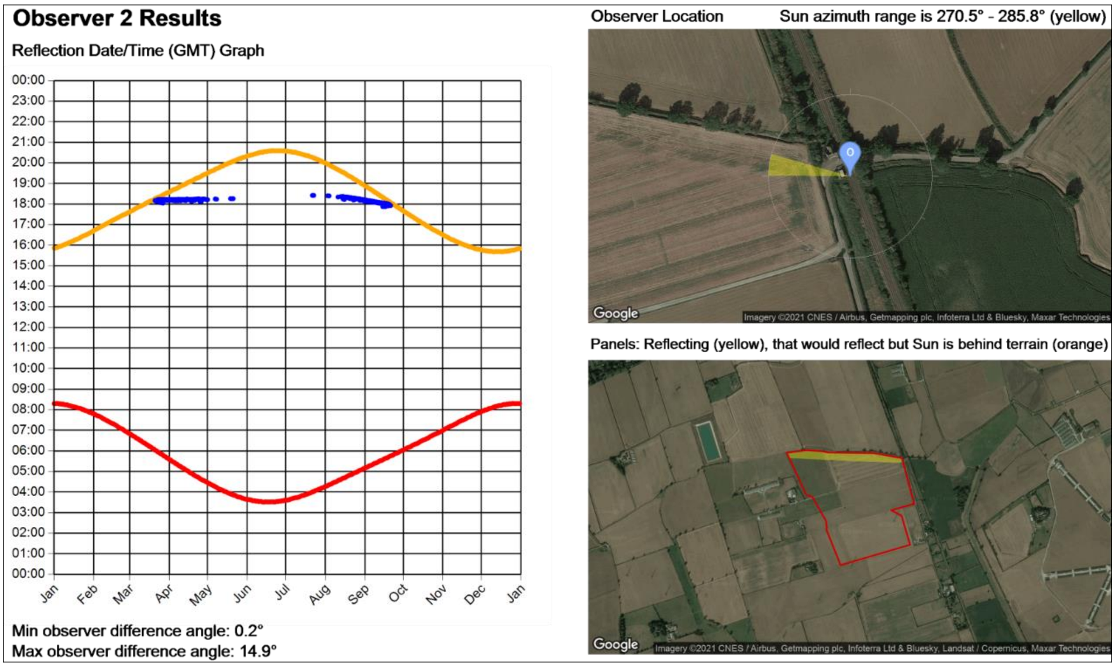
PV array 1 no glare found

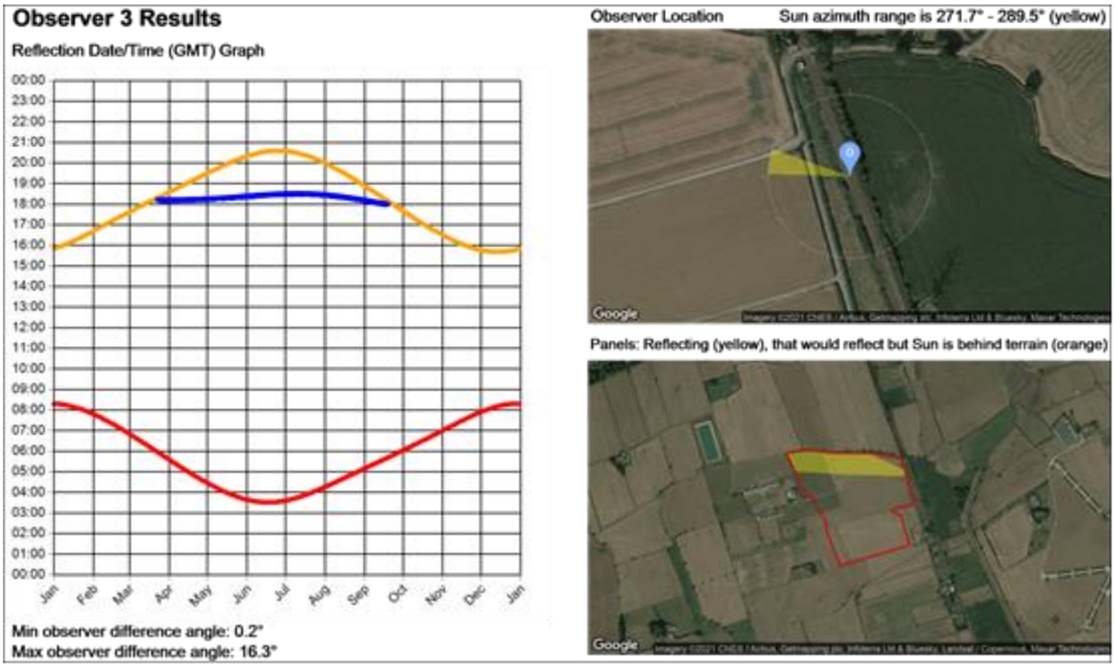
Component	Green glare (min)	Yellow glare (min)
FP: 02 Approach Path	0	0
FP: 08 Approach Path	0	0
FP: 20 Approach Path	0	0
FP: 26 Approach Path	0	0
OP: 1-ATCT	0	0

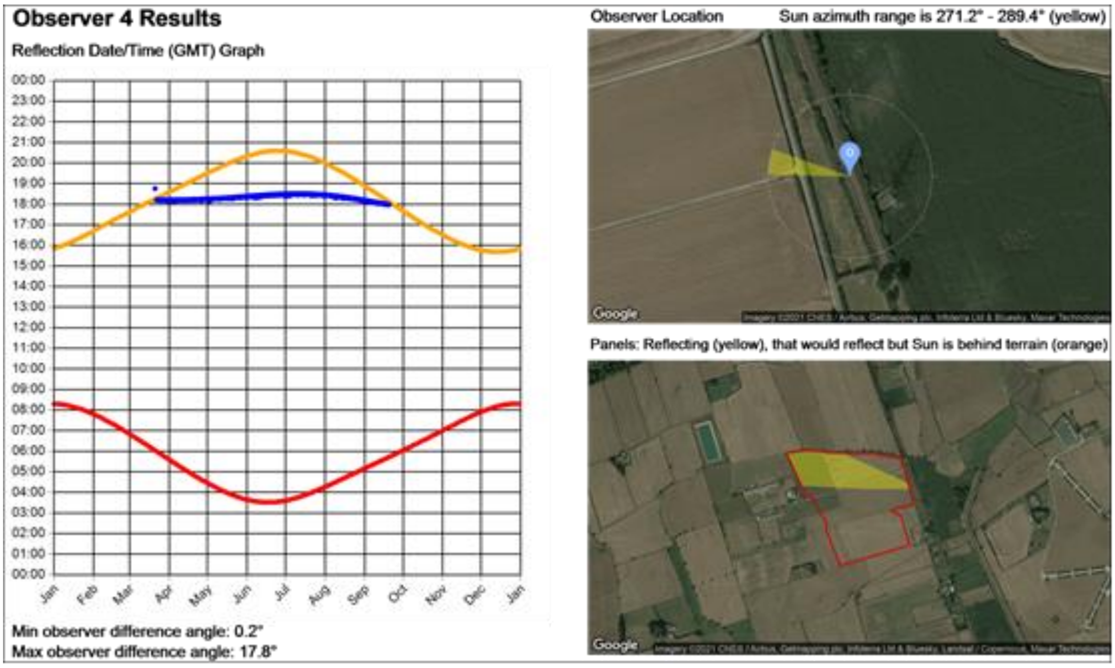
No glare found

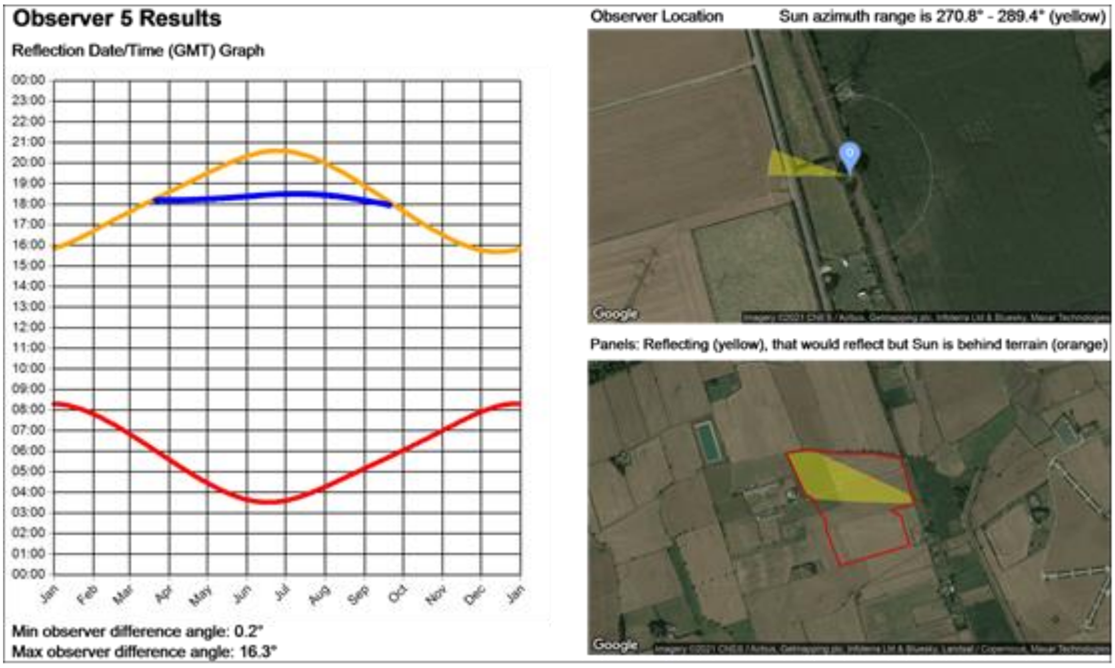
Train Driver Receptors

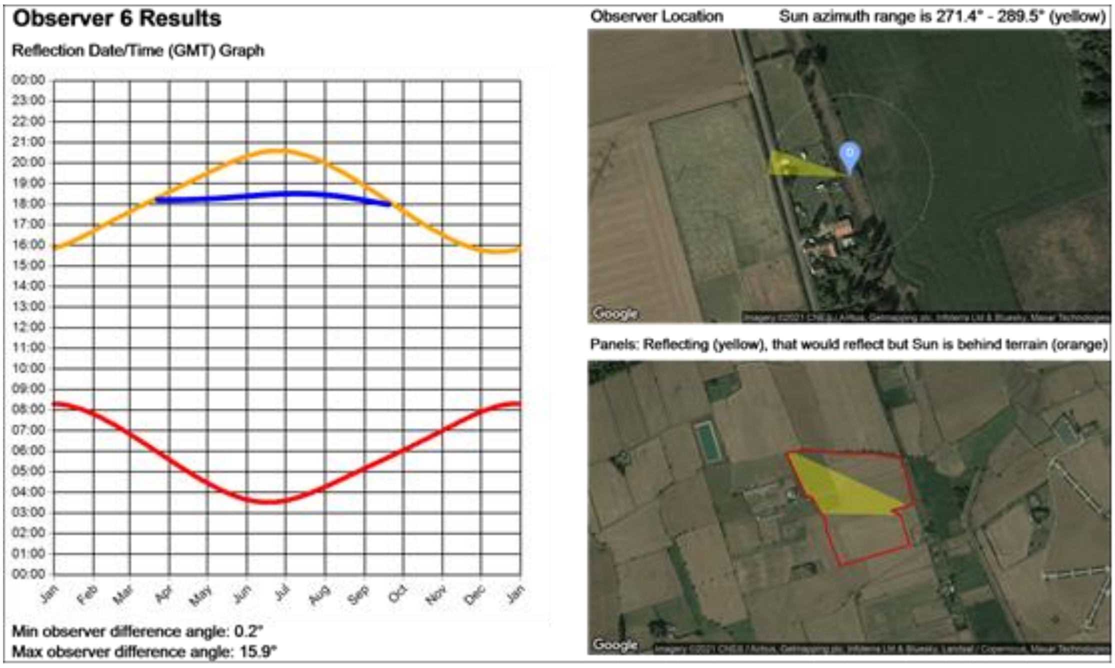
The modelling results for the train driver receptors have been included in this document below for completeness even though no significant impact is predicted.

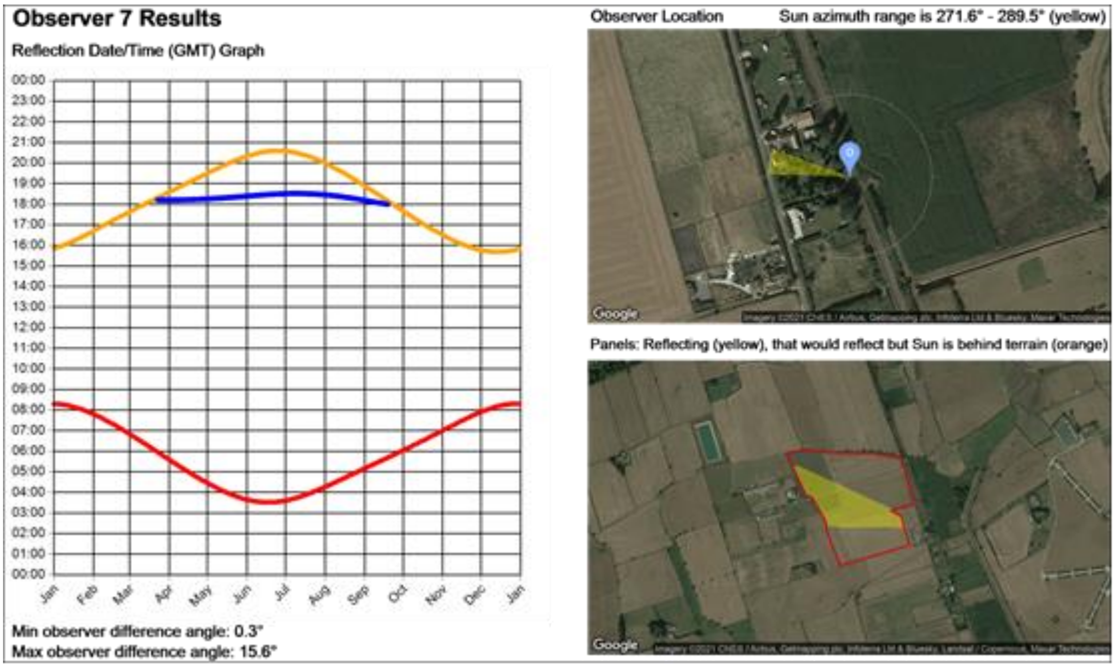


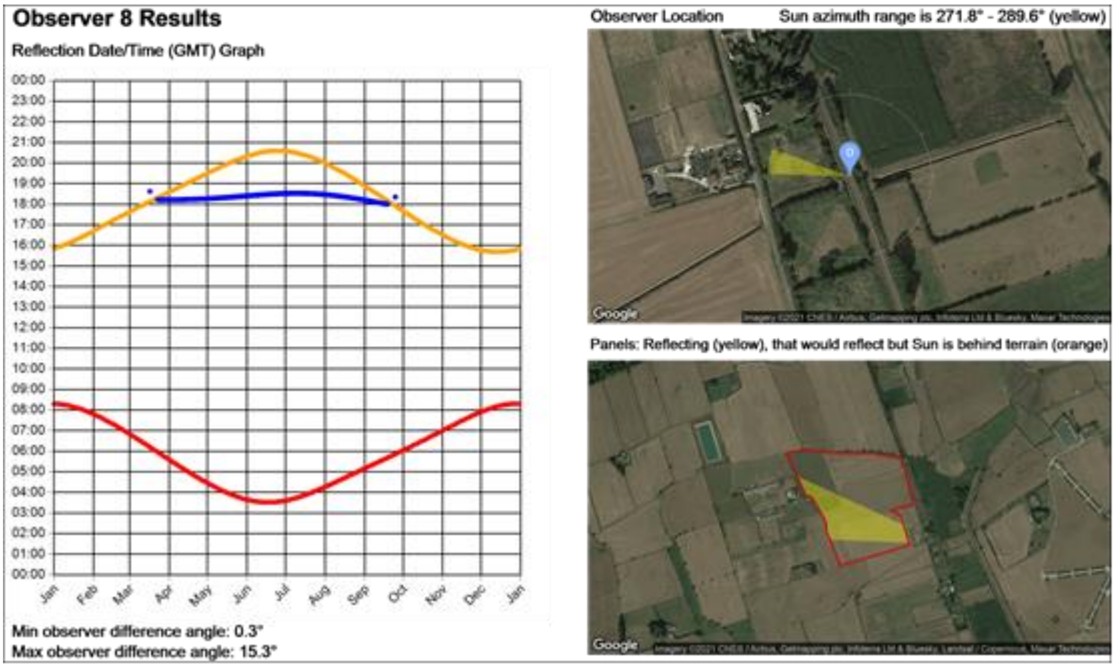


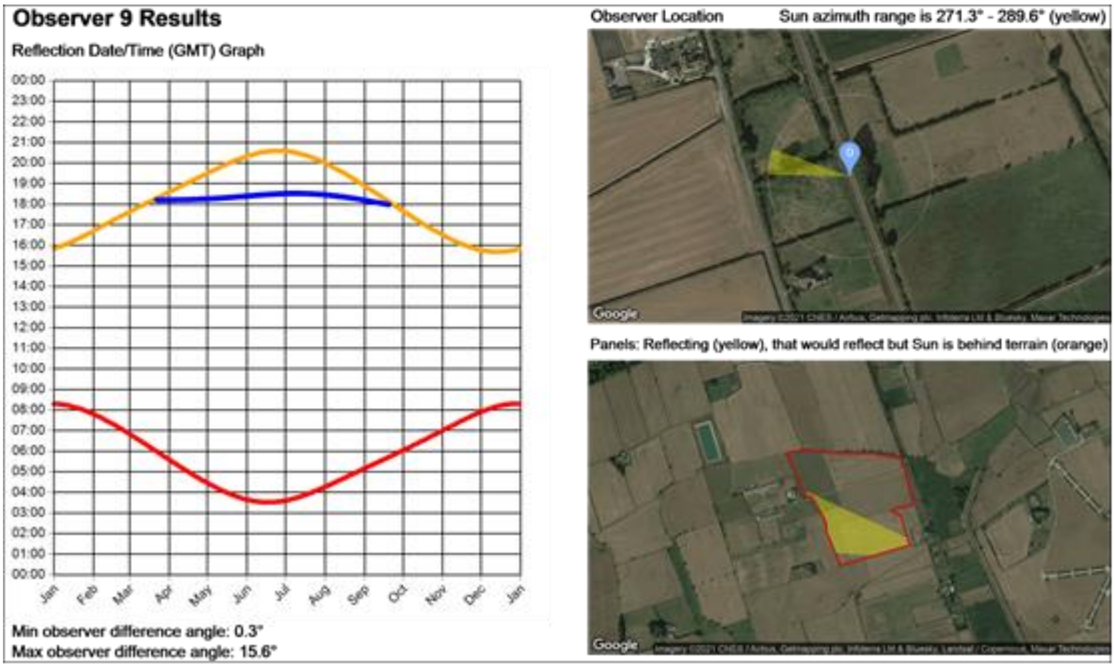

Observer 4 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 0.2°
Max observer difference angle: 17.8°
Observer Location
Sun azimuth range is 271.2° - 289.4° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

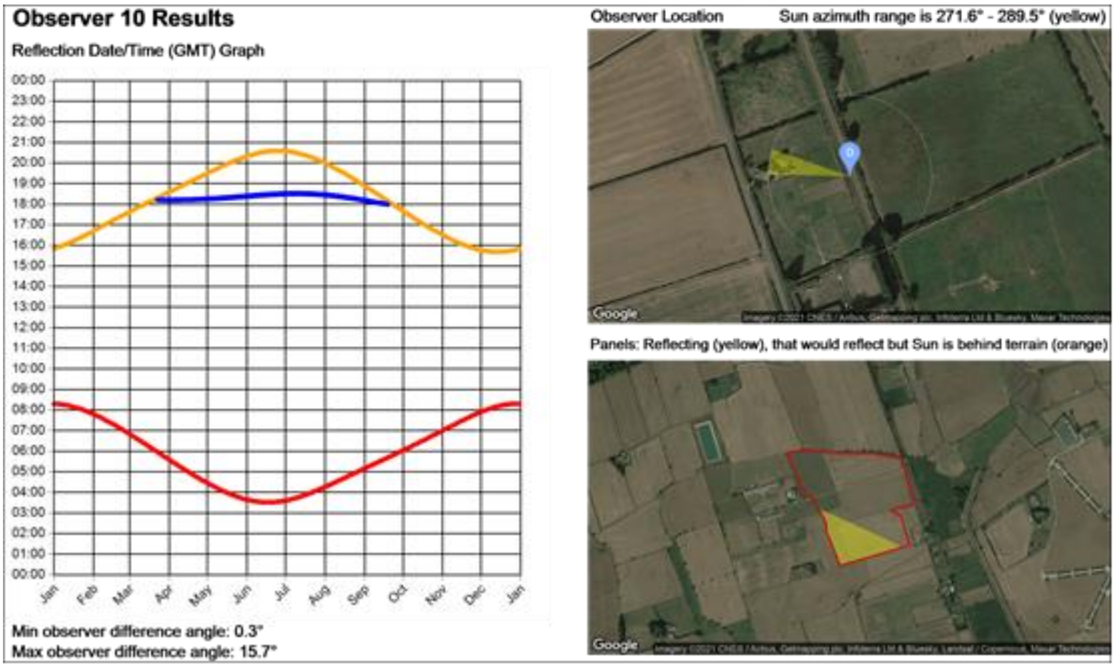

Observer 5 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 0.2°
Max observer difference angle: 16.3°
Observer Location
Sun azimuth range is 270.8° - 289.4° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

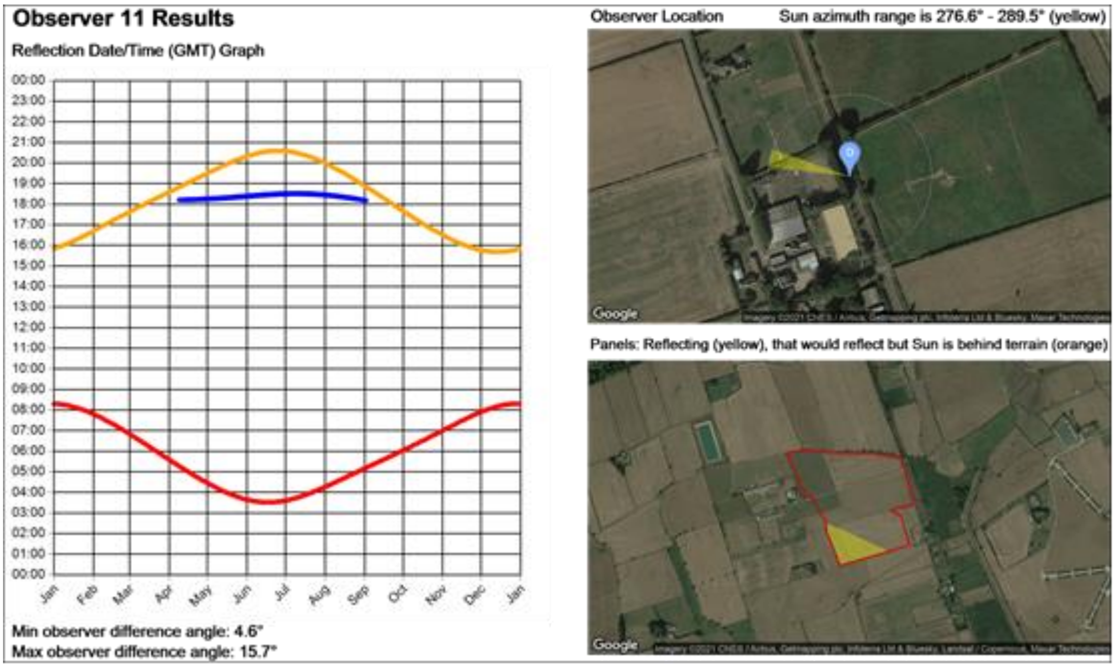

Observer 6 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 0.2°
Max observer difference angle: 15.9°
Observer Location
Sun azimuth range is 271.4° - 289.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)

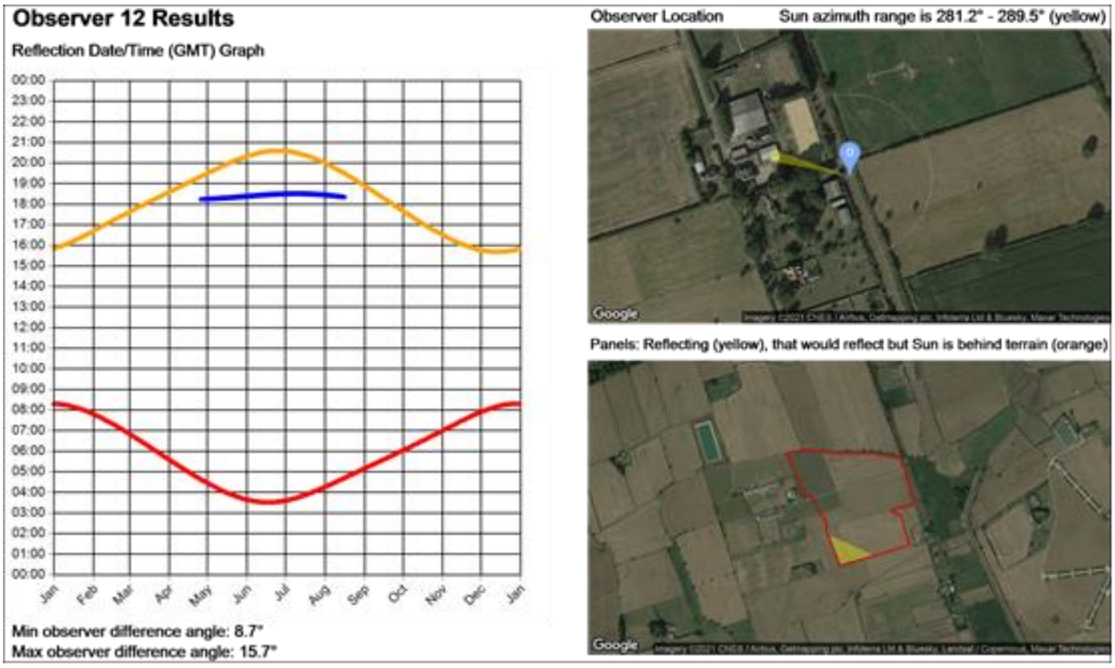

Observer 7 Results
Reflection Date/Time (GMT) Graph
Min observer difference angle: 0.3°
Max observer difference angle: 15.6°
Observer Location
Sun azimuth range is 271.6° - 289.5° (yellow)
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)


Observer 8 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.3°
Max observer difference angle: 15.3°
Observer Location
Sun azimuth range is 271.8° - 289.6° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer 9 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.3°
Max observer difference angle: 15.6°
Observer Location
Sun azimuth range is 271.3° - 289.6° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer 10 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 0.3°
Max observer difference angle: 15.7°
Observer Location
Sun azimuth range is 271.6° - 289.5° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer 11 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
Min observer difference angle: 4.6°
Max observer difference angle: 15.7°
Observer Location
Sun azimuth range is 276.6° - 289.5° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google


Observer 12 Results
Reflection Date/Time (GMT) Graph
00:00
23:00
22:00
21:00
20:00
19:00
18:00
17:00
16:00
15:00
14:00
13:00
12:00
11:00
10:00
09:00
08:00
07:00
06:00
05:00
04:00
03:00
02:00
01:00
00:00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Min observer difference angle: 8.7°
Max observer difference angle: 15.7°
Observer Location
Sun azimuth range is 281.2° - 289.5° (yellow)
Google
Panels: Reflecting (yellow), that would reflect but Sun is behind terrain (orange)
Google

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