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Wind Farm Aviation Safeguarding Ltd

Aviation Wind, Solar & Physical Safeguarding

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Glint and Glare Assessment

Hafod Road Solar

1 November 2024

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Issue

Wind Farm Aviation Safeguarding Ltd (WFAS) has been tasked with conducting an assessment of the potential Glint and Glare effects which might be experienced from a solar development at Hafod Road, East of Johnstown, Wrexham.

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Executive Summary

There is a proposal to develop a solar farm at Hafod Road, East of Johnstown, Wrexham.

The percentage of all sunlight reflected by modern solar panels is less than that reflected by bare soil or vegetation and on a par to open water (lakes) or that which might be expected from the hangars and industrial buildings around an airfield.

For this report sun position data for one year was predicted at 1-minute intervals and directions of solar reflections calculated for each data point. Given the extended lateral nature of the layout of the Proposed Development each array has been considered, and is reported on, singularly.

It should be noted that the results are calculated on a bare earth terrain data base; no allowance has been made for the screening effects of vegetation, development fencing or buildings between the dwellings assessed and the development.

For reflections from a solar array to have any potential to become an issue, the panels must be close to the direction of a viewer's main interest for extended periods. There is considered to be no possibility of 'flash blindness' from brief exposure to solar reflections given the high ambient light levels that must be present for such effects to occur; brief exposure to reflected sunlight from solar panels may be considered to be less significant than prolonged exposure.

The modelled receptors included the railway line to the west, the A483 to the east, the B5426 to the south, representative aviation routes and a sample of domestic properties within 1 km of the development location. It should be that the modelled Observation Points (OP) should not be regarded as a comprehensive list of those properties which could, potentially, be affected by a solar array but as a representative sample of all of the properties that could experience effects from the development. The sample was of those within the immediate vicinity of the development which may have line of sight, or partial line of sight, to the arrays.

Relying on the best experience of countries such as USA and Germany, and based on the best advice and wide body of research available together with Federal Aviation Administration modelling requirements there should be no effects on aviation in the area, no effects on the rail line to the west, no significant effects on domestic properties, no effects on traffic on the A384 and the potential effects on minor road traffic that might be experienced would appear to be transitory.

The results of the modelling show that there will be the potential for solar reflection at some assessed positions for very brief periods and at certain times of the year. The potential effects that could be experienced are either in the early morning or in the afternoon and are dependent on a number of factors including time of year, time of day, cloud cover etc. With that said, the albedo (measure of reflectance) of the PV modules is lower than other common surfaces in the surrounding area, including agricultural vegetation, windows on the nearby industrial units etc.

Where glare is possible the results demonstrate that glare may occur at that point if an individual is facing directly towards the array; no allowance can be made for the orientation of the individual receptor concerned and whether they are facing away or towards the direction of the solar panels.

The results of the modelling shown at the Annexes show that the results indicating that there will be the potential for glare at some of the assessed positions for brief periods during daylight hours and at certain times of the year.

Scope

WFAS have been tasked with writing a Glint and Glare assessment on the potential for effects from the proposed solar installation at Hafod Road, East of Johnstown, Wrexham.

The requirement was not to quantify the potential effect on all potential receptors likely to be affected but on the potential for the planned array to have an effect on potential receptors.

Based on the available information, and in combination with available guidance and best practice recommendations, a desk-based modelling assessment was undertaken to identify the potential for effects on various receptors in respect of the potential for glint and glare resulting from the installation. A solar glare analysis tool was utilised to model the solar PV array(s) and to examine the periods during the year (days, times etc.) when any such effects might occur.

The assessment considered any likely aviation effects and a sample of potentially sensitive viewpoints for road users. The nearby railway line was also considered as instances of solar reflection can also have the potential to affect train drivers' view of signals.

Time Zones

Unless otherwise specified, all times in this report are given in coordinated universal time (UTC) – equivalent to GMT for the purposes of this assessment.

Introduction

There is a proposal to develop a solar farm at Hafod Road, East of Johnstown, Wrexham.

The Proposed Development will consist of the construction of PV panels mounted on metal frames, access tracks, storage and welfare containers, combined inverter/ transformer units, with the panels aligned due south. Although there may be small amounts of glint and glare from the metal structures associated with the solar farm these are negligible and the main source of glint and glare will be from the panels themselves and this will be the focus of this assessment.

The overall site development is a single array as shown at Annex B. The site is generally surrounded by hedges, vegetation and trees whilst to the south is the former Hafod Quarry landfill site, to the west is Rhosllannerchrugog and to the north the Bonc-yr-Hafod Country Park.

Background - Solar Reflection (Glint and Glare) – Visual Impact

Glare, from whatever origin (natural or otherwise), is a phenomenon caused by the presence of bright light sources within the visual field. In extreme cases it can lead to visual discomfort and, if the glare source is very bright compared to the surrounding infrastructure, can cause difficulties in that objects can become difficult to discern/distinguish. The most meaningful research into potential effects has been conducted within the USA and is centred on aviation. Nevertheless, the modelling procedures and tools are considered just as relevant for assessing effects against ground-based receptors.

The Federal Aviation Authority (FAA) in their "Technical Guidance for Evaluating Selected Solar Technologies on Airports" have defined the terms 'Glint' and 'Glare' as meaning;

- Glint – "A momentary flash of bright light"
- Glare – "A continuous source of bright light"

In the UK there is little aviation guidance on the assessment of, or methods for, glint and glare from solar installations in respect of aviation safety or potential ground effects. (UK Government Policy definitions are on Page 10 – Definitions and Guidance.)

The Civil Aviation Authority (CAA) has published interim guidance on 'Solar Photovoltaic Systems'[1] with a view to undertaking a further review of the potential impacts of solar PV developments upon aviation but the date for which is, as yet, undetermined.

[1] December 2010.

In England the UK Government have published the National Planning Policy Framework for "Renewable and Low carbon energy"[2] which provides considerations to be applied in large scale solar development in relation to roads, railways, heritage sites etc. and includes aviation. This is also guidance within The Town and Country Planning (Environmental Impact Assessment) Regulations 2017, Planning Guidance for the Development of Large-Scale Ground Mounted Solar PV Systems and in the Building Research Establishment's guidance.

Collectively, the UK planning guidance requires the consideration of:

> "….*the proposal's visual impact, the effect on the landscape of glint and glare and on neighbouring uses and aircraft safety*….."[3]

The guidance states the effect of glint and glare should be considered in relation to the cumulative landscape and visual impact of a solar farm. No process for determining and contextualising the effects of glint and glare are provided. The WFAS approach is to utilise approved modelling software to determine if reflection from the proposed solar farm is geometrically possible at specified locations. Latitude, longitude, and PV panel elevation, together with the orientation and tilt of the PV panels, reflectance, environment, and ocular factors are used to determine the sun position and vector calculations in relation to solar reflection.

Solar panels are designed to absorb as much light as possible, and not to reflect it, but glint can be produced as a reflection of the sun from the surface of the solar PV panel. This can also be described as a momentary flash. This may be an issue due to visual impact and viewer distraction on ground-based receptors and on aviation.

With growing numbers of solar energy installations, glint/glare from PV arrays and concentrating solar systems has received increased attention as a potential hazard or distraction for pilots, air-traffic control personnel, dwellings, drivers, train drivers, pilots, motorists, and others.

WFAS use US Federal Aviation approved software that provides a quantified assessment of when and where solar reflection will occur throughout the year for a prescribed solar installation and potential effects on the human eye at specific locations where reflection can occur.

Existing sources of glare are many and varied and it can be experienced from glass windows, industrial buildings, solar farming, rooftops, office buildings and water bodies. It does not normally present an excessive nuisance or distraction and, obviously, will only occur when the sun is shining and there is little or no cloud cover. Potential solar reflection from solar panels should be viewed in this context.

[2] Updated 14 August 2023.
[3] National Planning Policy Framework on Renewable and Low Carbon Energy, Paragraph 0006 Reference ID: 5-006-20140306 and Paragraph 013 Reference ID: 5-013-20150327.

There is little evidence of any safety implications from solar reflections; looking towards glint/glare will always be much less severe than looking towards the sun which almost every car driver will have had to do on occasion e.g. driving westwards in the evening in clear skies.

Solar reflection can be considered to have least effect at small observed angles between the sun and the reflecting object; at angles close to 0° any glint/glare is effectively masked by the

brightness of the sun, shining very close to the glinting object as viewed by an observer. Similarly, at angles close to or greater than 90° from the focus of view (i.e., to the side or behind the observer's direction of vision), it has virtually no effect; a slight turn of the head would remove any minor nuisance effect completely.

Definitions and Guidance

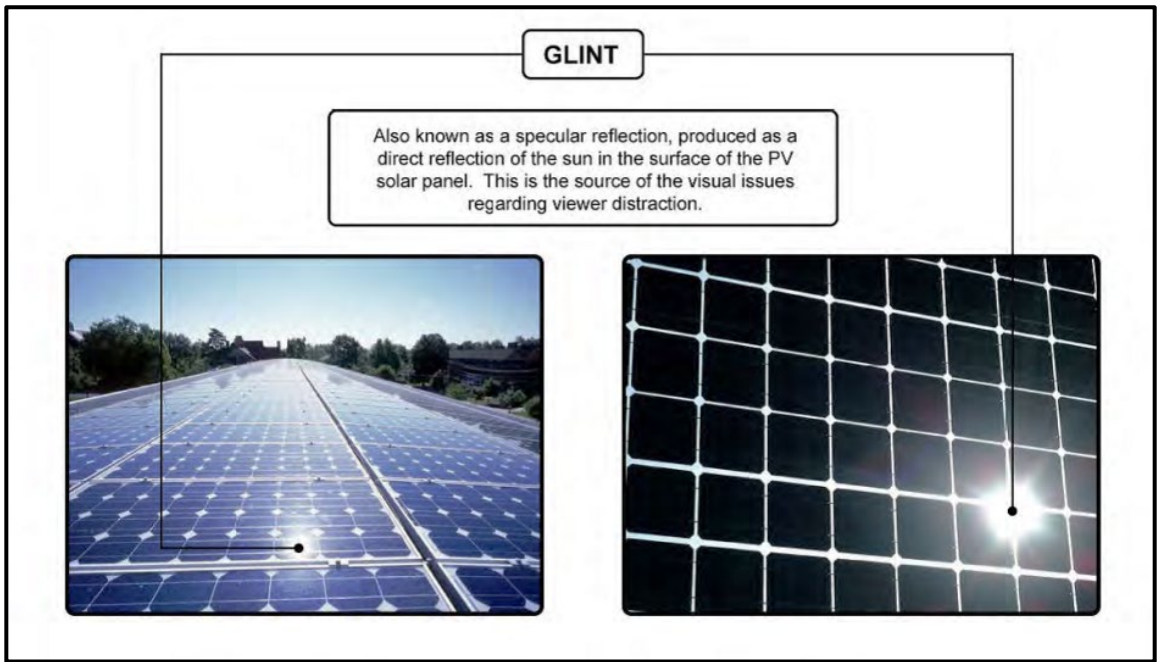
The following definitions and descriptions are key to understanding the potential issues:

- Photovoltaic Panel – Photovoltaic panels, also known as PV panels, are designed to absorb solar energy and retain as much of the solar spectrum as possible in order to produce electricity.

UK Government policy on renewable energy has the following definitions:[4]

- 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.



[4] UK Government, Department for Energy Security and Net Zero, Policy Paper "National Policy Statement for Renewable Energy Infrastructure" updated 17 January 2024, last accessed 1 November 2024.



Source: Panoche Valley Solar Farm Project Glint and Glare Study dated 21 May 2010 (Power Engineers)

Photovoltaic (PV) solar panels are designed to absorb sunlight in order to convert it into electricity. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules. Photovoltaic panels are using the absorbed energy in two ways:

- the panels generate electricity, and
- the mass of the panels heat up.

Silicon is naturally reflective. All solar panels are designed with a layer of anti-reflective material that allows the sunlight to pass through to the silicon but minimizes reflection. This design results in the dark appearance of the solar panel. Recent generations of panels have included an anti-reflective material on the outer surface of the glass in some panels to further limit sunlight reflection. The area of the aluminium frame is very thin and therefore reflection from the aluminium is not a concern.

The amount of sunlight interacting with the solar panel will vary based on geographic location, time of year, cloud cover, and solar panel orientation. Solar PV panels are designed to absorb as much daylight as possible to convert to electricity and, therefore, have a lower level of reflectivity than other surfaces such as window glass. Commercial designs of solar panel typically assert that less than 9% of total visible light is reflected by solar PV panels in comparison to the 17% that is reflected by normal window glass, although some panels can reflect as little as 2% of the

incoming sunlight depending on the angle of the sun and assuming use of anti-reflective coatings[5].

The following photograph illustrates solar reflection from typical domestic roof tiles.



Figure 1 – solar reflection off domestic roof tiles

While the amount of light reflected off a surface is important, the nature of the reflected light is even more important when assessing the potential for flash blindness. One important characteristic of light to consider is whether the reflected light is "specular" or "diffuse". Specular reflection reflects a more concentrated type of light and occurs when the surface in question is smooth and polished. Examples of surfaces that produce specular reflection include mirrors and still water. Diffuse reflection produces a less concentrated light and occurs from rough surfaces such as pavement, vegetation, and choppy water. Figure 2 illustrates specular and diffuse reflections. All surfaces in reality produce a mixture of both types of reflections, but the surfaces are generally dominated by one type. Outside of very unusual circumstances, flash blindness can only occur from specular reflections.

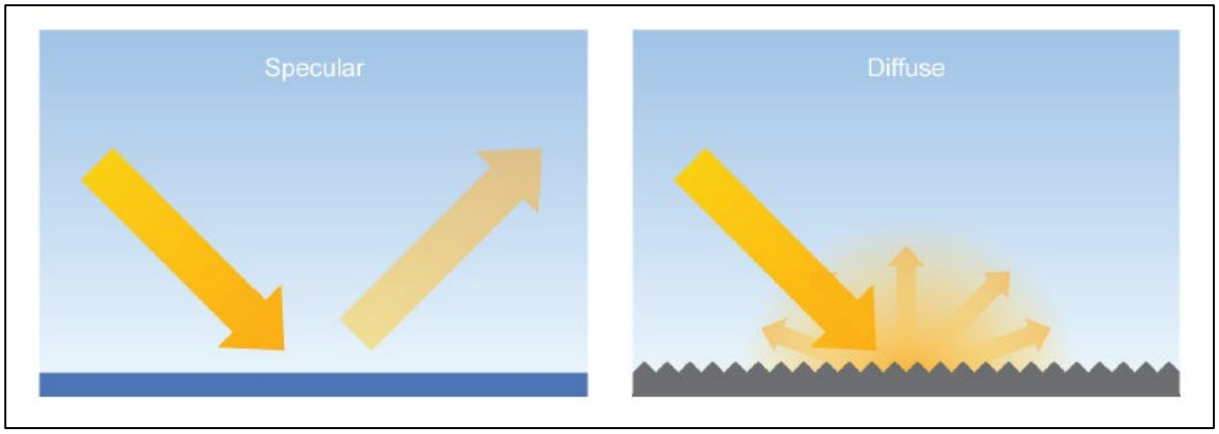


Figure 2: Different Types of Reflection
Source: Harris Miller Miller and Hanson (HMMH)

[5] (Evergreen Solar 2010 Evergreen Solar; More Electricity. Fact Sheet.)

Colour is important because some colours absorb light and its energy, whereas others reflect it. Light colours are most reflective (white being the most), whereas dark colours are least reflective. Figure 3 shows the percentage of sunlight that is reflected from a variety of common surfaces. The values provided are primarily influenced by colour and include two different types of solar technologies: PV and Concentrated Solar Power (CSP). The colours of the surface and the percentage of sunlight it reflects is only one-half of the equation; the other factor is the physical characteristics of the material's surface. Flat, smooth surfaces will 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 will reflect light in a diffuse or scattered manner and therefore will not be received by the viewer as brightly.

The solar reflectance of PV panels is based on the surface material of the panels used. The modelling tool used defines 5 panel surface material reflectance types:

- Smooth glass without Anti-Reflective Coating (ARC),
- Smooth glass with ARC,
- Light textured glass without ARC,
- Light textured glass with ARC,
- Deeply textured glass.

The following is the scale of reflectivity of surfaces (in general):

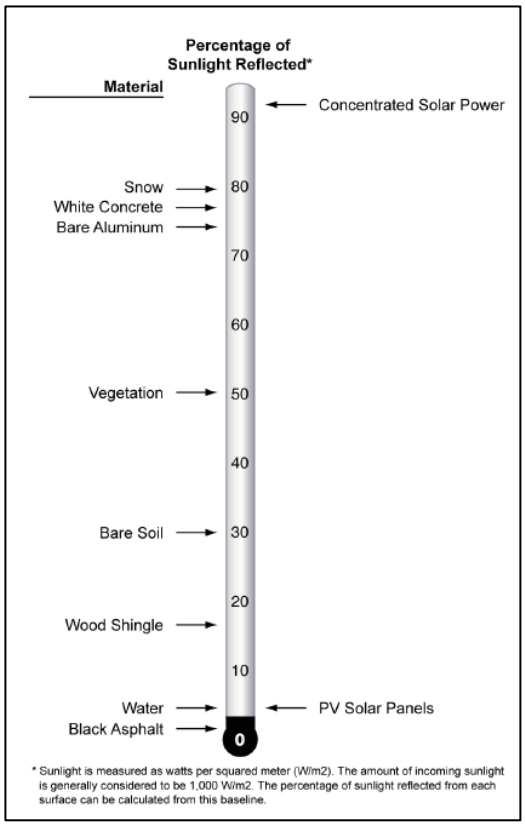


Figure 3: Reflectivity characteristics of differing surfaces.
Source: HMMH

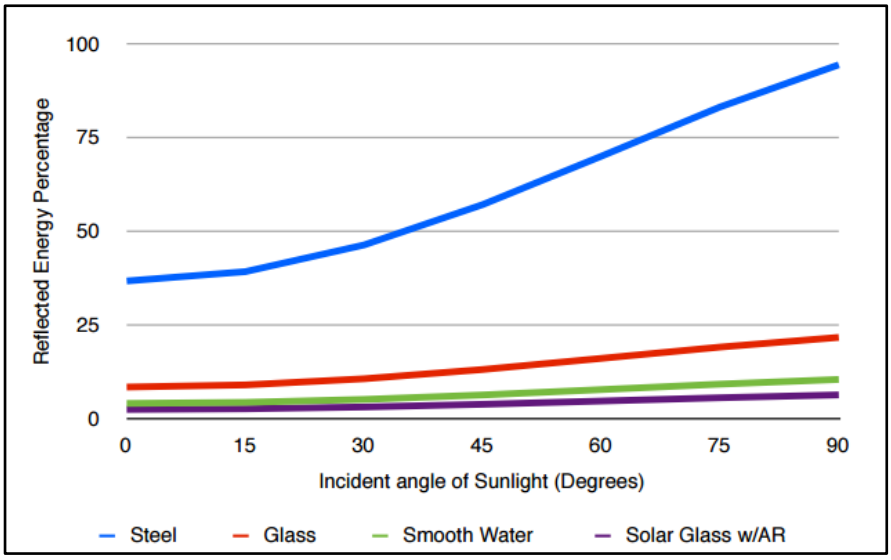


Figure 4: Reflected Energy Percentages
Source: Capital Solar Farm Visual Impact Assessment 2010 et al.

PV solar panels are amongst the least reflective and on the basis of this scale the reflectivity that might be expected from the Proposed Development would be less than that expected from the current farmland to the south and on a par with that from the surface of the roof of the adjacent industrial and office buildings.

Modelling assumptions/parameters

The model does not consider obstacles, either man-made or natural, between the observation points and the prescribed solar installation and which may obstruct observed glare e.g. trees, buildings, etc. The model uses a "bare-earth" data base and no allowance is made for the screening effects of such obstacles.

The variable direct normal irradiance (DNI) scales the 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[6] and the latitude and longitude obtained from Google maps. The actual DNI on any given day will be affected by cloud cover, atmospheric attenuation, and other environmental factors.

[6] Duffie, J.A. and W.A. Beckman, 1991, Solar engineering of thermal processes, 2nd ed., Wiley, New York, xxiii, 919 p.

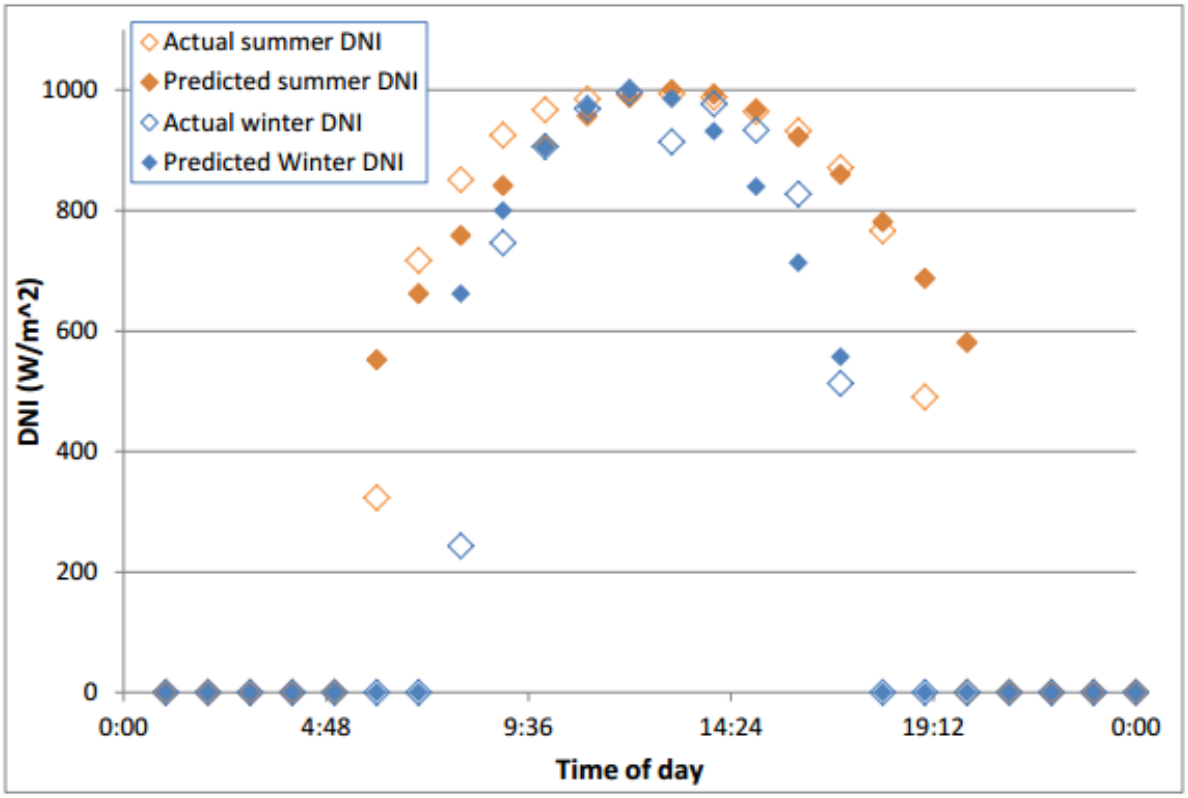


Figure 5 – DNI levels throughout the day

The sun position algorithm[7] calculates the sun's position in two forms: first as a unit vector extending from the Cartesian origin toward the sun, and second as azimuthal and altitudinal angles. The algorithm relies on the latitude, longitude and time zone offset from UTC in order to determine the position of the sun at every time step throughout the year, in this instance 1-minute intervals. (FAA policy requires that an ocular impact assessment must be assessed at 1-minute intervals from when the sun rises above the horizon until the sun sets below the horizon. This requirement establishes a quantitative threshold not present in current English guidance. This report follows the methodology required by the FAA as, in WFAS' opinion, it offers the most robust assessment method currently available.)

Once the sun's position is known for each time interval a simple vector reflection equation[8] can determine the reflected sun vector, based on the normal vector of the PV array panels.

If glare is found, the tool calculates the retinal irradiance and subtended source angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a simple, easy-to-interpret plot that specifies when glare will occur throughout the year, with colour codes indicating the potential ocular hazard.

[7] Duffie, J.A. and W.A. Beckman, 1991, Solar engineering of thermal processes, 2nd ed., Wiley, New York, xxiii, 919 p
[8] Weisstein, Eric W. "Reflection." From MathWorld.

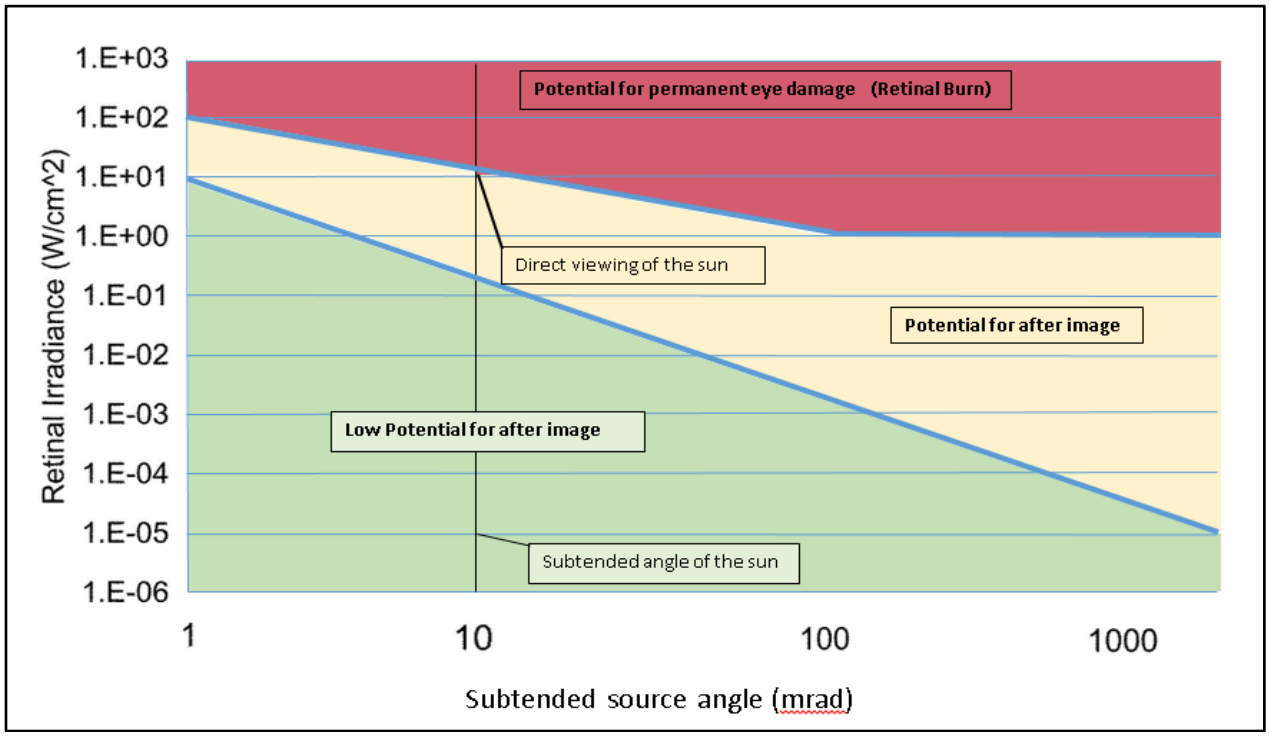


Figure 6 – potential for after image effect

The impacts from glint and glare can include discomfort, disability, after image and retinal burn. In terms of magnitude discomfort might lead to headaches, disability glare immediately reduces visual performance and can include after image effects, flash blindness and "veiling" where objects/areas are masked by the glare. If the retinal irradiance are sufficiently high temporary after image or permanent eye damage may occur.

Within the modelling tool there are three levels of ocular (eye) hazard as a result of glare. The hazards are defined as low, moderate or high, depending on the potential to impact vision. The following definitions are provided for the glare hazards in this report:

Low Potential Hazard: Indicates there is glare present however only a low potential for a temporary after-image (a possible lingering image of the glare in the field of view) and with no effect on ground-based receptors. This hazard is shown green on the glare potential plots.

Moderate Potential Hazard: Indicates that there is glare present with the potential to leave a temporary after-image of the glare. This hazard is shown yellow on the glare potential plots.

High Potential Hazard: Indicates that there is glare present with the potential for permanent eye damage if observed. This hazard is shown red on the glare potential plots.

There are a number of factors that can affect both the intensity and impact of glare including DNI, reflectance, distance, size, orientation of the reflecting surfaces etc. where DNI is the amount of solar irradiance striking a reflective surface perpendicular to the sun's rays. A typical clear sunny day may see a DNI of -1000 watts per square metre at solar noon with lower values in the morning and evening; this is the baseline for measurement of any solar glare source which can then be reduced by the reflectance of the surface in question.

Within the modelling results green glare can be ignored when looking at ground-based receptors. Green glare does not cause temporary flash blindness and happens at an instant with very slight disturbance.

Solar Data - Sun Position Data Model

Whether a surface will cause a glare effect on an observer depends on a number of factors, e.g.:

- Sun position,
- Discrete Observation Point Observer location,
- Discrete Observation Point Observer height/elevation,
- Tilt, orientation (Degrees), and extent of the solar array,
- The direction of the observer's view,
- The persistence of that view in a single direction in relation to the reflecting surface,

In conjunction with those factors, the amount of light that may be reflected of a surface will depend on:

- The amount of light hitting the surface,
- The nature of the reflecting surface,
- The orientation of the surface,
- The geographic location of the surface in relation to the position of the sun, and,
- The prevailing weather conditions and cloud cover.

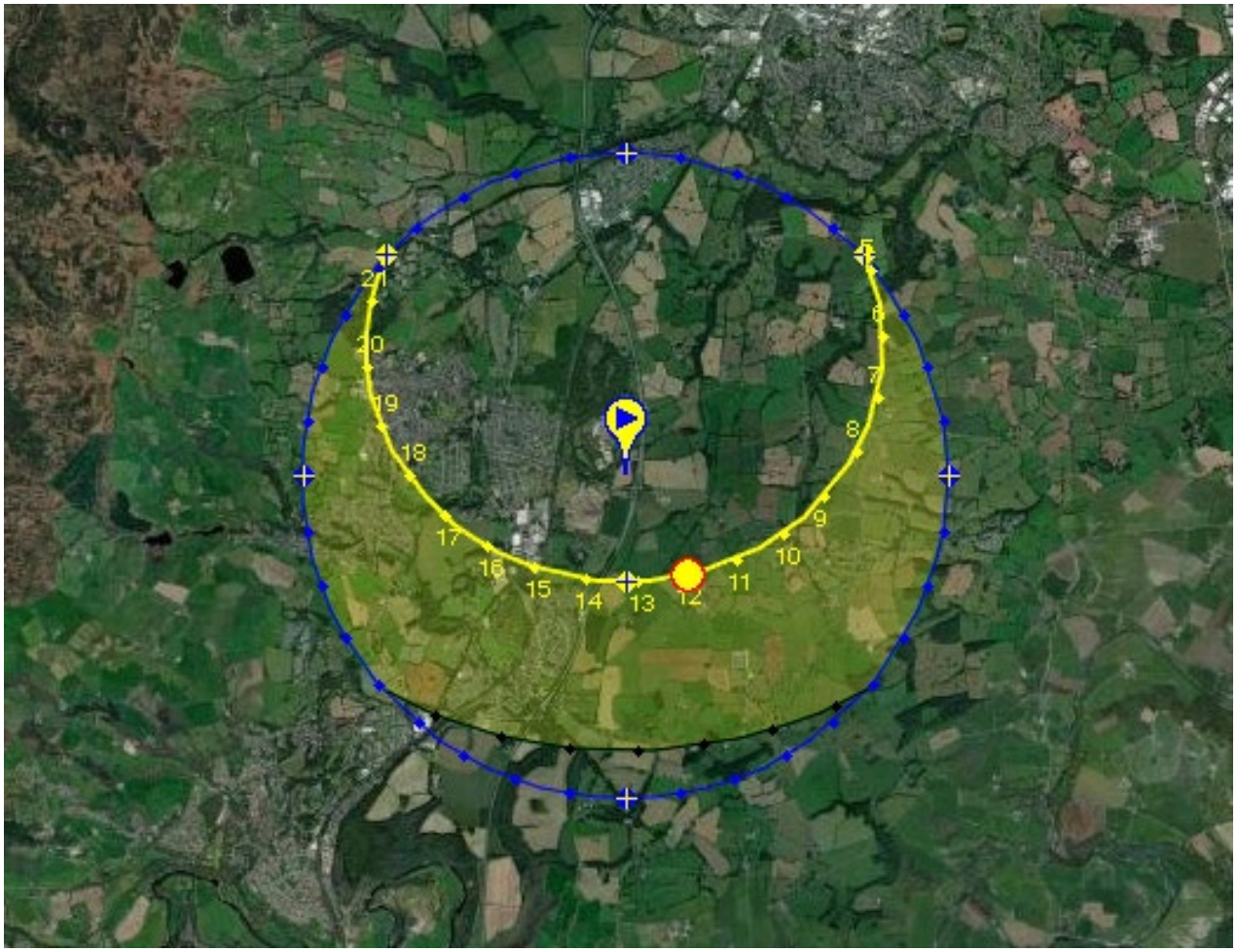


Figure 7 – the path of the sun and position (centred on the proposed array) at 12.00GMT 21st June 2024. Source: SET.com

sun position	Elevation	Azimuth	latitude	longitude
21/06/2024 12:00 | GMT0	57.27°	147.4°	53.0056047° N	3.0251478° W
twilight	**Sunrise**	**Sunset**	**Azimuth Sunrise**	**Azimuth Sunset**
twilight -0.833°	04:45:59	21:42:05	47.12°	312.86°
Civil twilight -6°	03:54:23	22:33:34	36.46°	323.5°
Nautical twilight -12°	02:25:09	00:02:30	16.66°	343.28°
Astronomical twilight -18°	--:--:--	--:--:--	342.71°	342.71°
daylight	**hh:mm:ss**	**diff. dd+1**	**diff. dd-1**	**Noon**
21/06/2024	16:56:06	-00:00:07	00:00:02	13:14:02

The following figures denote the position of the sun in the sky, and its relative angle, throughout the year and with the Solstices annotated at the seasonal reference points.

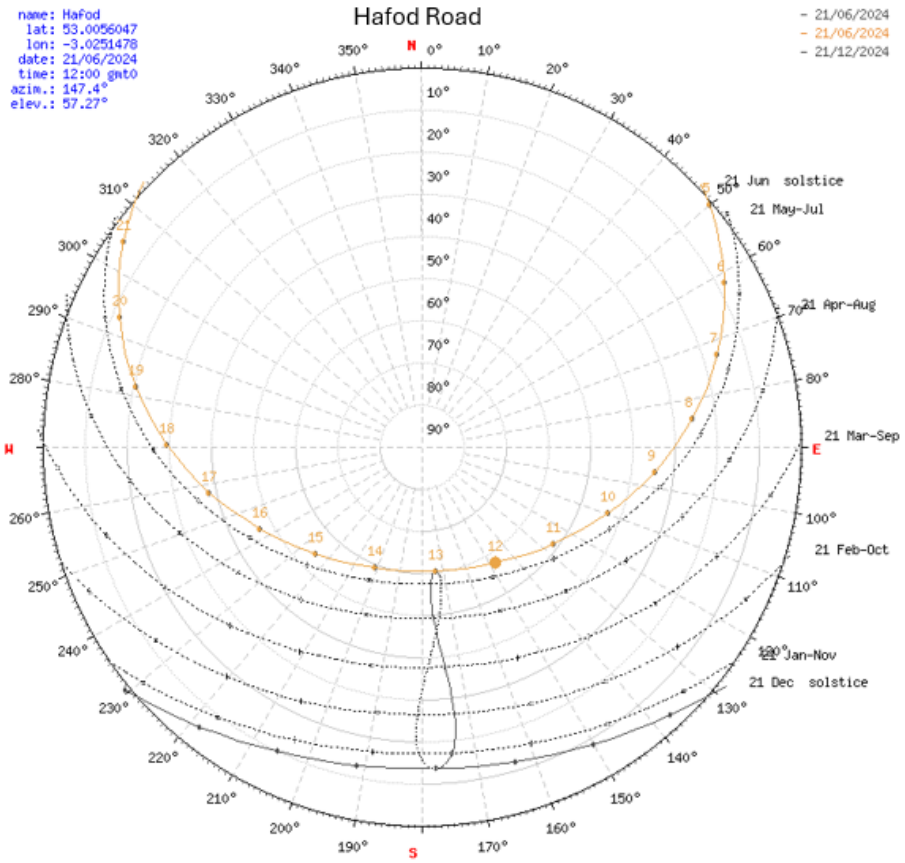


Figure 8 – elevation of the sun throughout the year

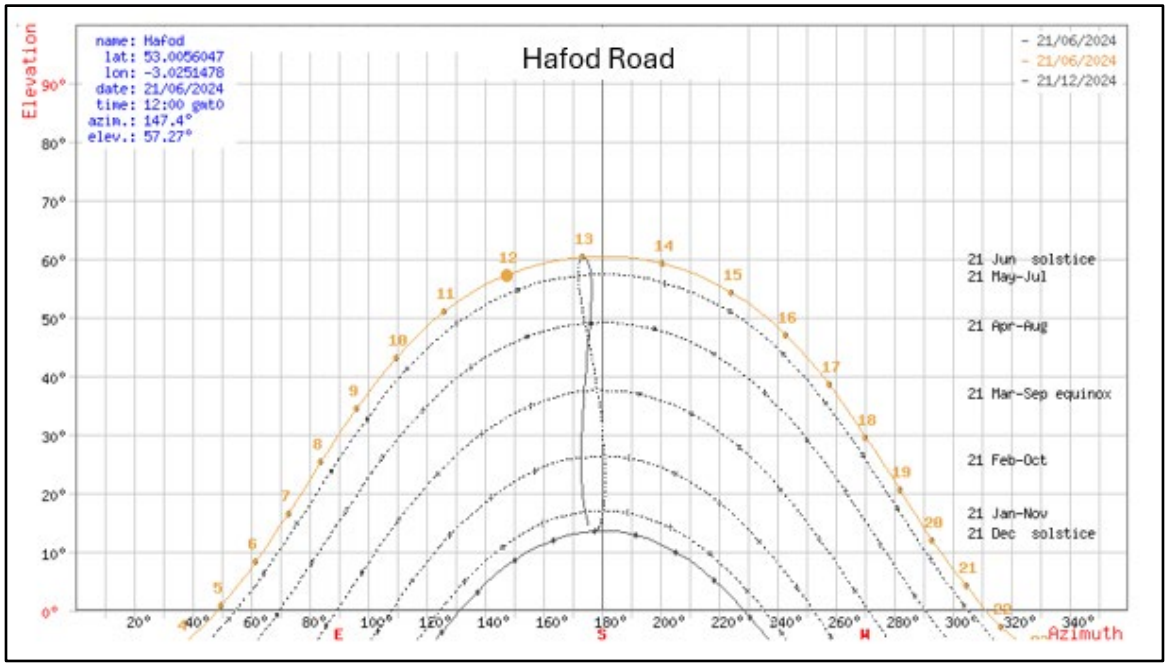


Figure 9 – elevation of the sun throughout the year

The data position model and the glare assessment model assume that the azimuth and horizontal angle of the sun is the same across the solar array.

Once the position of the sun is known for each time interval, a vector reflection equation determines the reflected sun vector, based on the normal vector of the solar array panels.

On knowing the vector of the solar reflection, the azimuth is calculated and the horizontal reflection from the assessment points within the solar array. These are then compared with the azimuth and horizontal angle of the receptor from the array to determine if it is likely to receive solar reflections.

The position of the sun is calculated at one-minute intervals of a typical year, in this illustration the last full year assessed for Glint and Glare was 2023.

Hafod Road – Solar Modelling

As the primary sources of information used in this report, this preliminary assessment relies on parameters contained within the Project Overviews supplied by Dulas.

In considering the proposed array in an aviation and ground-based receptors context the following parameters were applied across proposed array:

- UTC + 0.00,
- a panel height of 1.41mm (approximately 4.5ft) representing the approximate mid-point of the panels,
- a panel tilt of 22 degrees,
- the panels are orientated due south (180 degrees)
- textured glass with Anti-Reflective Coating,
- The panels are fixed, i.e. not tracking the sun.

When in shade but otherwise illuminated by an entire blue sky, the typical ambient light level is around 20,000 lux[9]; midday light levels with an overcast sky are typically 10,000 to 25,000 lux. For solar reflections to be seen from any surface, the sun must be shining so ambient light levels will be high and the worst-case effects caused by looking at or near reflecting panels. These effects will never be as harsh as looking directly towards the sun or, perhaps, when driving a car or landing an aircraft towards sunset both of which are relatively commonplace events but neither of which are considered to be safety issues.

For reflections from a solar array to have any potential to become an issue, the panels must be close to the direction of a viewer's main interest for extended periods. There is considered to be no possibility of 'flash blindness' from brief exposure to solar reflections given the high ambient light levels that must be present for such effects to occur; brief exposure to reflected sunlight from solar panels may be considered to be less significant than prolonged exposure.

For this report sun position data for one year was predicted at 1-minute intervals and directions of solar reflections calculated for each data point. It must be noted that at any instant, solar reflections across the whole solar farm will be parallel in a single discrete direction with the direction changing slowly through the day and year.

The model does not consider obstacles, either man-made or natural, between the observation points and the prescribed solar installation and which may obstruct observed glare e.g. trees, buildings, etc. The model uses a "bare-earth" database and no allowance is made for the screening effects of such obstacles.

[9] The lux is the SI unit of illuminance and luminous emittance, measuring luminous flux per unit area.

Within the modelling results green glare can be ignored when looking at ground-based receptors. Green glare does not cause temporary flash blindness and happens at an instant with very slight disturbance.

Summary

There is little guidance or policy available in the UK at present in relation to the assessment of glint and glare from proposed solar arrays. However, it is recognised as a potential impact which needs to be considered for a Proposed Development.

This assessment utilises an FAA modelling tool to determine the potential for effects on residential properties in the immediate vicinity of the Proposed Development at Hafod Road.

The results are on a "bare-earth" basis and make no allowance for screening that might be present from trees or hedgerows in the area.

There should be no effects on the rail line to the west.

There should be no effects on aviation at either Chirk or Plassey unlicensed airstrips or to aircraft transiting through the controlled airspace overlying the Proposed Development.

The results for each modelled Discrete Observation Point of domestic properties are contained at the Annexes. The majority of these representative receptors could be subject to some glare at some times of the year, predominantly for short periods of time in early morning or later afternoon. However, the glare effects that will be expected at most will be of the type that will not result in any form of "after-effect" i.e. "green glare". These occurrences are very transient and should have a low potential for after-image.

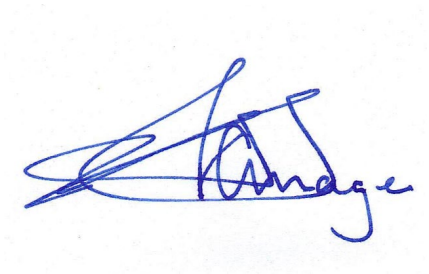
The "bare-earth" modelling data results indicate that, in the immediate vicinity of the array, traffic travelling in both directions on the B5426 (Bangor Road) could be subject to instances of glare at differing times of some days in the year. However, commensurate with UK Government Policy definitions, glare will only prove to be an issue when experienced on a steady direction/line of sight for extended periods of time; transitory effects should not cause after image, and it is considered that traffic will only be exposed to very intermittently visible effects from between the adjacent buildings and trees; any effects will be the same as those which motorists experience when driving anywhere and have a transitory exposure to reflections off windows, office buildings etc. or to any effects experienced by motorists driving along the roads surrounding the much more extensive developments north of Plas Madoc, approximately 3km to the south west. Furthermore, as with all solar developments it should be expected that the percentage of all sunlight reflected by modern solar panels is less than that reflected by bare soil or vegetation and on a par to open water (lakes).

Any potential effects that could be experienced are largely either in the early morning or in the afternoon and should be less than any effect from driving into sunrise or sunset.

The occurrences of glare are very transient and are dependent on a number of factors including time of year, time of day, cloud cover etc. With that said, the albedo (measure of reflectance) of the PV modules is lower than other common surfaces in the surrounding area, including agricultural vegetation, windows on the nearby industrial units etc.

Where glare is possible the results demonstrate that glare may occur at that point if an individual is facing directly towards the array; no allowance can be made for the orientation of the individual receptor welling concerned and whether they are facing away or towards the direction of the solar farm.

The window for any solar reflection is very narrow; the modelling calculates most periods of possible yellow glare, are brief, almost transitory with even less effect on a moving receptor.



Shane Savage
Director
Wind Farm Aviation Safeguarding Ltd

Annex A – Modelling parameters

The following parameters[10] were used in the modelling:

- **Height Units**: The units of distance for the height of solar panels and the height above ground of each observation point in feet or meters.
- **Subtended angle of the sun**: The average subtended angle of the sun as viewed from earth is ~9.3 mrad or 0.5°.
- **Peak DNI**: The maximum Direct Normal Irradiance (W/m2) at the given location at solar noon. This value may be scaled at each time step to account for the changing position of the sun and reduced DNI in the mornings and evenings. On a clear sunny day at solar noon, a typical peak DNI is ~1,000 W/m2 .
- **DNI variability**: "Variable" scales the peak DNI at each time step based on the changing position of the sun. "Fixed" uses the peak DNI value for every time step throughout the analysis, with no scaling.
- **Ocular transmission coefficient**: The ocular transmission coefficient accounts for radiation that is absorbed in the eye before reaching the retina. A value of 0.5 is typical.
- **Pupil diameter**: Diameter of the pupil (m). The size impacts the amount of light entering the eye and reaching the retina. Typical values range from 0.002 m for daylight adjusted eyes to 0.008 m for nightime vision.
- **Eye focal length**: Distance between the nodal point (where rays intersect in the eye) and the retina. This value is used to determine the projected image size on the retina for a given subtended angle of the glare source. Typical value is 0.017 m.
- **Time interval**: The time step for the glare analysis; a time step of 1-minute yields excellent resolution.
- **Orientation of array**: The orientation of the array in degrees, measured clockwise from true north. Modules facing east would have an orientation of 90°, and modules facing south would have an orientation of 180°.
- **Tilt of solar panels**: The tilt (elevation angle) of the modules in degrees, where 0° is facing up and 90° is facing horizontally.
- **Reflectivity of PV module**: Specify the solar reflectance of the PV module. Although near-normal specular reflectance of PV glass (e.g., with antireflective coating) can be as low as ~1-2%, the reflectance can increase as the incidence angle of the sunlight increases (glancing angles). Based on evaluation of several different PV modules, an average reflectance of 10% is entered as a default value.
- **Slope error**: This parameter specifies the amount of scatter that occurs from the PV module. Mirror-like surfaces that produce specular reflections will have a slope error closer to zero, while rough surfaces that produce more scattered (diffuse) reflections have higher slope errors. Based on observed glare from different PV modules, an RMS slope error of ~10 mrad (which produces a total reflected beam spread of 0.13 rad or 7°) appears to be a reasonable value.

[10] Ho, C.K., C.M. Ghanbari, and R.B. Diver, 2011, Methodology to Assess Potential Glint and Glare Hazards From Concentrating Solar Power Plants: Analytical Models and Experimental Validation,.

Annex B – Assessed Development

Name: PV array 1
Footprint area: 2.7 acres
Axis tracking: Fixed (no rotation)
Tilt: 22.0 deg
Orientation: 180.0 deg
Rated power: -
Panel material: Light textured glass with AR coating
Vary reflectivity with sun position? Yes
Correlate slope error with surface type? Yes
Slope error: 9.16 mrad



Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	53.006668	-3.024557	337.38	4.50	341.88
2	53.006678	-3.025029	340.61	4.50	345.11
3	53.006134	-3.026024	342.86	4.50	347.36
4	53.005514	-3.026053	337.95	4.50	342.45
5	53.005507	-3.024554	331.79	4.50	336.29

Where the height above ground is an approximation of the mid-point of the panels.

The specified area is determined within the submitted modelling parameters and based on the boundaries of the available land footprint. The client specifies that the actual surface area of the panels within that boundary will be 0.46ha or 4575.4sqm.

Annex C – Aviation

The UK Air Navigation Order states that,

> *"(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."*[11]

And further that,

> "*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 pilots of the aircraft.*[12]"

The Proposed Development is located in unrestricted airspace meaning that it is "open" to any airspace user ranging from small general aviation aircraft, microlights etc. up to military fast jet and transport aircraft[13]. That unrestricted airspace extends upwards to a height of 4500ft above which is controlled airspace (restricted users) used for commercial traffic transiting along air routes serving the civil airports in the area and under the control of National Air Traffic Services. The section of that airspace above Hafod is part of the Niton Control Area (CTA).

Within the vicinity of the Proposed Development there are a number of small unlicensed airstrips two of which (the closest) have been assessed for completeness together with two representative

[11] UK Air Navigation Order 2016, Part 8, Chapter 2, Article 224, last accessed 1 November 2024.
[12] UK Air Navigation Order 2016, Part 8, Chapter 2, Article 225, last accessed 1 November 2024.
[13] The airspace is close to a Radio Mandatory Zone (RMZ) surrounding Hawarden Airport. An RMZ is a designated area of airspace where aircraft are required to use radio equipment and communicate with air traffic control (ATC). RMZs are often created around airports to improve the safety of aircraft and flights, and to provide information to ATC.

routes above the development for the Niton CTA. (The gliding site at Llantysillo and the unlicensed airstrip at Trench Farm have been discounted due to their range from the development.)

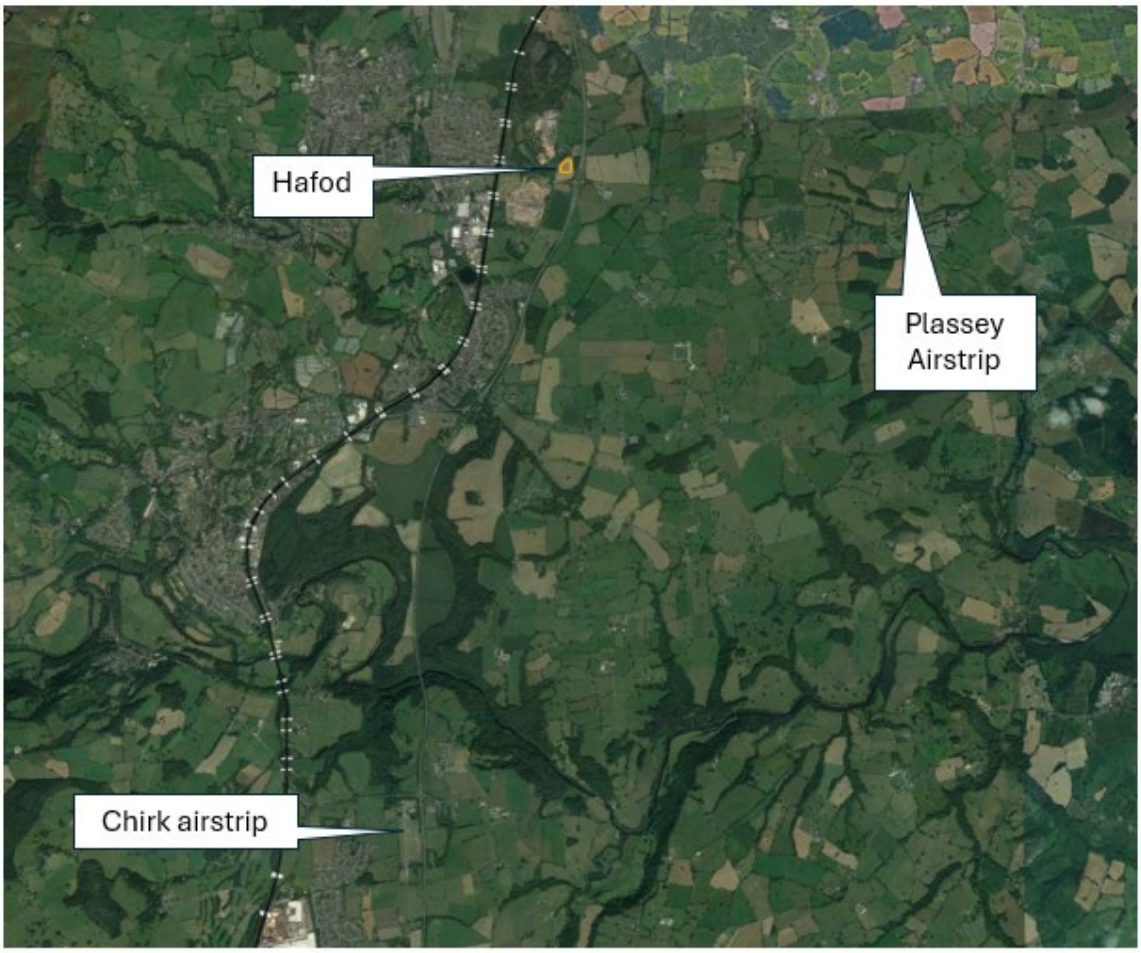


Figure C – 1: Unlicensed airstrips in the vicinity of the development

Flight Profile (FP) 1 – Chirk Airstrip

Chirk airstrip is approximately 6.5km (4.0 miles) south-southwest of the Proposed Development. There are no defined runways at ground level (there is a marked helicopter landing spot) due to the overlying market stall layout and surfaces but some available documentation lists the airstrip as having runways 01/19 (500m in length) and 33/15[14] (400m in length).

Given that the approach to the two northerly facing runways is in the direction of the Proposed Development, although at range, a representative final approach was assessed based on a 3-degree approach profile i.e. descending at approximately 300ft every mile, and to cross the runway threshold at 50ft. (In this instance there are no ground markings to delineate the thresholds at the airstrip and a single approach to the available field was modelled).



Figure C – 2: Assessed Chirk airstrip flight profile

[14] Runway designators are the True Bearing of the runway heading rounded to the nearest ten degrees and presented as a two-digit number. In this instance, the True Bearings pf the direction of landing as determined by the airstrip operator are aligned to 010/190 and 330/150 degrees which, rounded, become 01/19 degrees and 33/15. (The runways are reciprocal to allow for landing in either direction depending on the prevailing wind.)

Name: Chirk
Description:
Threshold height: 50 ft
Direction: 0.0 deg
Glide slope: 3.0 deg
Pilot view restricted? Yes
Vertical view restriction: 30.0 deg
Azimuthal view restriction: 50.0 deg

Point	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
Threshold	52.946467	-3.045132	438.94	50.00	488.94
2-mile point	52.917554	-3.045149	327.19	715.18	1042.37

No Glare was found to result from the planned array on the flight profile.

Flight Profile (FP) 2 – Plassey Airstrip

Plassey airstrip is located 3.3km (2.0 miles) to the east of the Proposed Development. There does not appear to be any documented information on the airstrip in any aviation publication and the airstrip in not annotated on aviation charts nor on OS maps of the area. There are no runway designators nor runway lengths on any aviation website that could be found and the last aerial photograph of a designated runway that could be found dates back to 2018. Nevetherless, for completeness an assessment of an approach from the south to the filed on which the runway was located was modelled.



Figure C –3: Assessed Plassey airstrip flight profile

Name: Plassey airstrip
Description:
Threshold height: 50 ft
Direction: 10.0 deg
Glide slope: 3.0 deg
Pilot view restricted? Yes
Vertical view restriction: 30.0 deg
Azimuthal view restriction: 50.0 deg

Point	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
Threshold	53.004328	-2.974433	212.85	50.00	262.85
2-mile point	52.975855	-2.982786	311.69	504.59	816.27

No Glare was found to result from the planned array on the flight profile.

An additional two aviation profiles were assessed overhead the Proposed Development and as a baseline for aircraft transiting through the Niton Control Area at 4500ft and 6500ft. These assessed routes are purely illustrative and to determine the potential for any effect on aircraft transiting overhead through the controlled airspace. The illustrative routes are overhead and/or are in close proximality laterally to existing solar developments and any effects would not affect any procedures at the civil licensed airports in the area and it should be expected that they would be similar to those other solar developments in the vicinity.

Flight Profile (FP) 3 – 4500ft



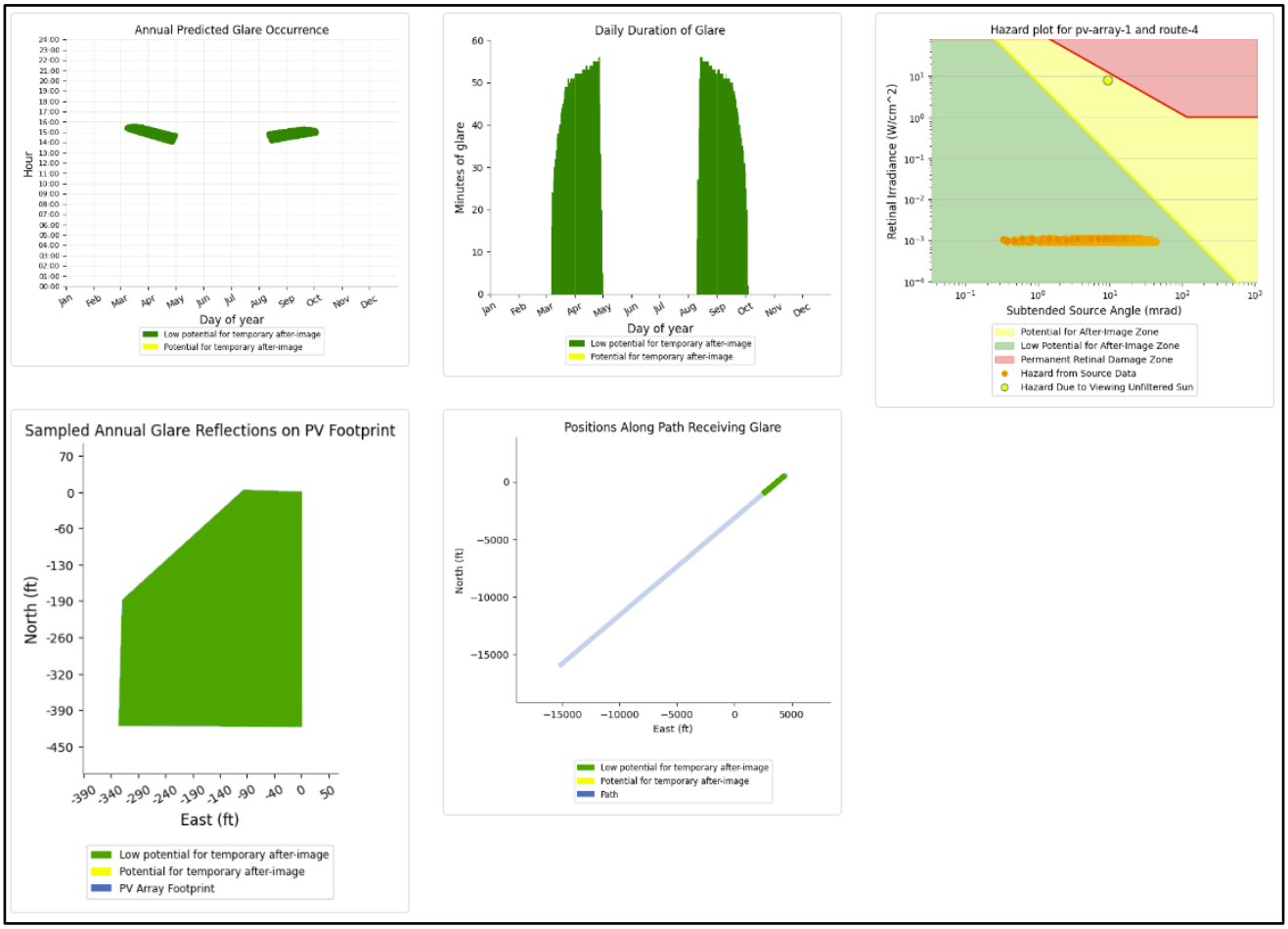
Figure C – 4: Assessed 4500ft overflight flight profile

Name: FP 3 – 4500ft
Route type Two-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	52.963121	-3.093081	344.59	4500.00	4844.59
2	53.008179	-3.004504	283.29	4500.00	4783.29

The PV array is expected to produce the following glare for this receptor:

- 5,185 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



"Green" glare would be possible between 1400 and 1600 in the months of March to May and from August to the start of October at the northern end of the assessed profile. Green glare has low potential for after image and the results would be dependent on an aircraft flying this illustrative route and the pilot looking downwards in the direction of the panels and assuming that there was a clear line of sight unobstructed by the aircraft fuselage.

Green Glare - Within the modelling results green glare can be ignored. Green glare is not considered to cause temporary flash blindness and happens at an instant with very slight disturbance.

Flight Profile (FP) 4 – 6500ft



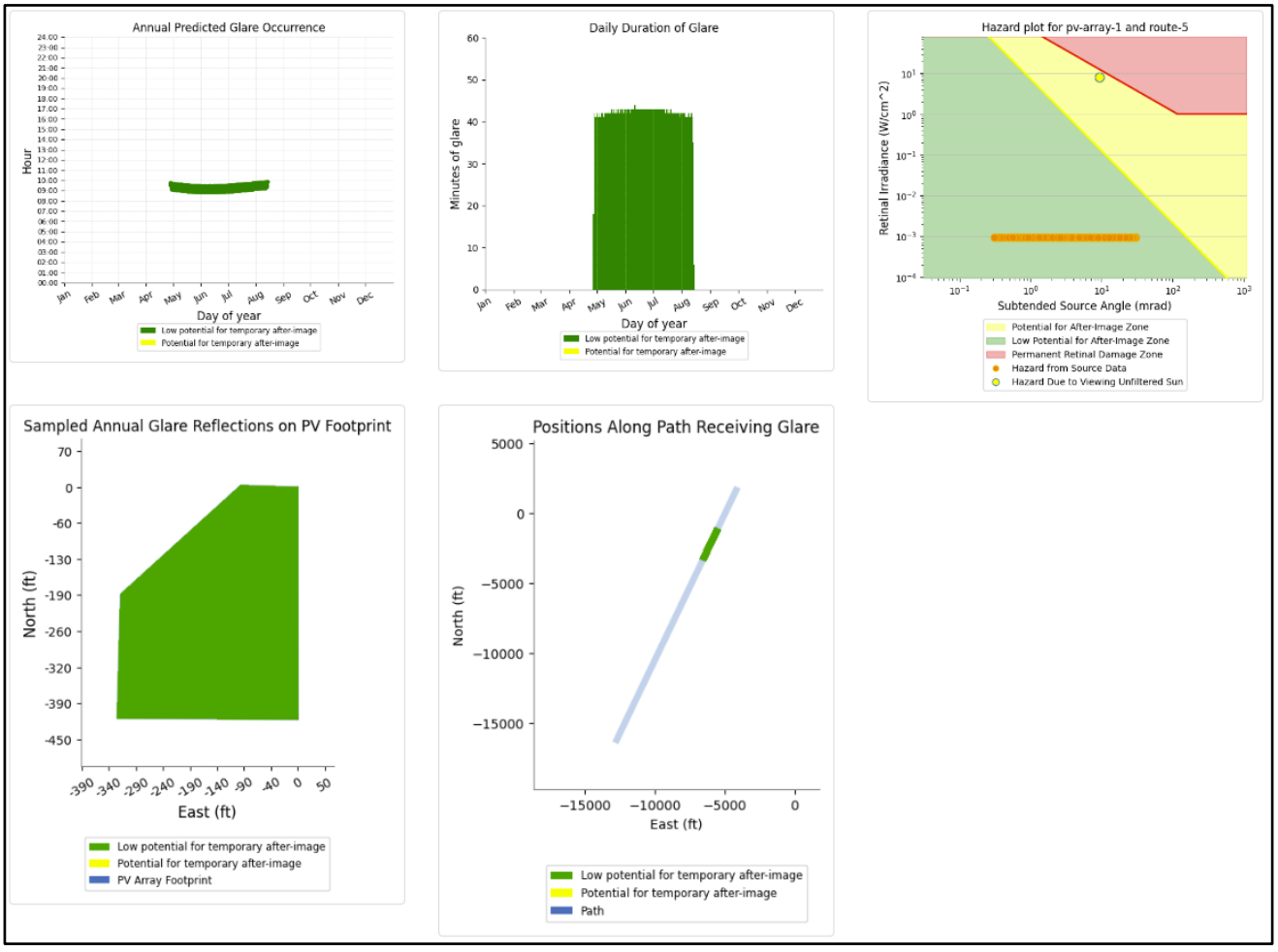
Figure C – 5: Assessed 6500ft overflight flight profile

Name: FP 4 – 6500ft
Route type Two-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	52.962300	-3.082296	404.57	6500.00	6904.57
2	53.011231	-3.043500	436.35	6500.00	6936.35

The PV array is expected to produce the following glare for this receptor:

- 4,595 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



"Green" glare would be possible between 0830 and 1000 from mid-April to mid-August at the northern end of the assessed profile. Green glare has low potential for after image and the results would be dependent on an aircraft flying this illustrative route and the pilot looking downwards in the direction of the panels and assuming that there was a clear line of sight unobstructed by the aircraft fuselage.

Annex D – Observation Points

The following are a selection of Observation Points within the general area of the proposed arrays south of a line running east/west through the Proposed Development and within 1km. They are nominally assessed at 3.5m (approximately 11ft) as representing a typical second floor window perspective. Based on either potential for complete or partial line of sight to the arrays as modelled, and without any screening by the vegetation/trees present, the following points were taken as a representative sample for each of the possible arrays. These points are not to be regarded as definitive but merely as a sample of residential properties that could lie within an area that could be subject to potential glare effects from the modelled arrays and the extent of any potential glare at those locations.



Figure D – 1: Assessed Observation Points

Discrete Observation Receptors

Number	Latitude	Longitude	Ground elevation	Height above ground	Total Elevation
	deg	deg	ft	ft	ft
OP 1	53.007005	-3.035731	367.79	11.00	378.79
OP 2	53.005559	-3.035817	371.54	11.00	382.54
OP 3	53.003261	-3.040194	392.40	11.00	403.40
OP 4	52.998508	-3.031311	362.67	11.00	373.67
OP 5	52.999438	-3.014531	321.45	11.00	332.45
OP 6	53.001479	-3.010969	314.96	11.00	325.96
OP 7	53.003622	-3.010411	307.72	11.00	318.72
OP 8	53.004345	-3.021054	328.08	11.00	339.08

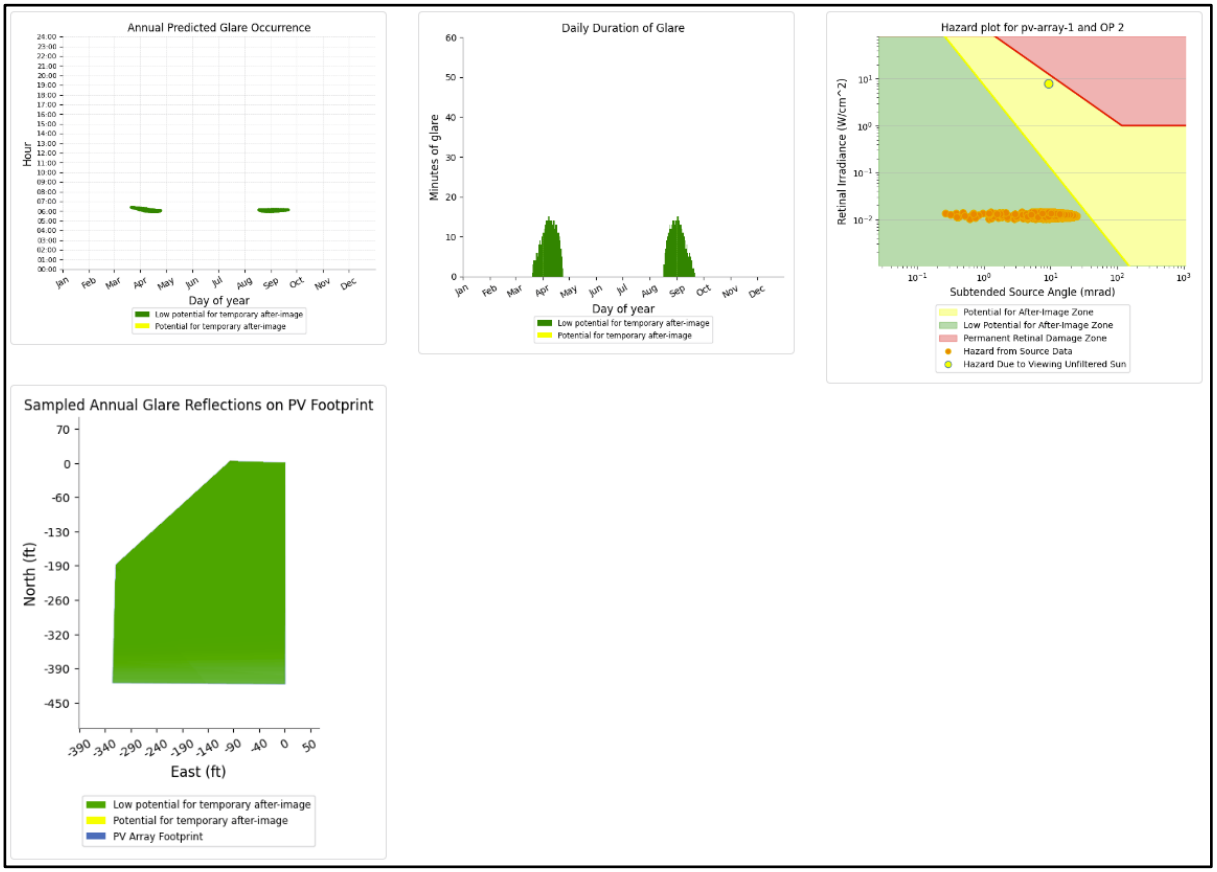
Observation Points Results

OP1 – No glare found

OP2

The PV array is expected to produce the following glare for this receptor:

- 686 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.

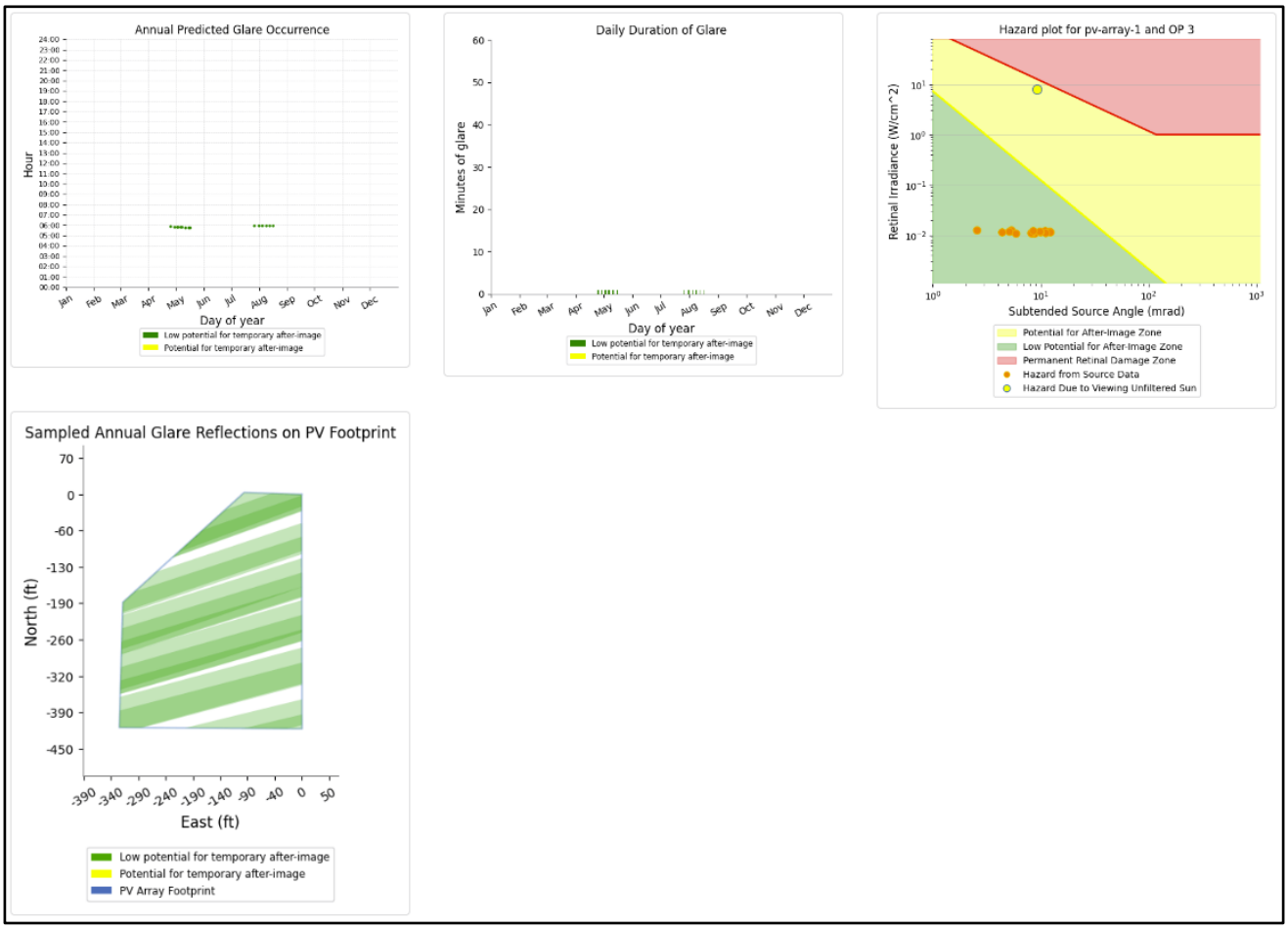


There is some potential for “Green” glare for approximately 30 minutes between the hours of 0530 and 0630 in the months of March to April and August to September.

OP 3

PV array is expected to produce the following glare for this receptor:

- 15 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



There is limited potential for “Green” glare for approximately 15 minutes between the hours of 0530 and 0600 in the months of April to May and July to August.

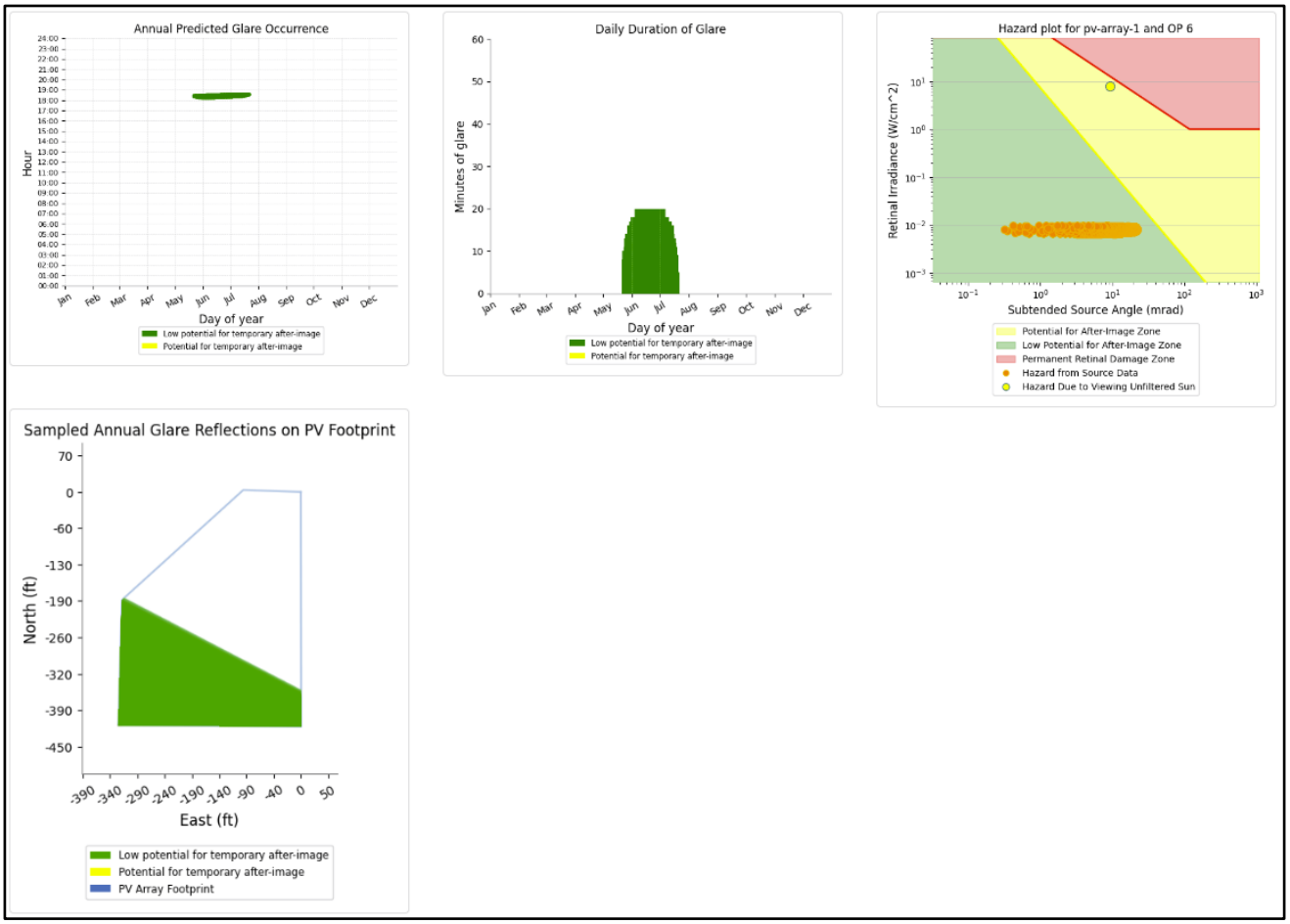
OP 4 – No glare found

OP 5 – No glare found

OP 6

The PV array is expected to produce the following glare for this receptor:

- 1,087 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.

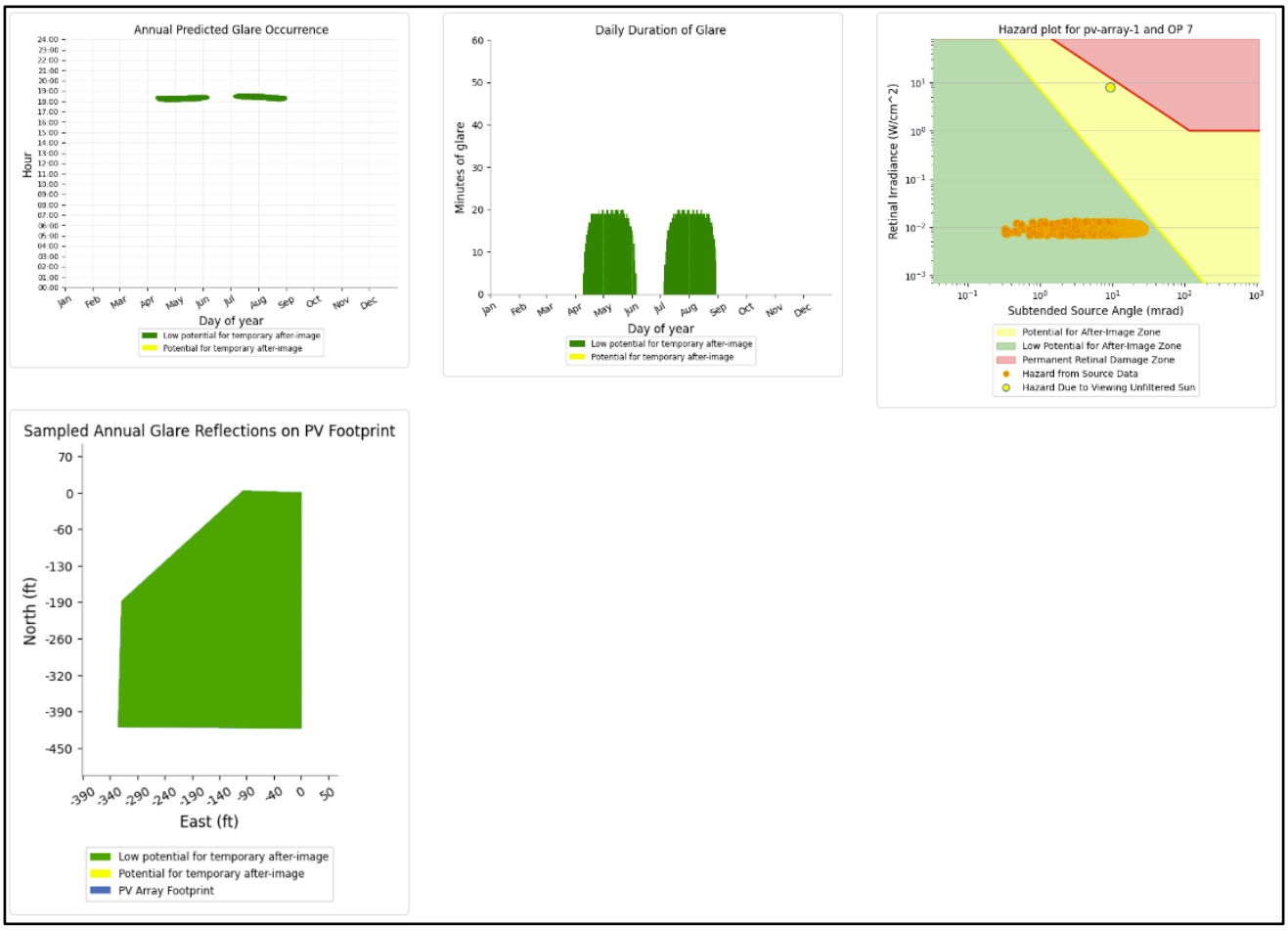


There is some potential for “Green” glare for approximately 45 minutes between the hours of 1700 and 1800 in the months of mid-May to July.

OP 7

The PV array is expected to produce the following glare for this receptor:

- 1,999 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.

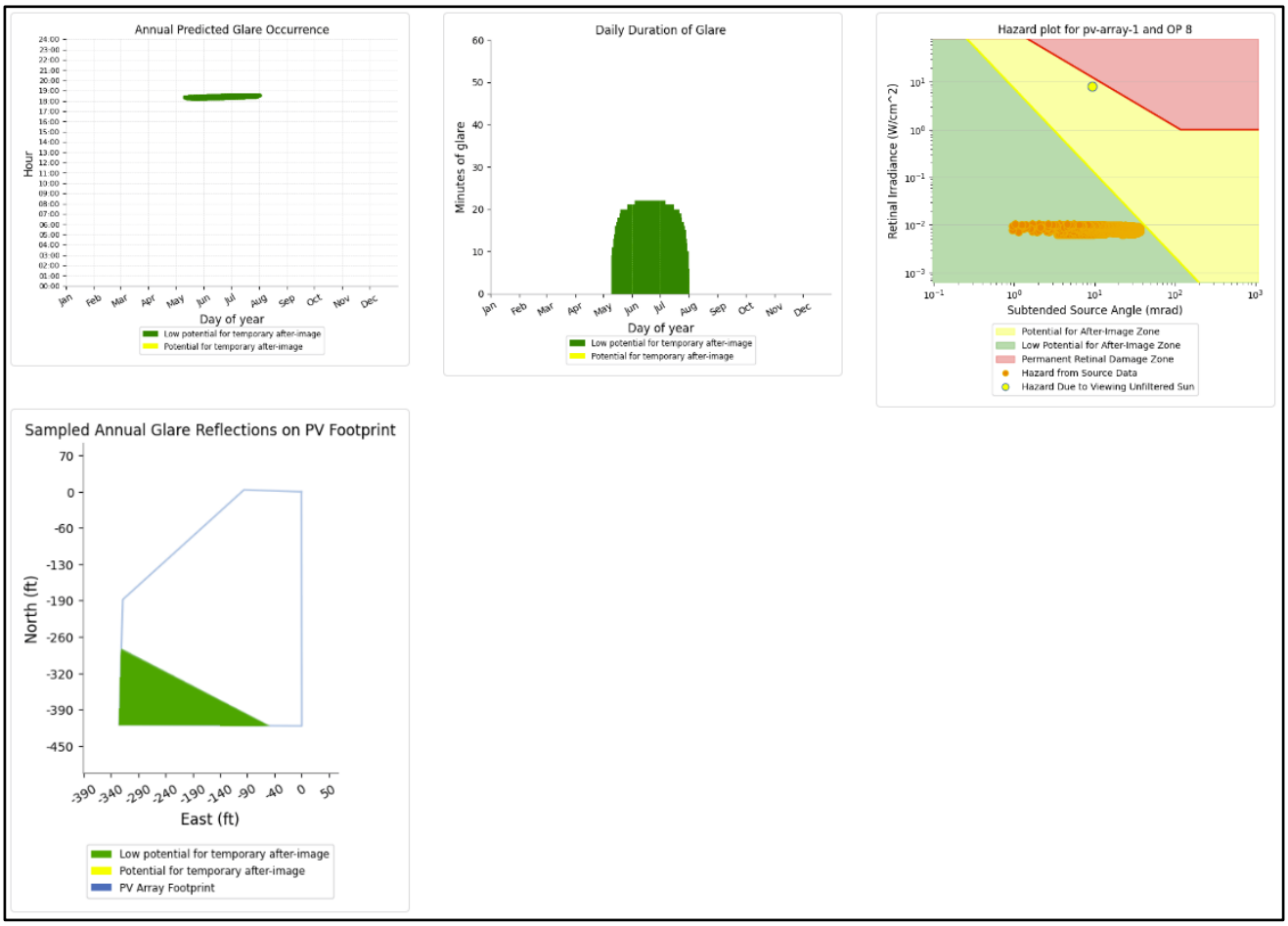


There is some potential for “Green” glare for approximately 45 minutes between the hours of 1800 and 1900 in the months of mid-April to mid-June and in July and August.

OP8

The PV array is expected to produce the following glare for this receptor:

- 1,657 minutes of "green" glare with low potential to cause temporary after-image.
- 0 minutes of "yellow" glare with potential to cause temporary after-image.



There is some potential for “Green” glare for approximately 45 minutes between the hours of 1800 and 1900 in the months of mid-May to September.

Totals

OP: OP 1	0	0
OP: OP 2	686	0
OP: OP 3	15	0
OP: OP 4	0	0
OP: OP 5	0	0
OP: OP 6	1087	0
OP: OP 7	1999	0
OP: OP 8	1657	0

Annex E – Moving Receptors

This assessment remains cognizant of UK Government Policy which states that Glare can only be experienced by a stationary receptor.

For reflections from a solar array to have any potential to become an issue, the panels must be close to the direction of a viewer's travel/main interest for extended periods. There is considered to be no possibility of 'flash blindness' from brief exposure to solar reflections given the high ambient light levels that must be present for such effects to occur; brief exposure to reflected sunlight from solar panels may be considered to be less significant than prolonged exposure. If a moving receptor is on a constant bearing towards the array then, in some circumstances it can be considered that, even through a receptor is moving, the line of sight towards the array is constant.

There is little/no guidance on how to measure the extent/magnitude of any glint or glare on moving receptors other than in aviation, but it is generally considered that the same approach can be used for road and rail.

This illustrative height for the road receptors is for modelling purposes. Changes to the modelling height by a few feet is not expected to significantly change the modelling results.

Route 1 - Rail

The UK Rail Industry Standard (RIS) RIS-0737-CCS on 'Signal Sighting Assessment Requirements' highlights that,

> *"a planned change external to the railway could affect signal sighting, for example changes that affect the built environment (for example, a new structure causing obscuration, a solar farm causing reflection)."*

There does not appear to be any definitive parameters for solar assessments but the Rail Safety and Standards Board assume an eye level at 2.75m (9ft) for signalling purposes.



Figure E - 1: Assessed rail profile (Route 1)

Name: Route 1
Route type One-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	52.992835	-3.038275	388.93	9.00	397.93
2	53.006652	-3.034971	360.88	9.00	369.88

No Glare was found to result from the planned array on the railway, Route 1.

Route 2 – Road

The UK Highway Code does not offer guidance specifically on Solar Glint or Glare but, rather, states that road users should be aware of hazards such as glare from the sun and should adjust their driving appropriately. An average eyeline height of 5 feet was used as an average across the various vehicle types.

The focus of the assessment on Route 2 was the A483 to the east of the Proposed Development.



Figure E - 2: Assessed road profile (Route 2)

Name: Route 2
Route type One-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	52.988406	-3.033914	369.05	5.00	374.05
2	52.992332	-3.031082	372.16	5.00	377.16
3	52.995329	-3.029708	360.75	5.00	365.75
4	52.998738	-3.026618	346.62	5.00	351.62
5	53.001941	-3.024387	331.94	5.00	336.94
6	53.006744	-3.022928	328.08	5.00	333.08

No Glare was found to result from the planned array on the A483 road, Route 2.

Route 3 – Road

The focus of the assessment on Route 3 was the B5426 to the south of the Proposed Development.



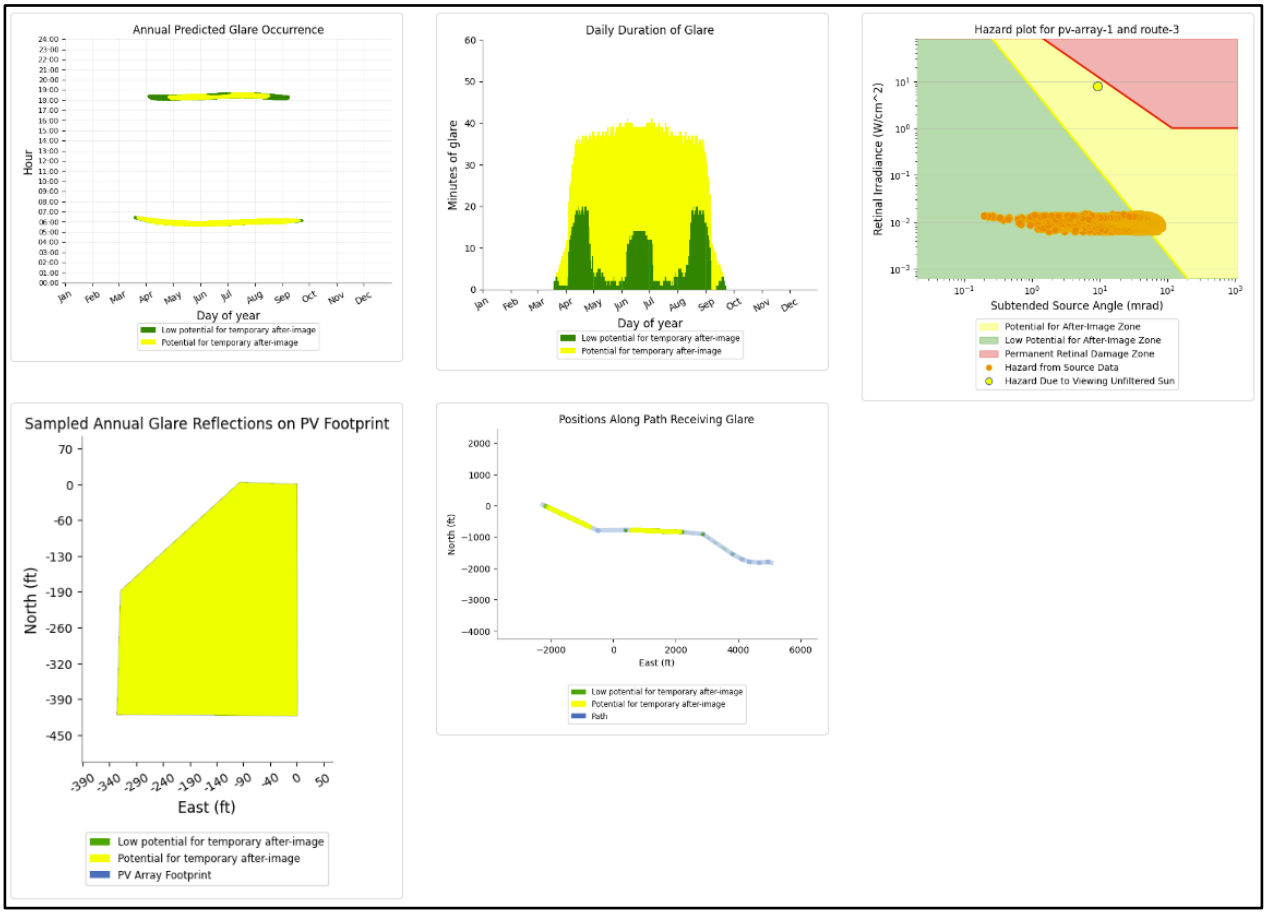
Figure E - 3: Assessed road profile (Route 3)

Name: Route 3
Route type Two-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	53.006731	-3.034833	360.45	5.00	365.45
2	53.004472	-3.026786	333.79	5.00	338.79
3	53.004536	-3.022774	333.90	5.00	338.90
4	53.004356	-3.014534	309.15	5.00	314.15
5	53.004162	-3.011509	307.89	5.00	312.89
6	53.002419	-3.007217	311.17	5.00	316.17
7	53.001967	-3.005822	309.34	5.00	314.34
8	53.001734	-3.004728	307.20	5.00	312.20
9	53.001670	-3.003290	306.56	5.00	311.56
10	53.001721	-3.002046	294.47	5.00	299.47
11	53.001670	-3.001574	294.37	5.00	299.37

The PV array is expected to produce the following glare for this receptor within a calendar year:

- 1,465 minutes of "green" glare with low potential to cause temporary after-image.
- 4,534 minutes of "yellow" glare with potential to cause temporary after-image.



On the B5426, Route 3, travelling in either direction there is some potential for glare at some sections of the road and which may be very intermittently visible to slow-moving traffic (assuming no cloud cover and direct sunlight). Within those limited sections of the road there could be glare for an approximate maximum of 45 minutes between the hours of 0530 and 0645 from mid-March and mid-October and between the hours of 1800 and 1900 between mid-April to mid-August.

For reflections from a solar array to have any potential to become an issue, the panels must be close to the direction of a viewer's travel/main interest for extended periods. There is considered to be no possibility of 'flash blindness' from brief exposure to solar reflections given the high ambient light levels that must be present for such effects to occur; brief exposure to reflected sunlight from solar panels such as that experienced in a moving vehicle/aircraft/train are considered to be less significant than prolonged exposure.

Route 4 – Road

The focus of the assessment was New Hall Road/Hafod Road running north/south to the west of the Proposed Development.



Name: Route 4
Route type Two-way
View angle: 50.0 deg

Vertex	Latitude	Longitude	Ground elevation	Height above ground	Total elevation
	deg	deg	ft	ft	ft
1	52.998557	-3.030515	358.44	5.00	363.44
2	52.999577	-3.029377	341.37	5.00	346.37
3	53.000572	-3.028948	329.23	5.00	334.23
4	53.001062	-3.028626	335.27	5.00	340.27
5	53.001540	-3.028068	347.77	5.00	352.77
6	53.003903	-3.027081	330.56	5.00	335.56
7	53.004639	-3.026695	335.31	5.00	340.31
8	53.005156	-3.026674	340.07	5.00	345.07
9	53.006137	-3.026373	344.96	5.00	349.96

No Glare was found to result from the planned array on New Hall Road/Hafod Road.

Summary Table - Worst Case Total Annual Glare

PV	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pv-array-1 (green)	0	0	1066	2091	1321	1575	1352	1973	1503	76	0	0
pv-array-1 (yellow)	0	0	55	528	1099	846	1100	739	167	0	0	0

The summary table reflects monthly totals and is based on modelling without cloud cover.

Green Glare - Within the modelling results green glare can be ignored when looking at ground-based receptors. Green glare is not considered to cause temporary flash blindness and happens at an instant with very slight disturbance.

Yellow Glare - Glare present with the potential to leave a temporary after-image of the glare.

Annex F - Assumptions

- Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
- Glare analyses do not automatically account for physical obstructions between reflectors and receptors. This includes buildings, tree cover and geographic obstructions.
- Detailed system geometry is not rigorously simulated.
- The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual values and results may vary.
- 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.
- Several V1 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.
- 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.)
- 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.
- Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.

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Commander Shane Savage, B.Sc, Royal Navy (Retd)

Shane spent over 27 years in the Royal Navy specialising in Air Traffic Control (ATC) and Air Defence. His extensive experience includes an appointment within MOD Main Building responsible for Defence Windfarm Policy, RN Airspace Policy, regulatory issues and Defence ATC equipment programmes. He had several operational tours including a tour as Lt Cdr (Flying) on the Commando Helicopter carrier, HMS Ocean (Norway, Mediterranean, Caribbean, South America), and with other appointments as the Senior Air Traffic Controller (SATCO) at both Plymouth Military Radar and at RNAS Culdrose, at that time one of the busiest military airfields in Europe. His naval career culminated in leading both the ATC and Fighter Control specialisations as Head of Operations Support to the Fleet Air Arm. He was latterly the Royal Navy's Desk Officer for aviation infrastructure including airfields, radars and radio sites as well as being the RN Safeguarding Authority for aviation and the Sponsor for the Royal Navy's offshore Danger Areas.

He took early retirement from the Royal Navy in 2011 to go into partnership with John Taylor in establishing Wind Farm Aviation Consultants Ltd, the associate company to Wind Power Aviation Consultants Ltd and latterly has been working as lead consultant of a group of associates on projects throughout Europe, and globally, on both onshore and offshore wind developments and solar projects. In the last 14 years he has assessed and/or provided input to more than 2500 wind farm and solar proposals in the UK, Europe, Africa and in the Caribbean, and which has included giving evidence at numerous UK and Irish planning inquiries and providing expert advice to local planning authorities in the UK and Ireland on wind and solar projects; he is currently the Senior Consultant and a Director of Wind Farm Aviation Safeguarding Ltd.

He has been a member of the following working groups and policy bodies:

- CAA National Air Traffic Management Advisory Committee
- CAA/MOD National Flight Safety Committee
- CAA Danger Areas User Group
- UK Airspace Strategy Steering Committee
- MOD Airspace Requirements Review Team
- MOD Wind Farm Policy Group
- Military Users Airspace Co-ordination Team
- MOD Air Command and Control Programme Delivery Board
- MOD ATC Aviation Safety Board
- National UK IFF and SSR Committee
- Defence UK IFF and SSR Committee
- MOD UAV Airspace Design Working Group

- USA Joint Forces Command Executive Steering Committee on Air Battlespace Management, Close Air Support and Digital Data links
- MOD Mode S Working Group
- Low Flying Policy Group
- MOD/NATS Joint Future Airspace Design Team
- MOD/CAA Flexible Use of Airspace Policy Group
- Royal Navy lead for all aspects of Project Marshall, the MOD ATC replacement radar programme
- Represented UK MOD interests on several international policy groups at Eurocontrol and NATO.