PAGERPOWER
Urban & Renewables

Solar Photovoltaic Glint and Glare Study

Green Energy International Ltd

Caudwell Farm

February 2023





PLANNING SOLUTIONS FOR:

- Solar
- Telecoms
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- Defence
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ADMINISTRATION PAGE

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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 Holdbeach St Matthew, Lincolnshire, England. This assessment pertains to the possible impact upon surrounding road safety, residential amenity and aviation activity associated with Red House Farm Airfield, Wingland Airfield, and Lutton-Garnsgate Airfield.

Conclusions

No significant impacts are predicted upon residential amenity, road safety and aviation activity at, Wingland Airfield, and Lutton-Garnsgate Airfield.

It is recommended that the potential glare times are made available to the owner of Red House Farm Airfield, where the impact of glare towards the runway 20 approach path has been considered in an operational context and judged to be operationally accommodatable.

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 fourth edition originally published in 2022[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

[1] Pager Power Glint and Glare Guidance, Fourth Edition, September 2022.

[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.

produced are 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 solar reflections are geometrically possible for six of the eight assessed dwellings. No impacts are predicted for two of these dwellings due to the presence of existing screening in the form of vegetation and buildings significantly obstructing visibility of the reflecting panel area. Therefore, no mitigation is required.

For the remaining four dwellings experiencing solar reflections, a low impact is predicted due to the presence of mitigating factors, including:

- A large separation distance between the dwelling and the reflecting panel area;
- Partial existing screening;
- Effects coinciding with sunlight which is a more prominent source of light.

Assessment Results – Roads

The roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Technical modelling 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.

Therefore, no significant impacts upon road users along the surrounding roads are predicted, and mitigation is not recommended.

Assessment Results – Aviation

Solar reflections are not geometrically possible towards the identified 2-mile approach paths for runways 02/20, 14/32, 16/34, and 06 at Wingland Airfield and runway 02 for Red House Farm Airfield. Therefore no impacts are predicted and no mitigation is required.

Solar reflections with a 'low potential for temporary after-image' are geometrically possible towards the 2-mile approach path for runway 24 at Wingland Airfield. This is acceptable in accordance with the associated guidance and industry best practice and mitigation is not required.

Solar reflections with 'potential for temporary after-image' are geometrically possible towards a 0.8 mile section of the 2-mile approach path for runway 20 at Red house Farm Airfield. There are mitigating factors that reduce the overall impact. In particular, effects are predicted to occur for a short duration of time throughout the year (1,290 minutes which is 0.491% of daylight hours), with a maximum duration of less than 38 minutes on the days when the glare is possible.

Overall, it is judged that the potential effects towards the runway 20 approach at Red House Farm Airfield can be operationally accommodated. It is expected that operational measures used by pilots to mitigate the effects of direct sunlight (see Section 5.6.3 for further details) will adequately mitigate the effects of solar glare from the panels.

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

It is recommended that the potential glare times are made available to the owner of the airfield so that it can be considered in the context of their operations.

Assessment Results – Lutton-Garnsgate Airfield (High-Level Aviation)

Considering the size of the proposed development, its location relative to Lutton-Garnsgate Airfield and its distance from the aerodrome, it can be reliably concluded that the proposed development will be outside a pilot's primary field of view (50 degrees either side of the approach bearing) along the 2-mile approach path towards runway thresholds 09 and 27. This is acceptable in accordance with the associated guidance and industry best practice.

Therefore, no significant impacts upon aviation activity associated with Lutton-Garnsagte Airfield are predicted, and no detailed modelling is recommended.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 54 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 Holdbeach St Matthew, Lincolnshire, England. This assessment pertains to the possible impact upon surrounding road safety, residential amenity and aviation activity associated with Red House Farm Airfield, Wingland Airfield, and Lutton-Garngate Airfield.

This report contains the following:

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

1.2 Pager Power's Experience

Pager Power has undertaken over 900 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 presented within the Draft National Policy Statement for Renewable Energy Infrastructure (EN-3) – published by the Department for Business, Energy & Industrial Strategy in September 2021 and the Federal Aviation Administration in the USA.

2 SOLAR DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Development Site Layout

Figure 1 below[5] shows the site layout plan. The blue and grey areas denote the fixed and tracking solar panel locations.

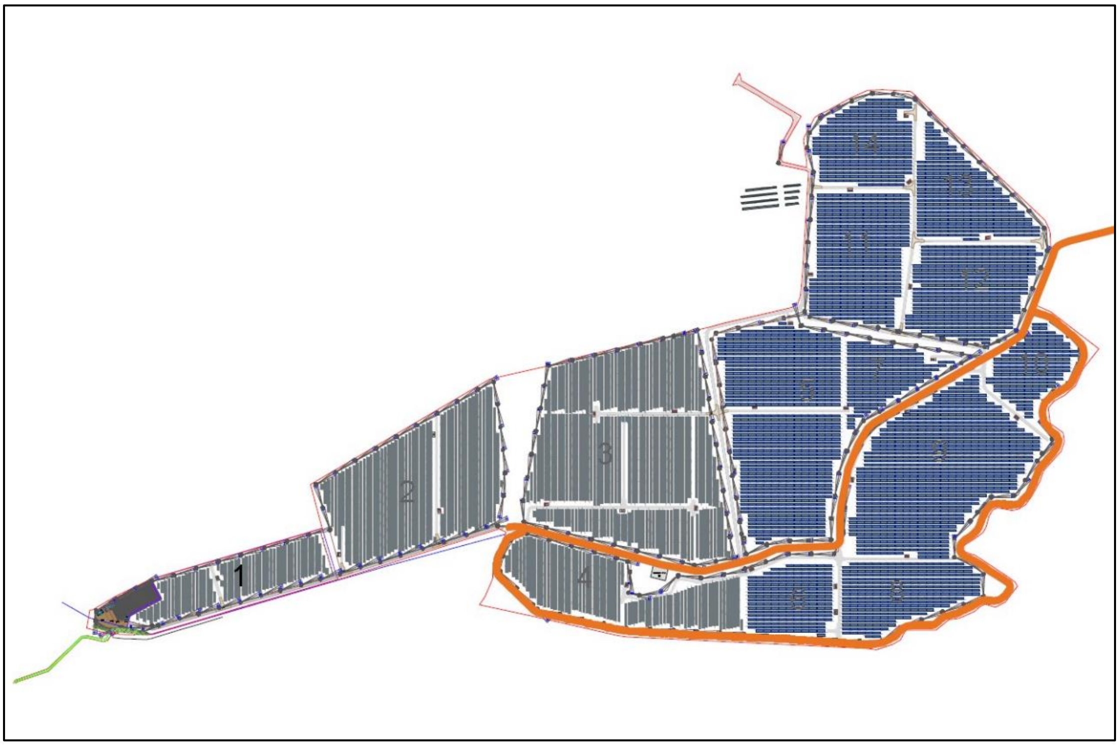

Figure 1 *Proposed development site layout*

[5] Provided to Pager Power by Green Energy International Ltd.

2.2 Proposed Development Location – Aerial Image

Figure 2 below shows the panel area overlaid onto aerial imagery (blue polygon).

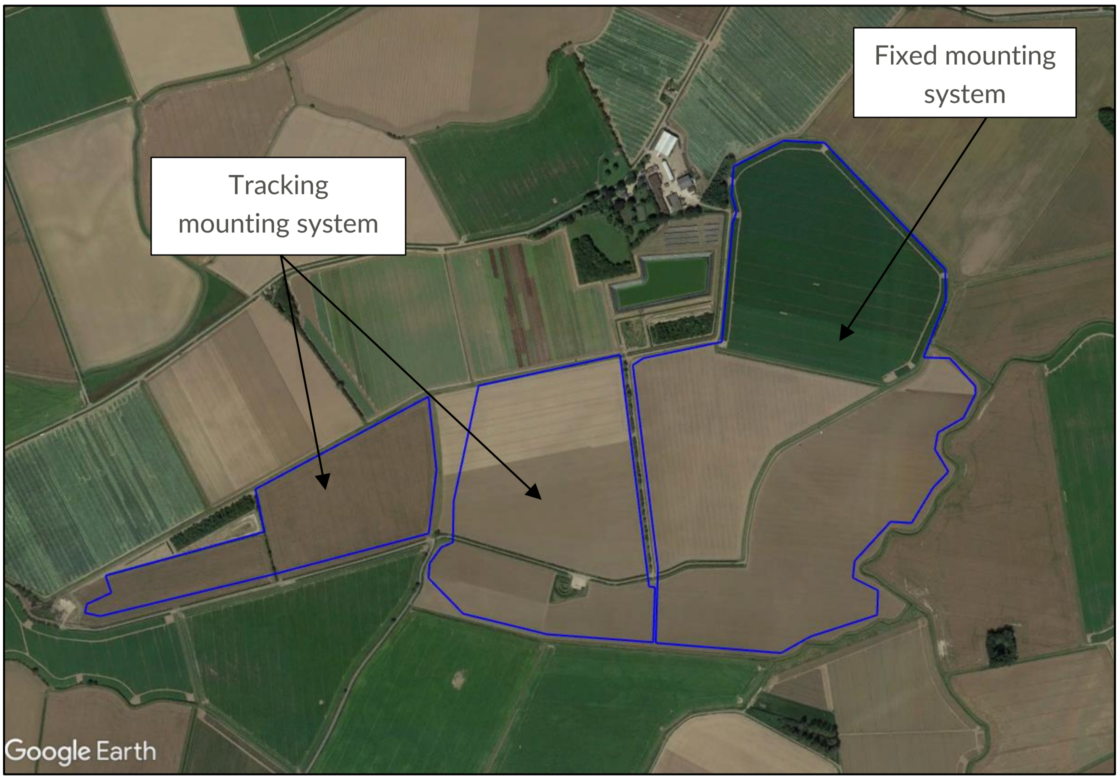

Figure 2 *Proposed development location – aerial image*

2.3 Photovoltaic Panel Mounting Arrangements and Orientation

The solar panel dimensions as assessed within this report are defined in the following sub-sections.

2.3.1 Fixed Panel Area

Solar Panel Technical Information	
Azimuth angle (°)	180 (south facing)
Assessed centre height (m agl)	1.478
Elevation angle (°)	20

Table 1 *Fixed panel area technical information*

2.3.2 Tracking Panel Area

Solar Panel Technical Information	
Assessed centre-height (m)	2 agl (above ground level)[6]
Tracking	Single Axis
Tilt of tracking axis (°)	0
Orientation of tracking axis (°)	0
Offset angle of module (°)	0
Tracker Range of Motion (°)	±55
Resting angle (°)	0
Surface material	Smooth glass without ARC (anti-reflective coating)

Table 2 *Tracking panel area technical information*

2.3.3 Solar Panel Backtracking

Shading considerations dictate the panel tilt. This is affected by:

- The elevation angle of the Sun;
- The vertical tilt of the panels;
- The spacing between the panel rows.

This means that early in the morning and late in the evening, the panels will not be directed exactly towards the Sun, as the loss from shading of the panels (caused by facing the sun directly when the Sun is low in the horizon), would be greater than the loss from lowering the panels to a less direct angle in order to avoid the shading Figure 3 on the following page illustrates this.

[6] Based on a provided pier point of 2m agl.

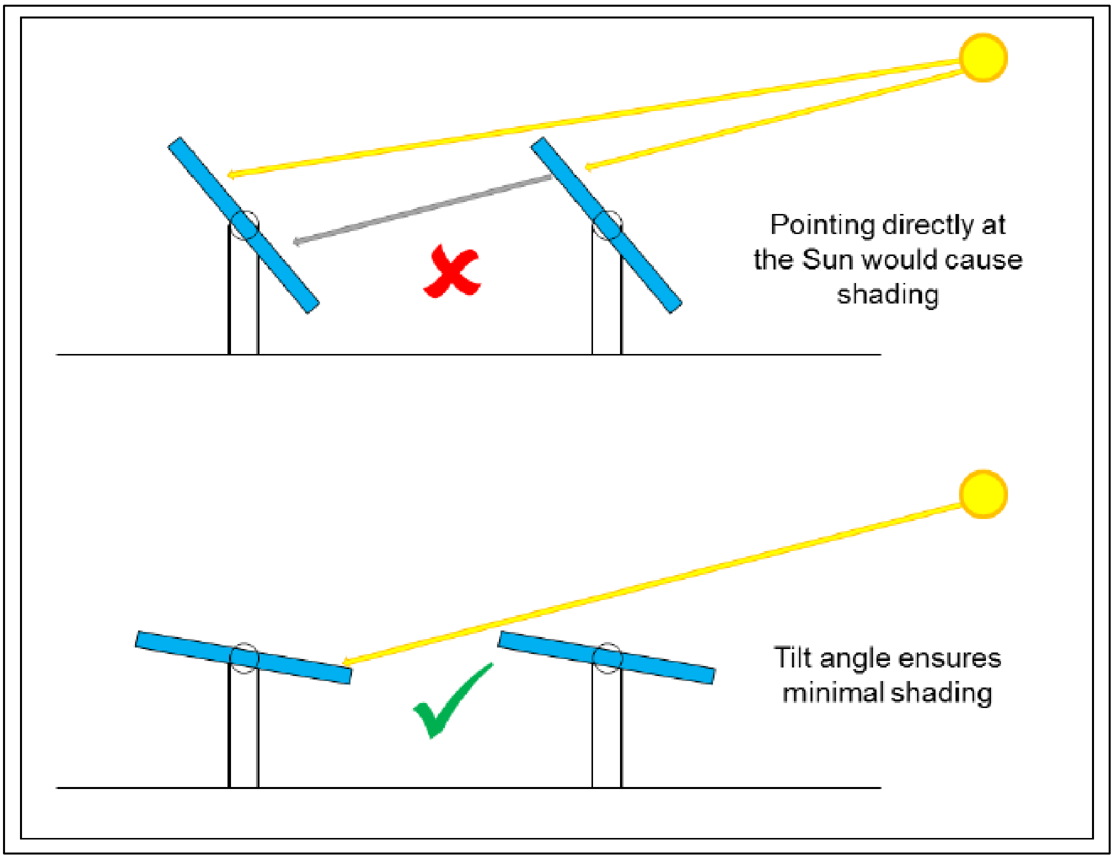

Figure 3 *Shading considerations*

Later in the day, the panels can be directed towards the Sun without any shading issues. This is illustrated in Figure 4 below.

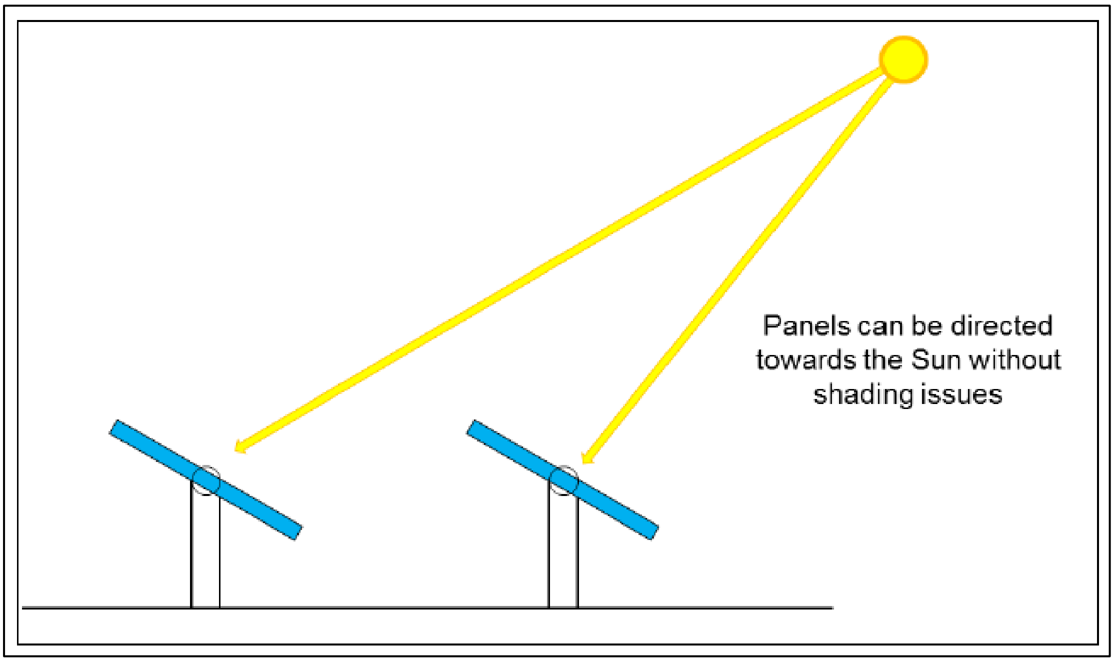

Figure 4 *Panel alignment at high solar angles*

Note that in reality, the lines from the Sun to each panel would be effectively parallel due to the large separation distance. The two previous figures are for illustrative purposes only.

The solar panels backtrack (where the panel angle gradually declines to prevent shading) by reverting to 0 degrees (flat) once the maximum elevation angle of the panels (55 degrees) becomes ineffective due to the low height of the Sun above the horizon and to avoid shading.

2.3.4 Back Tracking Solar Panel Model

Back tracking systems are sensitive to panel length, row spacing, topography and the level of shading which varies throughout the year. The Forge Solar model used in this assessment is a widely accepted model within this area. The model approximates a backtracking system by assuming the panels instantaneously revert to its resting angle of 0 degrees whenever the sun is outside the rotation range (55 degrees in this instance). Panels with a maximum tracking angle of 55 degrees and resting angle of 0 degrees would therefore lie horizontally from sunrise until the Sun enters the rotation range, and immediately after the sun leaves the rotation range until sunset daily. This definition is taken from Forge (see Appendix E) and by rotation range it is assumed the panels remain at 0 degrees until the Sun reaches 30 degrees above the horizon – when the Sun is at right angles to the panels at 55 degrees. It is understood that this option was created specifically to account for backtracking to the extent possible.

Whilst this model simplifies the backtracking process to be used by the solar panels within the solar development, panels that revert back to their resting angle immediately in many cases present a worst-case scenario for reflectors. This is because flatter panels can produce solar reflections in a much greater range of azimuth angles at ground level. The results would in most cases be more conservative than modelling a detailed back tracking system.

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 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.

3.2 Background

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

3.3 Pager Power's Methodology

3.3.1 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.

3.3.2 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.

3.4 Assessment Methodology and Limitations

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

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

4 IDENTIFICATION OF RECEPTORS

4.1 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.

Reflections towards ground-based receptors located further north than any **fixed** mounted proposed panels are highly unlikely[8]. Therefore, receptors north of the **fixed** panel area has 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.

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

4.1.1 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 5 below, along with the 1km assessment area (the green outlined polygon). A total of 8 dwelling locations have been assessed.

Figure 5 *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].

The dwellings, presented in the above area are buildings that are likely divided into multiple addresses. Modelling outputs have not been generated for every individual address independently. The sampling resolution is sufficiently high to capture the level of effect for all potentially affected dwellings.

Close-up images to illustrate the dwelling receptors are presented in Figures 6-12 on the following pages.

[9] This height is used for modelling purposes and views above the ground floor are considered in the results discussion, where appropriate.

Figure 6 *Dwelling 1*

Figure 7 *Dwelling 2*

Figure 8 *Dwelling 3*

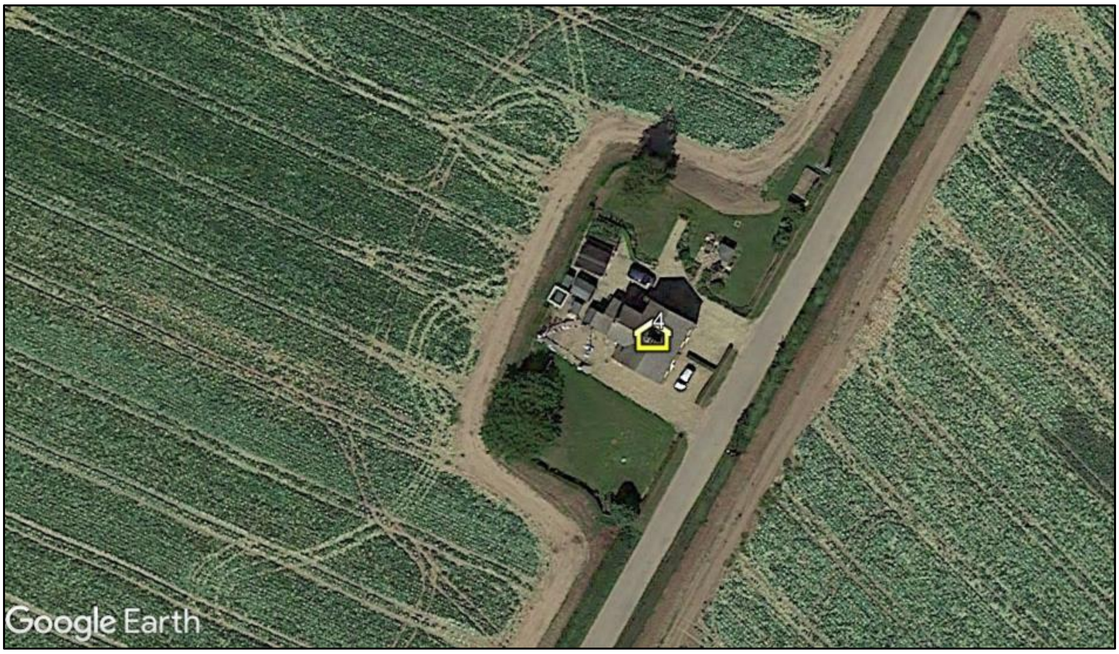

Figure 9 *Dwelling 4*

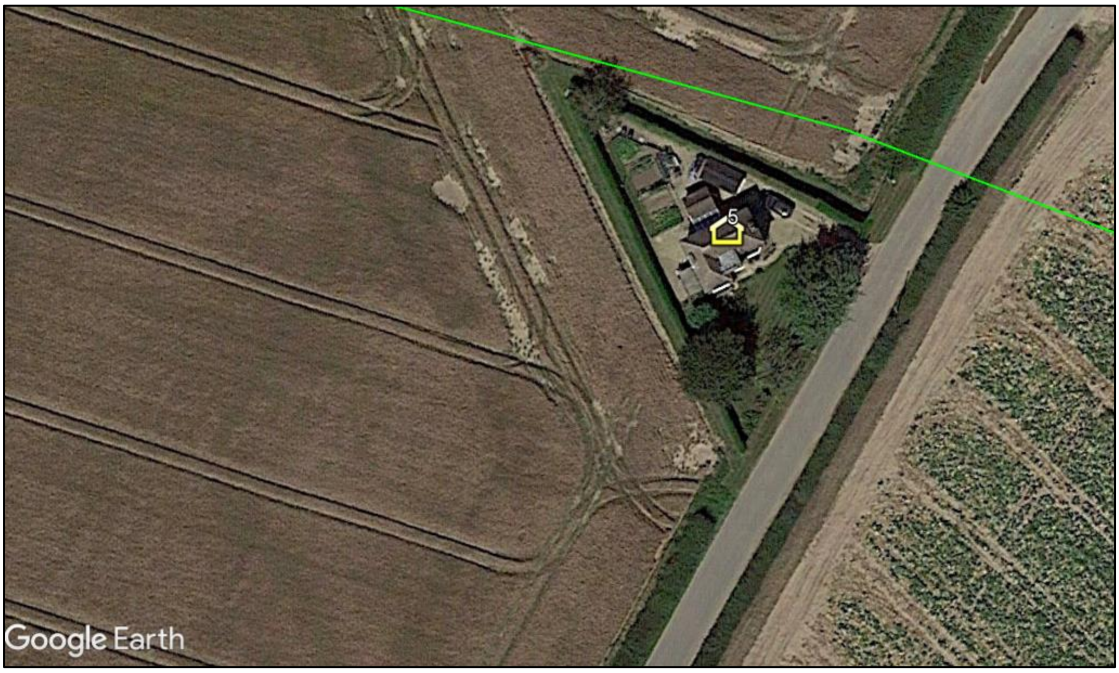

Figure 10 *Dwelling 5*

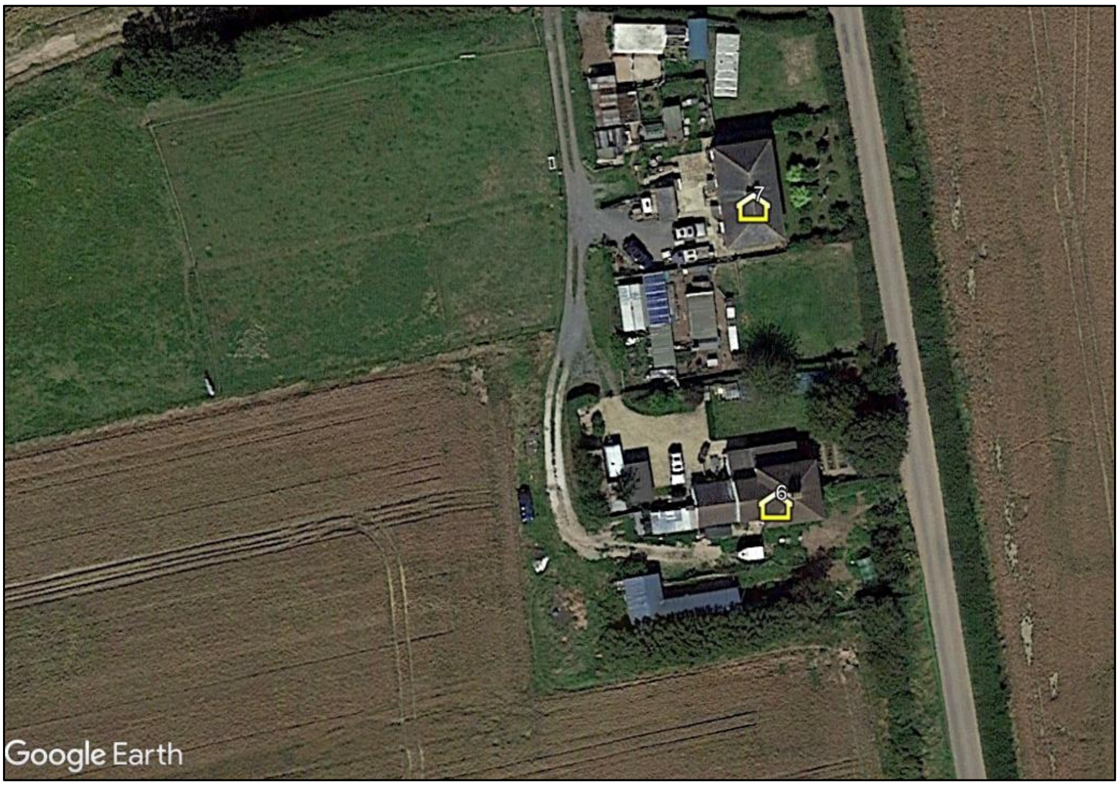

Figure 11 *Dwellings 6-7*

Figure 12 *Dwelling 8*

4.1.2 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 local roads where traffic densities are likely to be relatively low. Technical modelling 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 B1359, which is southwest of the panel area and outside of the 1km assessment area. The location of the B1359 relative to the proposed development is shown in Figure 13 on the following page.

Considering all of the above, no significant impacts upon road users are predicted and no mitigation is required.

Figure 13 *Nearest significant road to the proposed development*

4.2 Aviation Receptors

4.2.1 Airborne Receptors – Approaching Aircraft

Red House Farm Airfield and Wingfield Airfield are two unlicensed aerodromes within 5km of the proposed development.. 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. Both airfields are understood to not have an Air Traffic Control (ATC) Tower, and the following runways have been identified:

- 02/20 – approximately 783m (Red House Farm);
- 02/20 – approximately 260m (Wingland);
- 06/24 – approximately 210m (Wingland);
- 14/32 – approximately 250m (Wingland);
- 16/34 – approximately 225m (Wingland).

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 14 on the following page shows the assessed aircraft approach paths.

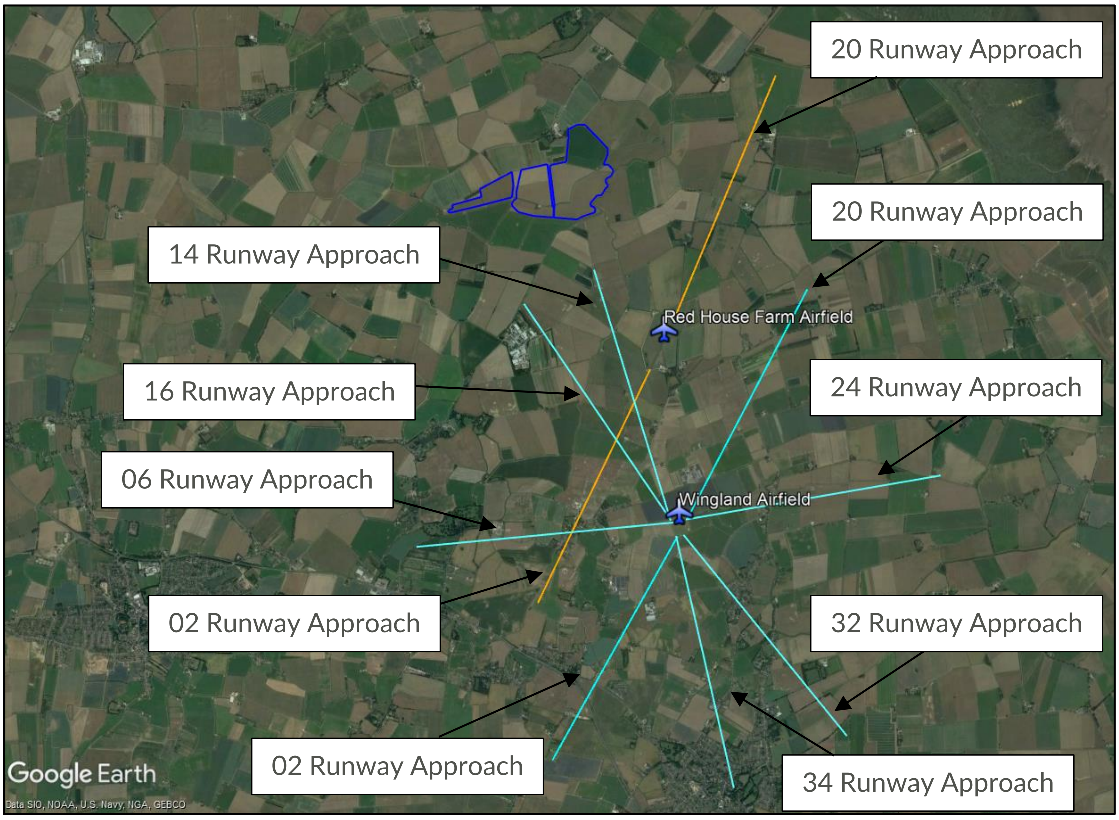

Figure 14 *Runway approach paths – aerial image*

5 GEOMETRIC ASSESSMENT RESULTS AND DISCUSSION

5.1 Overview

The following sub-sections summarise the results of the assessment:

- The key considerations for each receptor type. The criteria are determined by the assessment process for each receptor, which are set out in Appendix C.
- Geometric results of the assessment based solely on bare-earth terrain i.e., without consideration of screening in the form of buildings, dwellings, (existing or proposed) vegetation, and/or terrain. The modelling output for receptors, shown in Appendix H, presents the precise predicted times and the reflecting panel areas.
- Whether a reflection will be experienced in practice. When determining the visibility of the reflecting panels for an observer, a conservative review of the available imagery, landscape strategy plan, google earth viewshed (high-level terrain analysis), and/or site photography (if available) is undertaken, whereby it is assumed views of the panels are possible if it cannot be reliably determined that existing screening will remove effects.
- The impact significance and any mitigation recommendations/requirements.
- The desk-based review of the available imagery.

5.2 Dwelling Receptors

5.2.1 Overview

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

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

Where no solar reflections are geometrically possible or where solar reflections are predicted to be significantly screened, no impact is predicted, and mitigation is not required.

Where effects are predicted to be experienced for **less** than 3 months per year and **less** than 60 minutes on any given day, or where the separation distance to the nearest visible reflecting panel is over 1km, the impact significance is low, and mitigation is not recommended.

Where effects are predicted to be experienced for **more** than 3 months per year and/or for **more** than 60 minutes on any given day expert assessment of the following mitigating factors is required to determine the impact significance:

- 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 from a wide angle to observe the reflecting areas.

Following consideration of these mitigating factors, where the solar reflection does not remain significant, a low impact is predicted, and mitigation is not recommended. Where the solar reflection remains significant, the impact significance is moderate, and mitigation is recommended.

Where effects are predicted to be experienced for **more** than 3 months per year and **more** than 60 minutes on any given day and there are no mitigating factors, the impact significance is high, and mitigation is required.

5.2.2 Geometric Modelling Results Overview

The results of the modelling indicate that solar reflections are geometrically possible towards six of the eight assessed dwelling receptors. The dwellings where solar reflections are geometrically possible (receptors 1-3 and 6-8) are shown in Figure 15 below.

Figure 15 *Dwellings where solar reflections are geometrically possible*

5.2.3 Results Discussion

Table 3 below and on the following page presents the following:

- Geometric modelling results (without consideration of screening).
- Desk-based review of identified screening (presented in more detail in the following sub-section).
- Consideration of relevant mitigating factors (where appropriate).
- Predicted impact significance.
- Mitigation recommendation/requirement for the dwelling receptors.

Dwelling(s)	Geometric modelling results (without consideration of screening)	Identified Screening (desk-based review)	Relevant Mitigating Factors	Predicted Impact Classification	Mitigation Recommended/ Required?
1	Solar reflections predicted for **more** than three months per year and **less** than 60 minutes on any given day.	No.	Partial existing vegetation. Large separation distance of approximately 480m between the reflecting panel area and dwelling. Effects coincide with direct sunlight, which is a more prominent source of light.	Low impact.	No.
2-3	Solar reflections predicted for **more** than three months per year and **less** than 60 minutes on any given day.	Existing vegetation. Predicted to significantly obstruct views of the reflecting panels.	N/A.	No impact.	No.

Dwelling(s)	Geometric modelling results (without consideration of screening)	Identified Screening (desk-based review)	Relevant Mitigating Factors	Predicted Impact Classification	Mitigation Recommended/ Required?
4-5	No solar reflections geometrically possible.	N/A	N/A	No impact.	No.
6-7	Solar reflections predicted for **more** than three months per year and **less** than 60 minutes on any given day.	No.	Partial existing vegetation. Large separation distance of approximately 665m between the reflecting panel area and dwelling, at its closest point. Effects coincide with direct sunlight, which is a more prominent source of light.	Low impact.	No.
8	Solar reflections predicted for **more** than three months per year and **less** than 60 minutes on any given day.	No.	Partial existing vegetation. Large separation distance of approximately 775m between the reflecting panel area and dwelling. Effects coincide with direct sunlight, which is a more prominent source of light.	Low impact.	No.

Table 3 *Geometric analysis results for dwelling receptors*

5.2.4 Desk-Based Review

The desk-based review, of the available imagery, is shown in Figures 16-19 on the following pages. Within each figure:

- The yellow areas represent the location of the reflecting areas associated with the receptors.
- The orange outlined areas represent the location of the existing screening relative to the proposed development.

Figure 16 *Reflecting panel area relative to dwelling 1*

Figure 17 *Reflecting panel area relative to dwellings 2 and 3*

Figure 18 *Reflecting panel area relative to dwellings 6-7*

Figure 19 *Recommended screening location for dwelling 8*

5.3 Aviation Receptors

5.3.1 Overview

The Pager Power and Forge model has been used to determine whether reflections are possible. Intensity calculations in line with the Sandia National Laboratories methodology have been undertaken for aviation receptors. 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 4 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 4 *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 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 in terms of peak reflection intensity. 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 process for quantifying impact significance is defined in the report appendices. For the runway approach paths, the key considerations are:

- Whether a reflection is predicted to be experienced in practice.
- The location of glare relative to a pilot's primary field of view (50 degrees either side of the approach bearing).
- The intensity of glare for the solar reflections:
    - Glare with 'low potential for temporary after-image' (green glare);
    - Glare with 'potential for temporary after-image' (yellow glare);
    - Glare with 'potential for permanent eye damage' (red glare).
- Whether a reflection is predicted to be operationally significant in practice or not.

Where no solar reflections are geometrically possible or where solar reflections are predicted to be significantly screened, no impact is predicted, and mitigation is not required.

Where solar reflections are of an intensity no greater than 'low potential for temporary after-image' (green glare) or occur outside of a pilot's primary field of view (50 degrees either side of the approach bearing), the impact significance is low, and mitigation is not required.

Glare with 'potential for a temporary after-image' (yellow glare) was formerly not permissible under the interim guidance provided by the Federal Aviation Administration in the USA[10] for on-airfield solar. Whilst this guidance was never formally applicable outside of the USA, it has been a common point of reference internationally. Pager Power recommends a pragmatic approach whereby instances of 'yellow' glare are evaluated in a technical and operational context. As per Pager Power's glint and glare guidance document[11], where solar reflections are of an intensity no greater than 'low potential for temporary after-image' expert assessment of the following relevant factors is required to determine the impact significance[12]:

- The likely traffic volumes and level of safeguarding at the aerodrome. Licensed aerodromes typically have higher traffic volumes and are formally safeguarded. Unlicensed aerodromes have greater capacity for operational acceptance.
- The time of day at which glare is predicted. Will the aerodrome be operational such that pilots can be on the approach at the time of day at which glare is predicted?
- The duration of any predicted glare. Glare that occurs for low durations throughout the year is less likely to be experienced than glare that occurs for longer durations throughout a year.
- The location of the source of glare relative to a pilot's primary field of view (50 degrees either side of the approach bearing). Do solar reflections occur directly in front of a pilot?
- The relative size of the reflecting panel area. Does the reflecting area make up a large percentage of a pilot's primary field of view?
- The location of the source of glare relative to the position of the Sun at the times and dates in which solar reflections are geometrically possible. Effects that coincide with direct sunlight appear less prominent than those that do not.
- The intensity of the predicted glare. Is the intensity of glare close to the green/yellow glare threshold on the intensity chart?
- The level of predicted effect relative to existing sources of glare. A solar reflection is less noticeable by pilots when there are existing reflective surfaces in the surrounding environment.

[10] This FAA guidance from 2013 has since been superseded by the FAA guidance in 2021 whereby airports are tasked with determining safety requirements themselves.
[11] Pager Power Glint and Glare Guidance, Fourth Edition, September 2022.
[12] This approach taken is reflective of the changes made in the 2021 FAA guidance; however, it should be noted that this guidance states that it is up to the airport to determine the safety requirements themselves. Therefore, an airport may not accept any yellow glare towards approach paths.

Following consideration of these mitigating factors, where the solar reflection does not remain significant, a low impact is predicted, and mitigation is not recommended; however, consultation with the aerodrome is recommended to understand their position along with any feedback or comments regarding the proposed development. Where the solar reflection remains significant, the impact significance is moderate, and mitigation is recommended.

Where solar reflections are of an intensity greater than ‘potential for temporary after-image’, the impact significance is high, and mitigation is required.

5.3.2 Results Discussion

Table 5 and 6 below and on the following pages present the following:

- Geometric modelling results;
- Glare intensity;
- Comment and predicted impact significance.

Reference to a pilot's primary field-of-view is made when analysing the geometric results. A pilot's primary field-of-view is defined as 50 degrees either side of the runway approach relative to the runway threshold.

5.3.2.1 Red House Farm Airfield

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Impact Classification	Mitigation Recommended?
Runway 02	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 20 (threshold – 1.2 miles)	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 20 (1.2 miles – 2 miles)	Solar reflections with a 'potential for temporary after-image' are predicted.		Consideration within an operational context is required see Section 5.6.3.	Low impact	No

Table 5 *Geometric modelling results – Red House Farm Aviation Receptors*

5.3.2.2 Wingland Airfield

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Impact Classification	Mitigation Recommended?
Runway 02	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 20	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 06	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 24	Solar reflections with a 'low potential for temporary after-image' are predicted.		This level of glare intensity is acceptable in accordance with the associated guidance and industry best practice.	Low impact.	No.
Runway 14	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No

Receptor/Runway	Geometric Modelling Result	Glare Intensity	Comment	Impact Classification	Mitigation Recommended?
Runway 32	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 16	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No
Runway 34	Solar reflections are not geometrically possible	N/A	No impact predicted	No impact	No

Table 6 *Geometric modelling results –Wingland Aviation Receptors*

5.3.3 Further Analysis in an Operational Context

In cases where glare with potential for a temporary after-image is predicted, effects must be evaluated in an operational context. This includes consideration of:

- The type of airfield and the likely air traffic volumes;
- The impact of direct sunlight on pilots approaching the airfield;
- The extent to which glint and glare effects and direct sunlight are similar;
- Whether the measures pilots use to mitigate direct sunlight will also mitigate glint and glare.

There are many measures that pilots regularly employ to counter the effects of direct sunlight. These mitigation measures include:

- Wearing sunglasses;
- Using darkened cockpit sun visors to reduce the intensity of the sun;
- Overflying the airfield and inspecting the runway prior to landing;
- Landing in the opposite direction if wind conditions allow;
- Landing at an alternate airfield;
- Planning the flight to land at a different time;
- Aborting their landing if uncertain that it is to be successful (known as a missed approach or a go-around).

The suitability of these options is influenced by many factors including the aerodrome type. Red House Farm Airfield is a small unlicensed airfield with one grass runway and low air traffic volumes.

It is known that direct solar reflections from reflective surfaces, including solar panels, can be a distraction to pilots. The mitigation measures pilots use to mitigate the effects of direct sunlight can all be used to mitigate the effects of direct solar reflections from the solar panels.

A technical assessment has been undertaken to predict dates and times at which direct solar reflections will occur. The assessment has considered approaching aircraft and shows that aircraft approaching from the east could experience yellow glare from south-facing panels between 4.00pm and 5.50pm and would occur from late January to mid-March and late September to early November. The instances of 'yellow' glare are predicted for a maximum of 1,290 minutes in total per year. This represents a very small proportion of time compared to average daylight hours in any one year (0.491%[13]). The maximum duration would be for less than 38 minutes on the days when the glare is possible. In practice, effects are likely to be noticeable for at most a few minutes as an aircraft is moving towards the runway threshold.

[13] Based on 4380 daylight hours per year

The weather would have to be clear and sunny at the specific times when the glare was possible to be experienced. A pilot would also have to be on the approach path at the specific times and dates when solar reflections are geometrically possible.

Overall, no significant impacts are predicted and no mitigation is recommended.

6 HIGH-LEVEL AVIATION CONSIDERATIONS

6.1 Overview

Lutton-Garnsgate Airfield is an unlicensed airfield located approximately 7.8km south of the proposed development, as shown in Figure 20 below. The airport has one runway, 09/27, and is understood not to have an ATC tower.

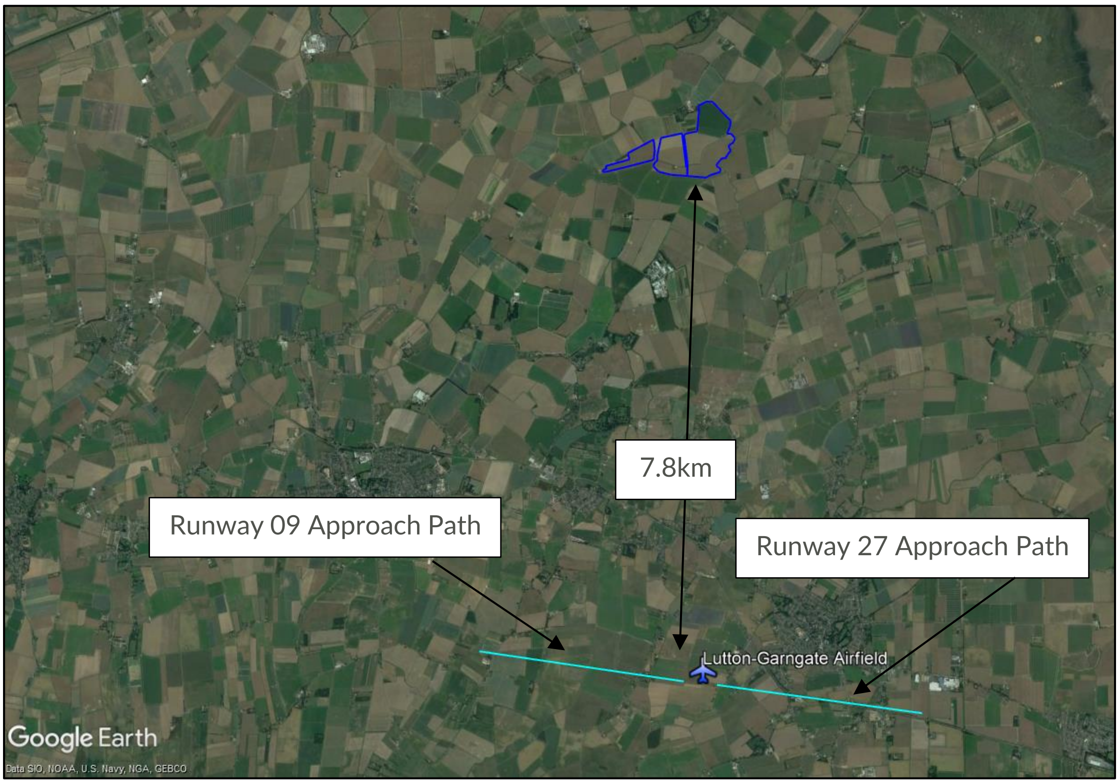

Figure 20 *Lutton-Garnsgate Airfield relative to the proposed development*

6.2 High-Level Conclusion

Considering the size of the proposed development, its location relative to Lutton-Garnsgate Airfield and its distance from the aerodrome, it can be reliably concluded that the proposed development will be outside a pilot's primary field of view (50 degrees either side of the approach bearing) along the 2-mile approach path towards runway thresholds 09 and 27. This is acceptable in accordance with the associated guidance and industry best practice.

Therefore, no significant impacts upon aviation activity associated with Lutton-Garnsagte Airfield are predicted, and no detailed modelling is recommended.

7 OVERALL CONCLUSIONS

7.1 Dwelling Receptors

The results of the analysis have shown that solar reflections are geometrically possible for six of the eight assessed dwellings. No impacts are predicted for two of these dwellings due to the presence of existing screening in the form of vegetation and buildings significantly obstructing visibility of the reflecting panel area. Therefore, no mitigation is required.

For the remaining dwellings experiencing solar reflections, a low impact is predicted due to the presence of mitigating factors, including:

- A large separation distance between the dwelling and the reflecting panel area;
- Partial existing screening;
- Effects coinciding with sunlight which is a more prominent source of light.

7.2 Road Receptors

The roads surrounding the proposed development are considered local roads where traffic densities are likely to be relatively low. Technical modelling 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.

Therefore, no significant impacts upon road users along the surrounding roads are predicted, and mitigation is not recommended.

7.3 Aviation Receptors

Solar reflections are not geometrically possible towards the identified 2-mile approach paths for runways 02/20, 14/32, 16/34, and 06 at Wingland Airfield and runway 02 for Red House Farm Airfield. Therefore no impacts are predicted and no mitigation is required.

Solar reflections with a 'low potential for temporary after-image' are geometrically possible towards the 2-mile approach path for runway 24 at Wingland Airfield. This is acceptable in accordance with the associated guidance and industry best practice and mitigation is not required.

Solar reflections with 'potential for temporary after-image' are geometrically possible towards a 0.8 mile section of the 2-mile approach path for runway 20 at Red house Farm Airfield. There are mitigating factors that reduce the overall impact. In particular, effects are predicted to occur for a short duration of time throughout the year (1,290 minutes which is 0.491% of daylight hours), with a maximum duration of less than 38 minutes on the days when the glare is possible.

Overall, it is judged that the potential effects towards the runway 20 approach at Red House Farm Airfield can be operationally accommodated. It is expected that operational measures used by pilots to mitigate the effects of direct sunlight (see Section 5.6.3 for further details) will adequately mitigate the effects of solar glare from the panels.

It is recommended that the potential glare times are made available to the owner of the airfield so that it can be considered in the context of their operations.

7.4 High-Level Aviation

Considering the size of the proposed development, its location relative to Lutton-Garnsgate Airfield and its distance from the aerodrome, it can be reliably concluded that the proposed development will be outside a pilot's primary field of view (50 degrees either side of the approach bearing) along the 2-mile approach path towards runway thresholds 09 and 27. This is acceptable in accordance with the associated guidance and industry best practice.

Therefore, no significant impacts upon aviation activity associated with Lutton-Garnsagte Airfield are predicted, and no detailed modelling is recommended.

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

Renewable and Low Carbon Energy

The National Planning Policy Framework under the planning practice guidance for Renewable and Low Carbon Energy[14] (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.'

[14] Renewable and low carbon energy, Ministry of Housing, Communities & Local Government, date: 18 June 2015, accessed on: 01/11/2021

Draft National Policy Statement for Renewable Energy Infrastructure

The Draft National Policy Statement for Renewable Energy Infrastructure (EN-3)[15] sets out the primary policy for decisions by the Secretary of State for nationally significant renewable energy infrastructure. Section 2.52 states:

'2.52.1 Solar panels may reflect the sun's rays, causing glint and glare. Glint is defined as a momentary flash of light that may be produced as a direct reflection of the sun in the solar panel. Glare is a continuous source of excessive brightness experienced by a stationary observer located in the path of reflected sunlight from the face of the panel. The effect occurs when the solar panel is stationed between or at an angle of the sun and the receptor.

2.52.2 In some instances, it may be necessary to seek a glint and glare assessment as part of the application. This may need to account for 'tracking' panels if they are proposed as these may cause differential diurnal and/or seasonal impacts. The potential for solar PV panels, frames and supports to have a combined reflective quality should be assessed. This assessment needs to consider the likely reflective capacity of all of the materials used[16] in the construction of the solar PV farm.

2.52.3 Applicants should consider using, and in some cases the Secretary of State may require, solar panels to be of a non-glare/ non-reflective type and the front face of the panels to comprise of (or be covered) with a non-reflective coating for the lifetime of the permission.

2.52.4 Solar PV panels are designed to absorb, not reflect, irradiation. However, the Secretary of State should assess the potential impact of glint and glare on nearby homes and motorists.

2.52.5 There is no evidence that glint and glare from solar farms interferes in any way with aviation navigation or pilot and aircraft visibility or safety. Therefore, the Secretary of State is unlikely to have to give any weight to claims of aviation interference as a result of glint and glare from solar farms.'

Consultation to determine whether EN-3 provides a suitable framework to support decision making for nationally significant energy infrastructure ended in November 2021. Pager Power is aware that aviation stakeholders were not consulted prior to the publication of the draft policy and understands that they will still request a glint and glare assessment on the basis that glare may lead to impact upon aviation safety. It is possible that the draft policy will change in light of the consultation responses from aviation stakeholders.

Finally, it should be noted that the EN-3 relates solely to nationally significant renewable energy infrastructure and therefore does not apply to all planning applications for solar farms.

Assessment Process – Ground-Based Receptors

No process for determining and contextualising the effects of glint and glare has been determined when assessing the impact of solar reflections upon surrounding roads and dwellings.

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[15] Draft National Policy Statement for Renewable Energy Infrastructure (EN-3), Department for Business, Energy & Industrial Strategy, date: September 2021, accessed on: 01/11/2021.

[16] In Pager Power's experience, the solar panels themselves are the overriding source of specular reflections which have the potential to cause significant impacts upon safety or amenity.

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[17] which was produced due to the absence of existing guidance and a specific standardised assessment methodology.

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[18] however the advice is still applicable[19] 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[20], 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

[17] Solar Photovoltaic Development Glint and Glare Guidance, Third Edition V3.1, May 2021. Pager Power.

[18] Archived at Pager Power

[19] Reference email from the CAA dated 19/05/2014.

[20] Aerodrome Licence Holder.

approval to the developer or LPA is granted, in accordance with the procedures set out in CAP 791 Procedures for Changes to Aerodrome Infrastructure.

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 has been produced by the United States Federal Aviation Administration (FAA). The first guidelines were produced initially in November 2010 and updated in 2013. A final policy was released in 2021, which superseded the interim guidance.

The 2010 document is entitled '*Technical Guidance for Evaluating Selected Solar Technologies on Airports'*[21], the 2013 update is entitled '*Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports'*[22], and the 2021 final policy is entitled '*Federal Aviation Administration Policy: Review of Solar Energy System Projects on Federally-Obligated Airports'*[23].

Key excerpts from the final policy are presented below:

Initially, FAA believed that solar energy systems could introduce a novel glint and glare effect to pilots on final approach. FAA has subsequently concluded that in most cases, the glint and glare from solar energy systems to pilots on final approach is similar to glint and glare pilots routinely experience from water bodies, glass-façade buildings, parking lots, and similar features. However, FAA has continued to receive reports of potential glint and glare from on-airport solar energy systems on personnel working in ATCT cabs. Therefore, FAA has determined the scope of agency policy should be focused on the impact of on-airport solar energy systems to federally-obligated towered airports, specifically the airport's ATCT cab.

The policy in this document updates and replaces the previous policy by encouraging airport sponsors to conduct an ocular analysis of potential impacts to ATCT cabs prior to submittal of a Notice of Proposed Construction or Alteration Form 7460-1 (hereinafter Form 7460-1). Airport sponsors are no longer required to submit the results of an ocular analysis to FAA. Instead, to demonstrate compliance with 14 CFR 77.5(c), FAA will rely on the submittal of Form 7460-1 in which the sponsor confirms that it has analyzed the potential for glint and glare and determined there is no potential for ocular

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[21] Archived at Pager Power

[22] 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: 08/12/2021.

[23] Federal Aviation Administration Policy: Review of Solar Energy System Projects on Federally-Obligated Airports, Federal Aviation Administration, date: May 2021, accessed on: 08/12/2021.

impact to the airport's ATCT cab. This process will enable FAA to evaluate the solar energy system project, with assurance that the system will not impact the ATCT cab.

FAA encourages airport sponsors of federally-obligated towered airports to conduct a sufficient analysis to support their assertion that a proposed solar energy system will not result in ocular impacts. There are several tools available on the open market to airport sponsors that can analyze potential glint and glare to an ATCT cab. For proposed systems that will clearly not impact ATCT cabs (e.g., on-airport solar energy systems that are blocked from the ATCT cab's view by another structure), the use of such tools may not be necessary to support the assertion that a proposed solar energy system will not result in ocular impacts.

The excerpt above states where a solar PV development is to be located on a federally obligated aerodrome with an ATC Tower, it will require a glint and glare assessment to accompany its application. It states that pilots on approach are no longer a specific assessment requirement due to effects from solar energy systems being similar to glint and glare pilots routinely experience from water bodies, glass-façade buildings, parking lots, and similar features. Ultimately it comes down to the specific aerodrome to ensure it is adequately safeguarded, and it is on this basis that glint and glare assessments are routinely still requested.

The policy also states that several different tools and methodologies can be used to assess the impacts of glint and glare, which was previously required to be undertaken by the Solar Glare Hazard Analysis Tool (SGHAT) using the Sandia National Laboratories methodology.

In 2018, the FAA released the latest version (Version 1.1) of the '*Technical Guidance for Evaluating Selected Solar Technologies on Airports*'[24]. Whilst the 2021 final policy also supersedes this guidance, many of the points are still relevant because aerodromes are still safeguarding against glint and glare irrespective of the FAA guidance. The key points are presented below for reference:

- *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*[25].
- *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*[26]*, 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.*

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[24] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.

[25] 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.

[26] First figure in Appendix B.

- *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 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[27] *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.*

Air Navigation Order (ANO) 2016

In some instances, an aviation stakeholder can refer to the ANO 2016[28] with regard to safeguarding. Key points from the document are presented below.

Lights liable to endanger

224. (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

225. 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.

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[27] 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.

[28] The Air Navigation Order 2016. [online] Available at: <https://www.legislation.gov.uk/uksi/2016/765/contents/made> [Accessed 4 February 2022].

Endangering safety of an aircraft

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

Endangering safety of any person or property

241. A person must not recklessly or negligently cause or permit an aircraft to endanger any person or property.

APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

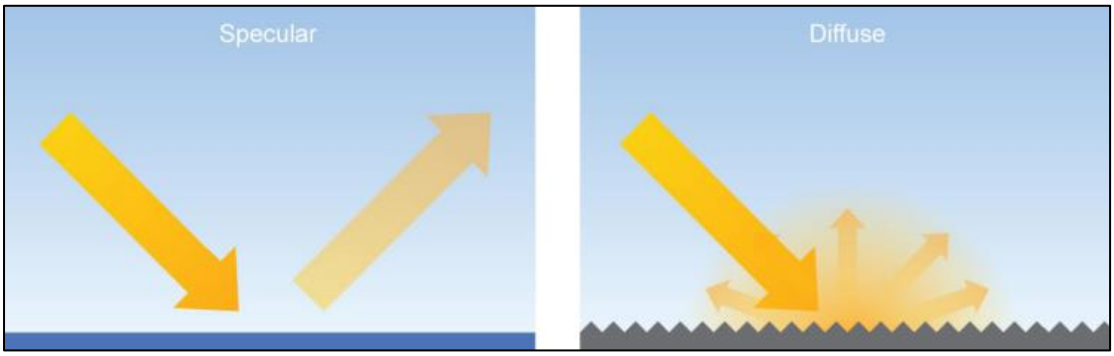
Overview

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[29], 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

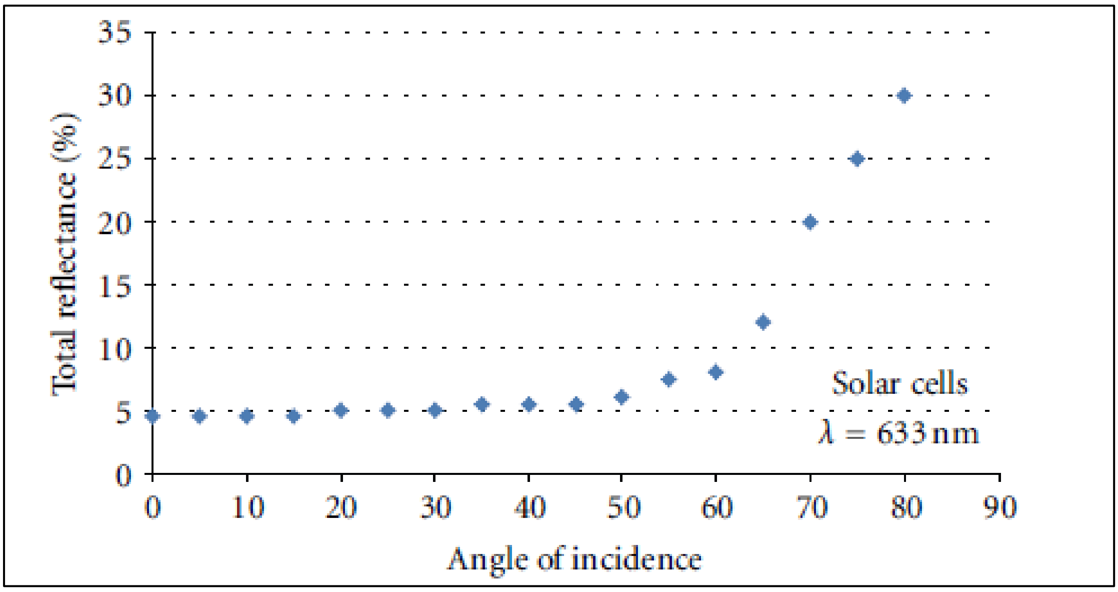
[29] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.

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*[30]". 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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[30] 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"[31]

The 2018 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[32]
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.

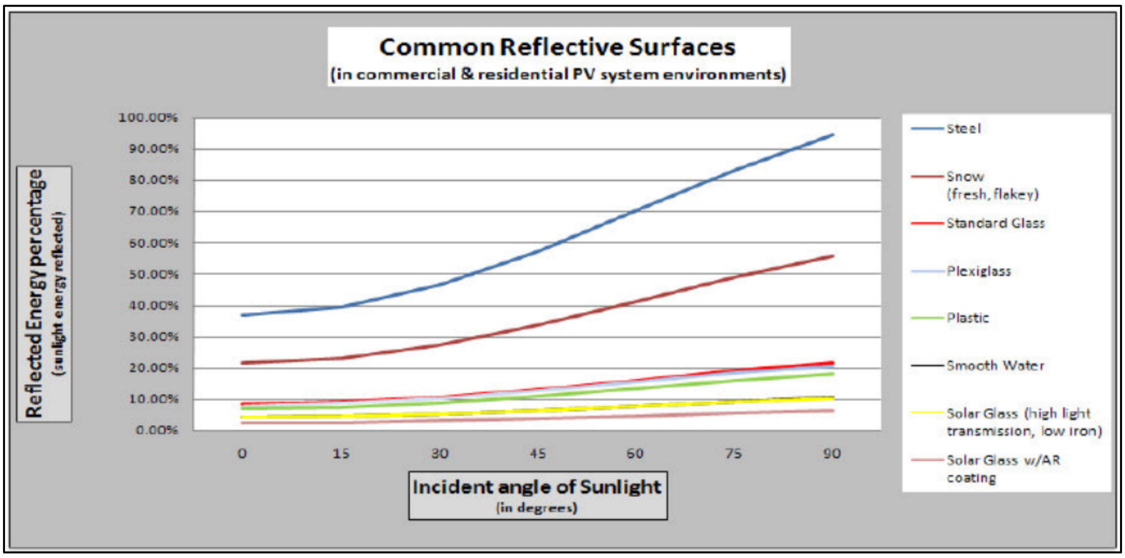
[31] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 08/12/2021.

[32] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[33] 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.

[33] 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.

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

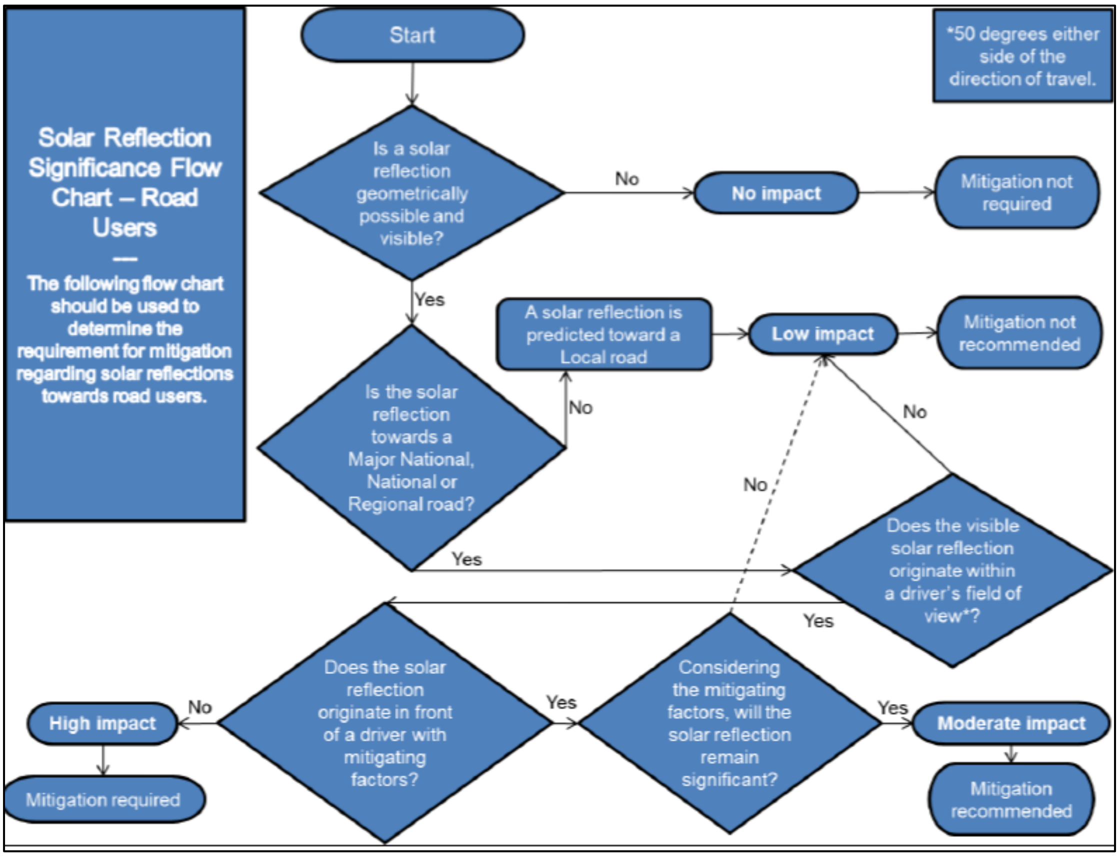
The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

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 significantly.	No mitigation recommended.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case given individual receptor criteria.	Mitigation recommended.
Major	A solar reflection is geometrically possible and visible under worst-case conditions that will produce a significant impact given individual receptor criteria	Mitigation will be required if the proposed development is to proceed.

Impact significance definition

Assessment Process for Road Receptors

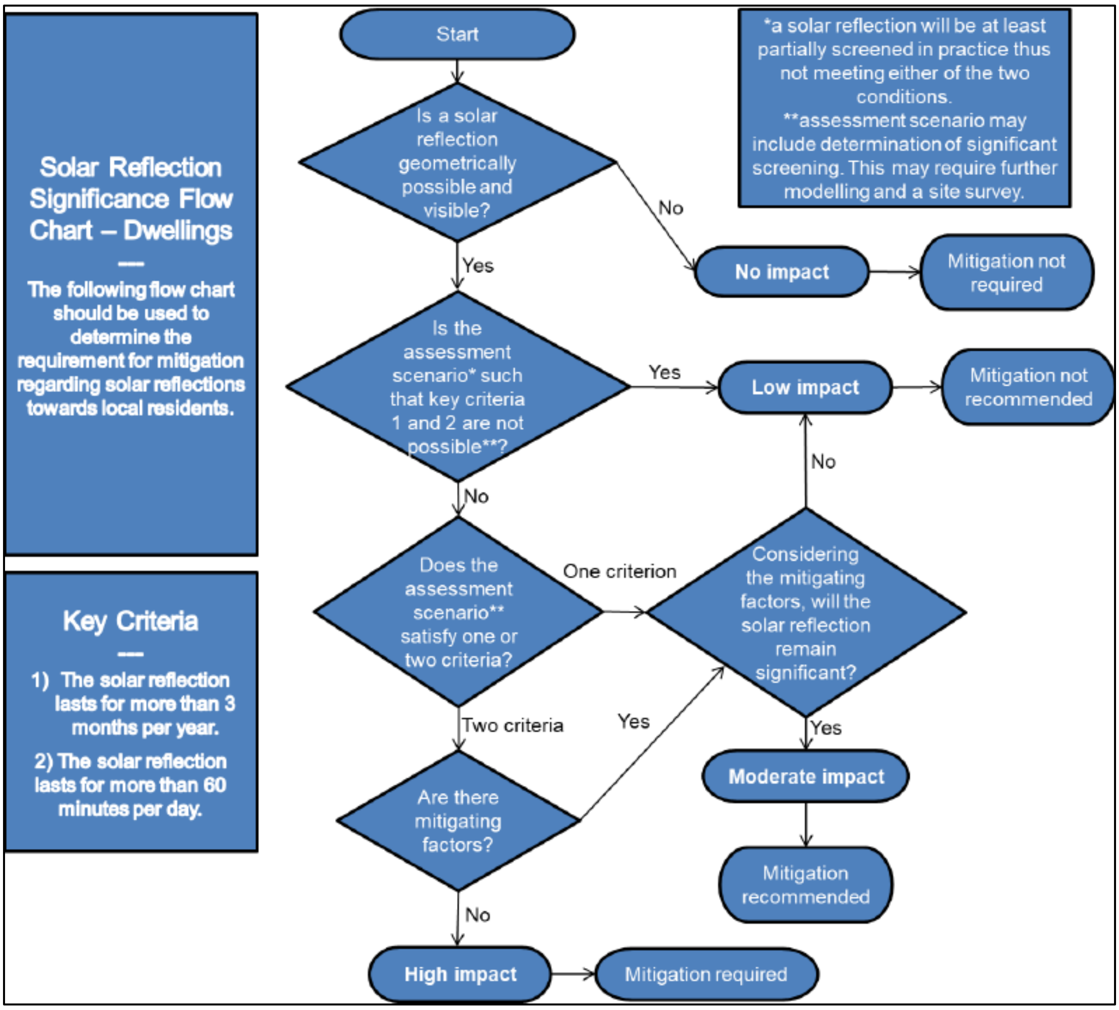
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Assessment Process for Dwelling Receptors

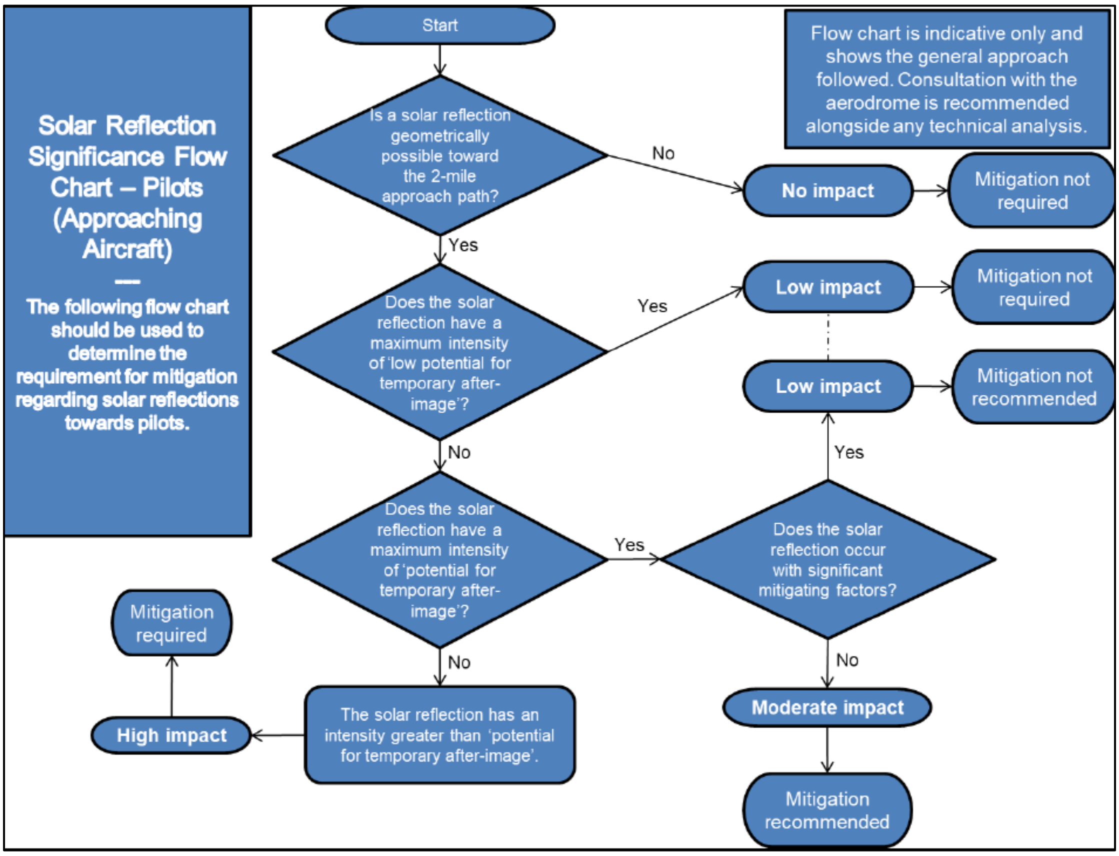
The flow chart presented below has been followed when determining the mitigation requirement for dwelling receptors.



Dwelling receptor mitigation requirement flow chart

Assessment Process – Approaching Aircraft

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



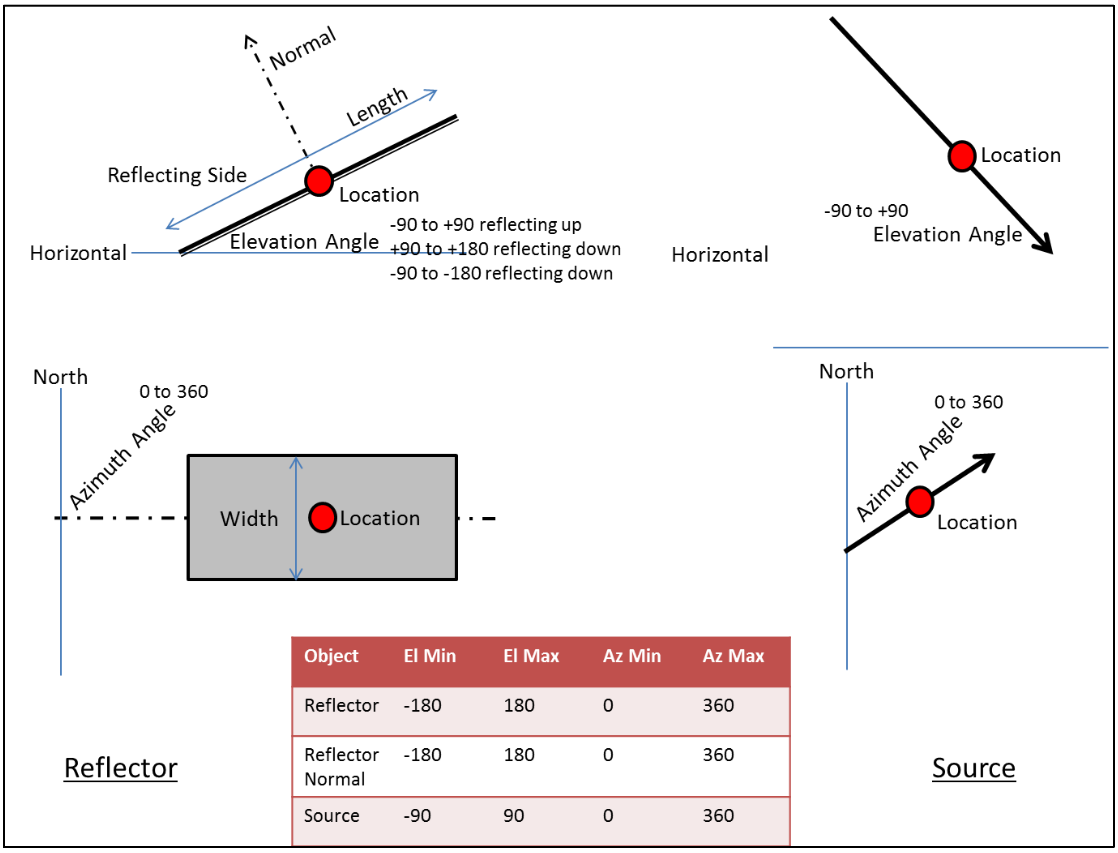
Approaching aircraft receptor mitigation requirement flow chart

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

Forge's Sandia National Laboratories' (SGHAT) Model

The following text is taken from Forge[34] 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.

[34] 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	0.06406	52.85111	5	0.09349	52.86292
2	0.07707	52.85577	6	0.11032	52.85685
3	0.08910	52.85779	7	0.11028	52.85721
4	0.09077	52.85989	8	0.06028	52.85192

Dwelling data

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 (19.24m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.10796	52.83164	Threshold	19.24
2	0.10691	52.83034	160.9	27.67
3	0.10587	52.82903	321.9	36.11
4	0.10482	52.82773	482.8	44.54
5	0.10378	52.82642	643.7	52.98
6	0.10274	52.82512	804.7	61.41
7	0.10169	52.82382	965.6	69.85
8	0.10065	52.82251	1126.5	78.28

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
9	0.09960	52.82121	1287.5	86.71
10	0.09856	52.81991	1448.4	95.15
11	0.09752	52.81860	1609.3	103.58
12	0.09647	52.81730	1770.3	112.02
13	0.09543	52.81599	1931.2	120.45
14	0.09438	52.81469	2092.1	128.88
15	0.09334	52.81339	2253.1	137.32
16	0.09230	52.81208	2414.0	145.75
17	0.09125	52.81078	2575.0	154.19
18	0.09021	52.80948	2735.9	162.62
19	0.08916	52.80817	2896.8	171.06
20	0.08812	52.80687	3057.8	179.49
21	0.08708	52.80556	2 miles	187.92

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 (18.24m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11280	52.83785	Threshold	18.24
2	0.11376	52.83917	160.9	26.67
3	0.11471	52.84050	321.9	35.11
4	0.11567	52.84183	482.8	43.54

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
5	0.11663	52.84316	643.7	51.98
6	0.11759	52.84448	804.7	60.41
7	0.11854	52.84581	965.6	68.85
8	0.11950	52.84714	1126.5	77.28
9	0.12046	52.84847	1287.5	85.71
10	0.12142	52.84979	1448.4	94.15
11	0.12237	52.85112	1609.3	102.58
12	0.12333	52.85245	1770.3	111.02
13	0.12429	52.85378	1931.2	119.45
14	0.12525	52.85511	2092.1	127.88
15	0.12620	52.85643	2253.1	136.32
16	0.12716	52.85776	2414.0	144.75
17	0.12812	52.85909	2575.0	153.19
18	0.12908	52.86042	2735.9	161.62
19	0.13003	52.86174	2896.8	170.06
20	0.13099	52.86307	3057.8	178.49
21	0.13195	52.86440	2 miles	186.92

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

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 (18.24m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.12977	52.81305	Threshold	18.24
2	0.12861	52.81178	160.9	26.67
3	0.12745	52.81051	321.9	35.11
4	0.12630	52.80924	482.8	43.54
5	0.12514	52.80798	643.7	51.98
6	0.12398	52.80671	804.7	60.41
7	0.12282	52.80544	965.6	68.85
8	0.12166	52.80417	1126.5	77.28
9	0.12051	52.80290	1287.5	85.71
10	0.11935	52.80164	1448.4	94.15
11	0.11819	52.80037	1609.3	102.58
12	0.11703	52.79910	1770.3	111.02
13	0.11587	52.79783	1931.2	119.45
14	0.11472	52.79656	2092.1	127.88
15	0.11356	52.79530	2253.1	136.32
16	0.11240	52.79403	2414.0	144.75
17	0.11124	52.79276	2575.0	153.19
18	0.11008	52.79149	2735.9	161.62
19	0.10893	52.79022	2896.8	170.06

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
20	0.10777	52.78896	3057.8	178.49
21	0.10661	52.78769	2 miles	186.92

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 (68.3m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11476	52.81501	Threshold	18.24
2	0.11591	52.81628	160.9	26.67
3	0.11706	52.81755	321.9	35.11
4	0.11821	52.81882	482.8	43.54
5	0.11936	52.82009	643.7	51.98
6	0.12051	52.82136	804.7	60.41
7	0.12166	52.82263	965.6	68.85
8	0.12282	52.82390	1126.5	77.28
9	0.12397	52.82517	1287.5	85.71
10	0.12512	52.82644	1448.4	94.15
11	0.12627	52.82771	1609.3	102.58
12	0.12742	52.82898	1770.3	111.02
13	0.12857	52.83025	1931.2	119.45
14	0.12973	52.83152	2092.1	127.88
15	0.13088	52.83279	2253.1	136.32

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
16	0.13203	52.83406	2414.0	144.75
17	0.13318	52.83533	2575.0	153.19
18	0.13433	52.83660	2735.9	161.62
19	0.13548	52.83787	2896.8	170.06
20	0.13663	52.83914	3057.8	178.49
21	0.13779	52.84041	2 miles	186.92

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

The Approach Path for Aircraft Landing on Runway 06

The table below presents the data for the assessed locations for aircraft on approach to runway 06. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (67.7m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11222	52.81459	Threshold	18.24
2	0.10988	52.81426	160.9	26.67
3	0.10755	52.81394	321.9	35.11
4	0.10521	52.81362	482.8	43.54
5	0.10288	52.81329	643.7	51.98
6	0.10054	52.81297	804.7	60.41
7	0.09820	52.81265	965.6	68.85
8	0.09587	52.81233	1126.5	77.28
9	0.09353	52.81200	1287.5	85.71
10	0.09120	52.81168	1448.4	94.15
11	0.08886	52.81136	1609.3	102.58

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
12	0.08652	52.81104	1770.3	111.02
13	0.08419	52.81071	1931.2	119.45
14	0.08185	52.81039	2092.1	127.88
15	0.07952	52.81007	2253.1	136.32
16	0.07718	52.80975	2414.0	144.75
17	0.07484	52.80942	2575.0	153.19
18	0.07251	52.80910	2735.9	161.62
19	0.07017	52.80878	2896.8	170.06
20	0.06783	52.80846	3057.8	178.49
21	0.06550	52.80813	2 miles	186.92

Assessed receptor (aircraft) locations on the approach path for runway 06

The Approach Path for Aircraft Landing on Runway 24

The table below presents the data for the assessed locations for aircraft on approach to runway 24. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (68.3m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11452	52.81492	Threshold	18.24
2	0.11685	52.81523	160.9	26.67
3	0.11919	52.81555	321.9	35.11
4	0.12153	52.81586	482.8	43.54
5	0.12387	52.81618	643.7	51.98
6	0.12621	52.81649	804.7	60.41
7	0.12855	52.81681	965.6	68.85

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
8	0.13089	52.81712	1126.5	77.28
9	0.13323	52.81744	1287.5	85.71
10	0.13557	52.81775	1448.4	94.15
11	0.13791	52.81807	1609.3	102.58
12	0.14024	52.81838	1770.3	111.02
13	0.14258	52.81870	1931.2	119.45
14	0.14492	52.81901	2092.1	127.88
15	0.14726	52.81933	2253.1	136.32
16	0.14960	52.81964	2414.0	144.75
17	0.15194	52.81996	2575.0	153.19
18	0.15428	52.82027	2735.9	161.62
19	0.15662	52.82059	2896.8	170.06
20	0.15896	52.82090	3057.8	178.49
21	0.16129	52.82122	2 miles	186.92

Assessed receptor (aircraft) locations on the approach path for runway 24

The Approach Path for Aircraft Landing on Runway 14

The table below presents the data for the assessed locations for aircraft on approach to runway 14. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (67.7m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11177	52.81483	Threshold	19.24
2	0.11023	52.81595	160.9	27.67
3	0.10870	52.81706	321.9	36.11

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
4	0.10716	52.81817	482.8	44.54
5	0.10562	52.81928	643.7	52.98
6	0.10409	52.82039	804.7	61.41
7	0.10255	52.82150	965.6	69.85
8	0.10101	52.82261	1126.5	78.28
9	0.09948	52.82372	1287.5	86.71
10	0.09794	52.82484	1448.4	95.15
11	0.09640	52.82595	1609.3	103.58
12	0.09487	52.82706	1770.3	112.02
13	0.09333	52.82817	1931.2	120.45
14	0.09179	52.82928	2092.1	128.88
15	0.09026	52.83039	2253.1	137.32
16	0.08872	52.83150	2414.0	145.75
17	0.08718	52.83261	2575.0	154.19
18	0.08564	52.83373	2735.9	162.62
19	0.08411	52.83484	2896.8	171.06
20	0.08257	52.83595	3057.8	179.49
21	0.08103	52.83706	2 miles	187.92

Assessed receptor (aircraft) locations on the approach path for runway 14

The Approach Path for Aircraft Landing on Runway 32

The table below presents the data for the assessed locations for aircraft on approach to runway 32. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (68.3m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11271	52.81307	Threshold	18.24
2	0.11421	52.81194	160.9	26.67
3	0.11571	52.81082	321.9	35.11
4	0.11722	52.80969	482.8	43.54
5	0.11872	52.80856	643.7	51.98
6	0.12022	52.80743	804.7	60.41
7	0.12173	52.80631	965.6	68.85
8	0.12323	52.80518	1126.5	77.28
9	0.12473	52.80405	1287.5	85.71
10	0.12624	52.80292	1448.4	94.15
11	0.12774	52.80179	1609.3	102.58
12	0.12924	52.80067	1770.3	111.02
13	0.13075	52.79954	1931.2	119.45
14	0.13225	52.79841	2092.1	127.88
15	0.13375	52.79728	2253.1	136.32
16	0.13526	52.79616	2414.0	144.75
17	0.13676	52.79503	2575.0	153.19
18	0.13826	52.79390	2735.9	161.62
19	0.13977	52.79277	2896.8	170.06

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
20	0.14127	52.79164	3057.8	178.49
21	0.14277	52.79052	2 miles	186.92

Assessed receptor (aircraft) locations on the approach path for runway 32

The Approach Path for Aircraft Landing on Runway 16

The table below presents the data for the assessed locations for aircraft on approach to runway 16. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (19.24m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11170	52.81483	Threshold	19.24
2	0.11088	52.81619	160.9	27.67
3	0.11006	52.81755	321.9	36.11
4	0.10925	52.81891	482.8	44.54
5	0.10843	52.82028	643.7	52.98
6	0.10761	52.82164	804.7	61.41
7	0.10680	52.82300	965.6	69.85
8	0.10598	52.82436	1126.5	78.28
9	0.10516	52.82572	1287.5	86.71
10	0.10435	52.82708	1448.4	95.15
11	0.10353	52.82845	1609.3	103.58
12	0.10271	52.82981	1770.3	112.02
13	0.10190	52.83117	1931.2	120.45
14	0.10108	52.83253	2092.1	128.88
15	0.10026	52.83389	2253.1	137.32

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
16	0.09944	52.83525	2414.0	145.75
17	0.09863	52.83661	2575.0	154.19
18	0.09781	52.83798	2735.9	162.62
19	0.09699	52.83934	2896.8	171.06
20	0.09618	52.84070	3057.8	179.49
21	0.09536	52.84206	2 miles	187.92

Assessed receptor (aircraft) locations on the approach path for runway 16

The Approach Path for Aircraft Landing on Runway 34

The table below presents the data for the assessed locations for aircraft on approach to runway 34. The altitude of the aircraft is based on a 3-degree descent path referenced to 50 feet (15.2m) above the runway threshold (18.24m amsl).

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
1	0.11408	52.81322	Threshold	18.24
2	0.11481	52.81184	160.9	26.67
3	0.11555	52.81046	321.9	35.11
4	0.11628	52.80908	482.8	43.54
5	0.11702	52.80770	643.7	51.98
6	0.11775	52.80632	804.7	60.41
7	0.11849	52.80495	965.6	68.85
8	0.11922	52.80357	1126.5	77.28
9	0.11996	52.80219	1287.5	85.71
10	0.12069	52.80081	1448.4	94.15
11	0.12143	52.79943	1609.3	102.58

No.	Longitude (°)	Latitude (°)	Distance from Runway Threshold (m)	Assessed Altitude (m) (m amsl)
12	0.12216	52.79805	1770.3	111.02
13	0.12290	52.79667	1931.2	119.45
14	0.12363	52.79530	2092.1	127.88
15	0.12437	52.79392	2253.1	136.32
16	0.12510	52.79254	2414.0	144.75
17	0.12584	52.79116	2575.0	153.19
18	0.12657	52.78978	2735.9	161.62
19	0.12731	52.78840	2896.8	170.06
20	0.12804	52.78702	3057.8	178.49
21	0.12878	52.78565	2 miles	186.92

Assessed receptor (aircraft) locations on the approach path for runway 34

Modelled Reflector Data

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

Eastern Panel Area

Vertex number	Longitude (°)	Latitude (°)	Vertex number	Longitude (°)	Latitude (°)
1	0.09299	52.85745	16	0.09969	52.85176
2	0.09287	52.85723	17	0.10023	52.85210
3	0.09249	52.85478	18	0.09977	52.85256
4	0.08981	52.85444	19	0.09987	52.85290
5	0.08945	52.85430	20	0.10075	52.85320
6	0.09030	52.85011	21	0.10116	52.85371

Vertex number	Longitude (°)	Latitude (°)	Vertex number	Longitude (°)	Latitude (°)
7	0.09022	52.84857	22	0.10115	52.85386
8	0.09450	52.84836	23	0.10028	52.85444
9	0.09551	52.84870	24	0.09938	52.85445
10	0.09779	52.84914	25	0.10015	52.85563
11	0.09782	52.84965	26	0.10013	52.85627
12	0.09696	52.84991	27	0.09600	52.85888
13	0.09702	52.85026	28	0.09461	52.85893
14	0.09825	52.85107	29	0.09289	52.85839
15	0.09897	52.85104	30	0.09283	52.85781

Modelled reflector area – Eastern Panel Area

Mid Panel Area

Vertex number	Longitude (°)	Latitude (°)	Vertex number	Longitude (°)	Latitude (°)
1	0.08330	52.85065	16	0.09014	52.84858
2	0.08290	52.85055	17	0.09020	52.84972
3	0.08250	52.85022	18	0.09000	52.84973
4	0.08246	52.84991	19	0.08901	52.85451
5	0.08364	52.84917	20	0.08418	52.85388
6	0.08633	52.84878	21	0.08332	52.85149
7	0.08649	52.84875			

Modelled reflector area – Mid Panel Area

Western Panel Area

Vertex number	Longitude (°)	Latitude (°)	Vertex number	Longitude (°)	Latitude (°)
1	0.07726	52.85000	16	0.07072	52.84919
2	0.08248	52.85083	17	0.07124	52.84913
3	0.08274	52.85214	18	0.00000	52.85445
4	0.08247	52.85365	19	0.10015	52.85563
5	0.07655	52.85175	20	0.10013	52.85627
6	0.07687	52.85087	21	0.09600	52.85888
7	0.07142	52.84996	22	0.09461	52.85893
8	0.07163	52.84961	23	0.09289	52.85839
9	0.07078	52.84938	24	0.09283	52.85781

Modelled reflector area – Western Panel Area

APPENDIX H – DETAILLED MODELLING RESULTS

Model Output Charts

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

- The annual predicted solar reflections.
- The daily duration of the solar reflections.
- The location of the proposed development where glare will originate.
- The calculated intensity of the predicted solar reflections.

For approach paths, two further charts are shown within the Forge modelling results:

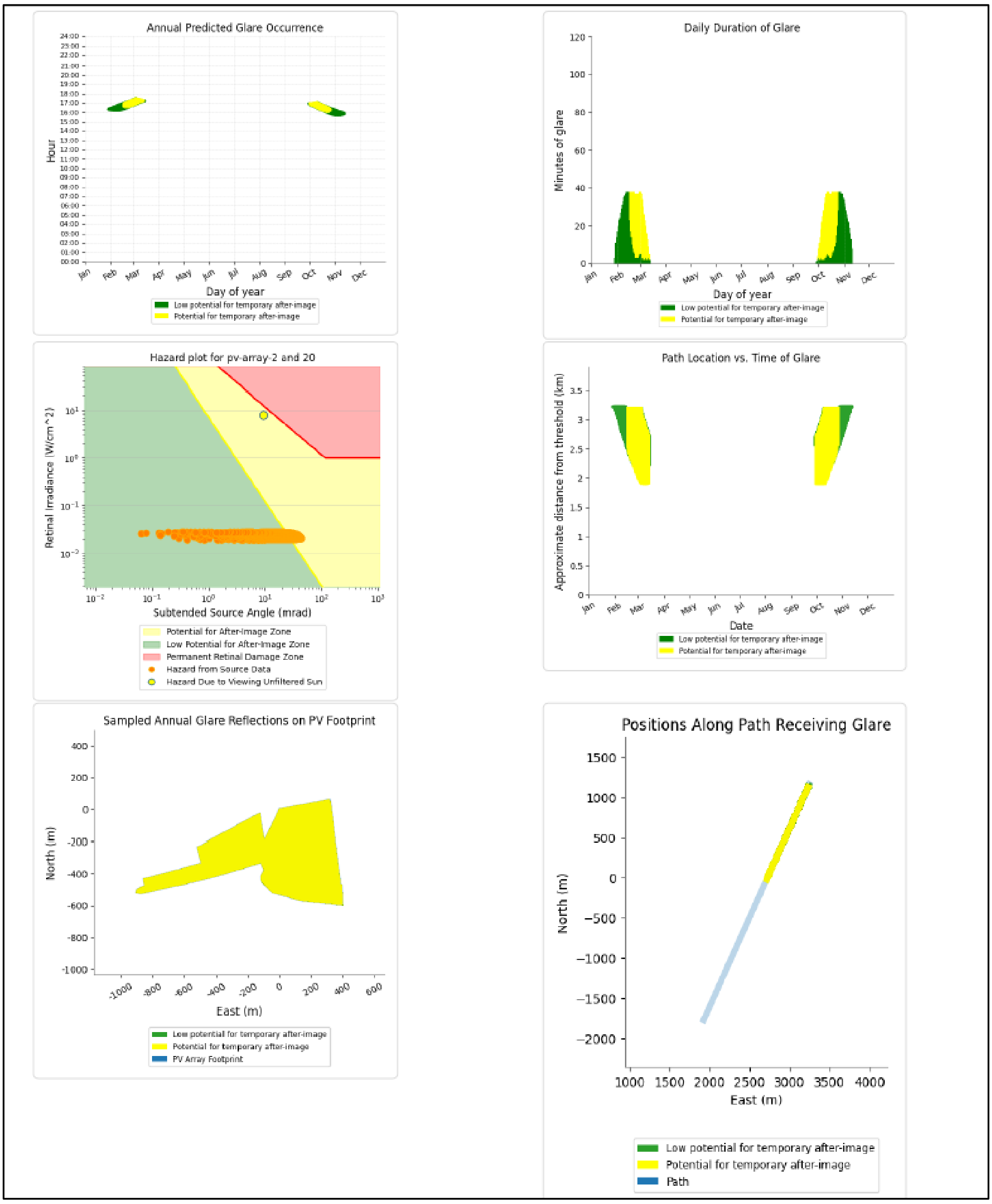
- Locations along the approach path receiving glare.
- The dates when glare would occur at each location along the approach.

Full modelling results can be provided upon request.

Aviation Receptors

Results have been included for all receptors where a ‘potential for temporary after-image’ has been predicted.

Modelling output for the remaining receptors can be provided on request.


Annual Predicted Glare Occurrence
Hour
Day of year
Low potential for temporary after-image
Potential for temporary after-image
Daily Duration of Glare
Minutes of glare
Day of year
Low potential for temporary after-image
Potential for temporary after-image
Hazard plot for pv-array-2 and 20
Retinal Irradiance (W/cm^2)
Subtended Source Angle (mrad)
Potential for After-image Zone
Low Potential for After-image Zone
Permanent Retinal Damage Zone
Hazard from Source Data
Hazard Due to Viewing Unfiltered Sun
Path Location vs. Time of Glare
Approximate distance from threshold (km)
Date
Low potential for temporary after-image
Potential for temporary after-image
Sampled Annual Glare Reflections on PV Footprint
North (m)
East (m)
Low potential for temporary after-image
Potential for temporary after-image
PV Array Footprint
Positions Along Path Receiving Glare
North (m)
East (m)
Low potential for temporary after-image
Potential for temporary after-image
Path

APPENDIX I – BACKTRACKING METHOD DISCUSSION

Modelling Solar Reflections

Modelling output for glint and glare modelling must quantify – at a minimum – the dates and times at which reflections are possible.

To do this requires some assumptions. Assumptions that are applied by Pager Power in its modelling include:

- That the sun is always unobstructed.
- That the panels are exactly aligned as proposed.
- The panels are perfectly smooth.

Responsible assumptions should ensure that the output presents a 'realistic worst-case scenario', that is the most significant impact that could reasonably be expected in real life.

Modelling Tracker Systems vs Modelling Fixed Systems

For fixed systems, the appropriate assumptions for generating a realistic worst-case scenario are relatively apparent and their consequences are quite straightforward to evaluate.

Quantifying predicted reflections from tracker systems leaves space for further assumptions with consequences that are more complex. The industry-standard model for evaluating tracker systems is based on the SGHAT model originally devised by Sandia Laboratories and currently hosted most prolifically by Forge Solar.

Factors that influence modelling output for tracker systems include:

1. Whether the system is a single or dual axis tracker.
2. The range of motion of the panels.
3. The backtracking behaviour of the system.

Point 3 above warrants particular attention. In general terms, the purpose of a tracker system is to keep the panels facing the Sun directly as far as possible for as long as possible. Backtracking is a mechanism by which the panel arrays are tilted to minimise shading each other – because the losses due to shading outweigh the gains from directing the array towards the Sun.

Backtracking occurs when the Sun is relatively low in the sky, this is also the time at which the majority of solar reflections are possible, particularly for ground-based receptors.

Therefore, changes to how backtracking is modelled have significant consequences for the level of predicted impact. This causes a non-linear trade-off between capturing the most realistic backtracking behaviour and ensuring that the results represent a realistic worst-case scenario.

Things that influence backtracking behaviour in a real system include:

a. How it is programmed.
b. The dimensions of the panels on each array.

c. The spacing between the arrays.
d. The slope of the terrain.

The most effective way of quantifying backtracking within the Forge Solar model has historically been via the 'resting angle', which relates to the panel configuration when the Sun's elevation is outside the tracker's range of motion.

More recently, options for more sophisticated parameters have been introduced, that allow incorporation of points a-d above to some extent (but not to their complete extent).

Pager Power's default approach is to model tracker systems using the original method i.e. based on the resting angle only. The predominant reasons for this are threefold:

- The additional modelling options are relatively new.
- The accuracy of the new options is difficult to independently verify.
- To optimise the output with reference to backtracking using the new options can require a level of partitioning that compromises other aspects of the output – specifically the cumulative intensity considerations.

Further evaluation of the effects of backtracking remains a viable option where significant impacts are predicted based on the worst-case.

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