Glare Assessment Report

Viewbank Solar Farm

15 October 2020

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The business of sustainability

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15 October 2020

Glare Assessment Report

Viewbank Solar Farm

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EXECUTIVE SUMMARY

FRV Services Australia Pty Ltd (FRV) is proposing to develop a solar farm on the land generally known as Viewbank Solar Farm (the Project). The subject site is approximately 5km east of Stanhope and 30km west of Shepparton. In relation to Melbourne, the site is approximately 200km to the north. It is situated within Campaspe Shire Council.

The Project involves the construction of a solar farm including the photovoltaic (PV) plant array, substation, inverter buildings (either containerised or in an outdoor configuration), ancillary control building, car park and refuse storage area, over approximately a 217 ha area, on the land generally known as No. 90 McCague Road Girgarre East.

Environmental Resources Management Australia Pty Ltd (ERM) have been engaged to provide an assessment of the potential glare impact resulting from the Project utilising the Forge Solar Glare Analysis Tool (FSGAT) to assess potential glare and ocular impact ratings.

This report identifies the environmental factors that contribute to glare and sensitive receptors near the Project, and describes the likely impacts and mitigation measures should they be required, noting that the model is based on relative heights between observation points, does not take any vegetation screening into account, and is therefore conservative in its prediction.

Observation points have been chosen based on proximity to the Project site and potential visibility. An initial GIS based topographic model was used to identify areas that may have visibility of the site, with 12 residential receptors, and McCague Road, McEwen Road, Midland Highway and Poole Road and assessed using the FSGAT.

In analysing the results from the FSGAT it is evident that there are no potential impacts of either yellow or green glare at any time throughout the year from the proposed 2 m and 4.2 m high single axis rotational PV array with Anti-Reflective Coating applied.

CONTENTS

1. INTRODUCTION 1
2. ASSESSMENT APPROACH 3
2.1 Project information relevant to methodology explanation 3
2.1.1 Reflectivity 4
2.1.2 Observation points and route analysis 5
3. PROJECT DESCRIPTION 6
4. GLARE EFFECTS 8
4.1 Reflectivity 8
4.2 Reflection and Angle of Incidence 9
4.3 Intensity 9
4.4 Scale of Effects 10
5. IMPACT ASSESSMENT 12
5.1 Identification of Observation Points 12
5.2 Solar Glare Hazard Assessment Tool 13
5.3 Visual Assessment .... **Error! Bookmark not defined.**
5.4 PV Array Configuration 14
5.5 Glare Assessment 14
5.5.1 Component Comparison Assessment .... **Error! Bookmark not defined.**
5.5.2 Assessment of Observation Points .... **Error! Bookmark not defined.**
6. DISCUSSION & CONCLUSION 16
7. LIMITATIONS 18

APPENDIX A FORGE SOLAR GLARE ANALYSIS RESULTS

List of Tables

Table 5-1 Observation Point Locations 12
Table 5-3 Potential Temporary After-Image Glare Minutes 16

List of Figures

Figure 1-1 Project Location 2
Figure 2-1 Glare Assessment Methodology 3
Figure 2-2 Difference in reflectivity due to angle incidence 4
Figure 2-3 Reflectance profiles of typical PV module materials 5
Figure 3-1 Project Site 7
Figure 4-1 Specular reflection 8
Figure 4-2 Diffuse reflection 9
Figure 4-3 Angle of incidence 9
Figure 4-4 Ocular Impacts and Hazard Ranges 10
Figure 5-12 Observation points and roads analysed utilising FSGAT 13

1. INTRODUCTION

Environmental Resources Management Australia Pty Ltd (ERM) has been appointed by FRV Services Australia Pty Ltd (FRV) to undertake an assessment of the potential glare impact resulting from a proposed solar farm on the land generally known as No. 90 McCague Road Girgarre East (Viewbank Solar Farm). The assessment will be conducted utilising the Forge Solar Glare Analysis Tool to assess potential glare and ocular impact ratings. ERM is a registered user with key personnel having completed training on the tool.

The subject site is approximately 5km east of Stanhope and 30km west of Shepparton. In relation to Melbourne, the site is approximately 200km to the north. The subject site is illustrated in **Figure 1-1**. The subject site is approximately 217 ha and is farmland that is used for cropping and grazing. The topography of the land is generally flat, with an elevated area to the north of the site. The property then slopes down towards the irrigation areas which also includes a natural drainage channel and swamp that are located to the south west corner. There is an existing dwelling and associated buildings on the site of 90 McCague Road, Cooma to the north of the site. No surface waters are located on the property.

This report identifies the environmental factors that contribute to glare and sensitive receptors near the Project, and describes the likely impacts and mitigation measures should they be required.

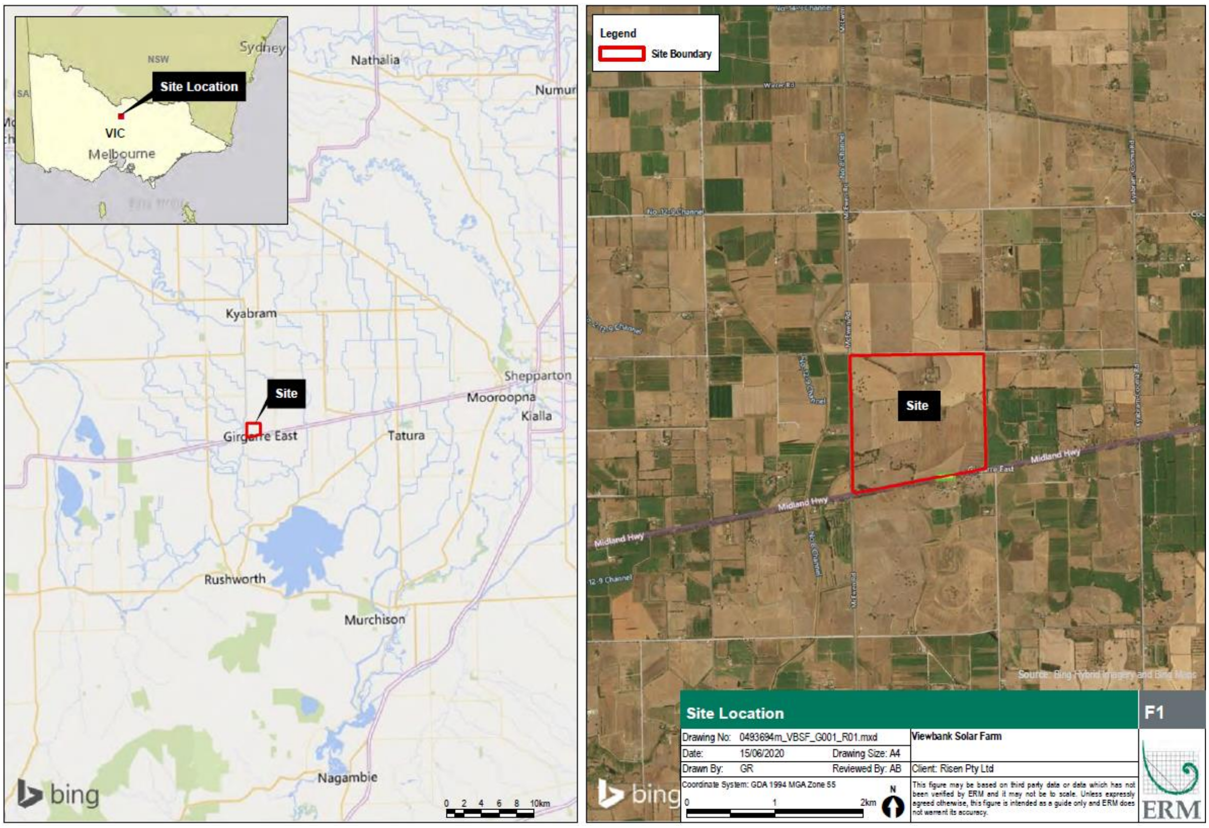


Figure 1-1 Project Location

2. ASSESSMENT APPROACH

The assessment methodology utilises the Forge Solar Glare Assessment Tool (FSGAT) to assess potential glare and ocular impact rating. The assessment of glare impacts associated with the Project include the following steps:

- Describes the Project and components that may contribute to glare;
- Describes the environmental factors that contribute to glare;
- Defines the study area;
- Identifies receptors within the study area;
- Describes the likely impact to those key receptors: and
- Describes mitigation measures available for the Project should they be required.

The glare assessment methodology adopted for the Project is shown in Figure 2-1. The methodology comprises a combination of quantitative and qualitative assessments for glare from the Project. Quantitative assessment includes definition of the study area. The study area is defined by the components of the Project that are pertinent to glare. Note that the area chosen is larger than the likely development footprint to allow flexibility in design and is therefore more conservative. These include the photovoltaic arrays and reflectivity parameters of surfaces.

Qualitative components within the assessment include sensitivity of receptors (human) to glare.

2.1 Project information relevant to methodology explanation

As the FSGAT is an analysis tool that produces its analysis outputs based on the variable inputs of the PV specifications from the user (such as direction, single or fixed axis, anti-reflective coating, etc.) and the fixed parameters of the tool itself. It is worth noting what inputs were used in the FSGAT tool. This is to ensure appropriate interpretation of the **FSGAT** results and clarify why the FSGAT tool may produce the results it does.

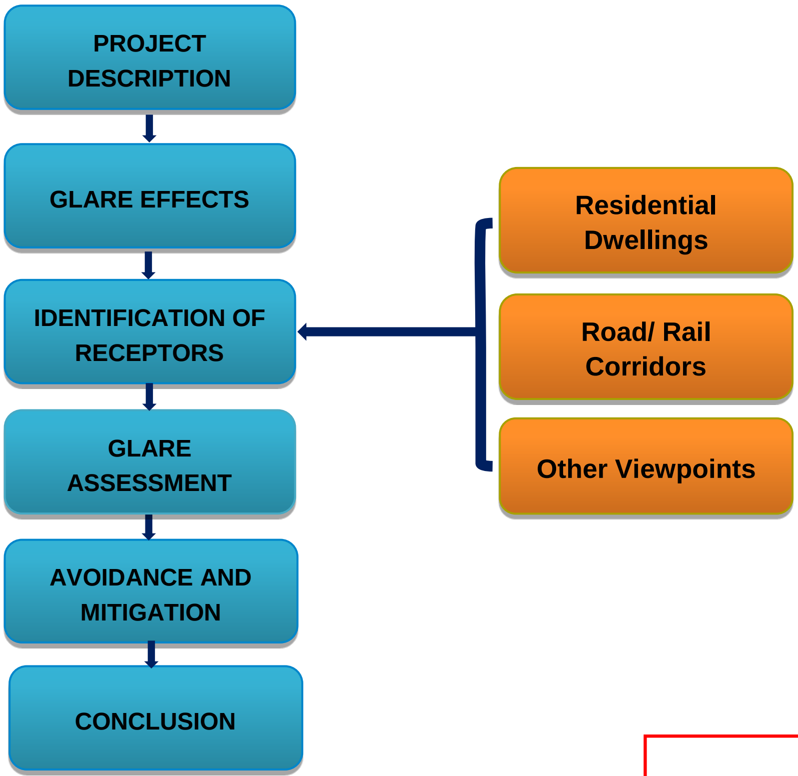


Figure 2-1 Glare Assessment Methodology

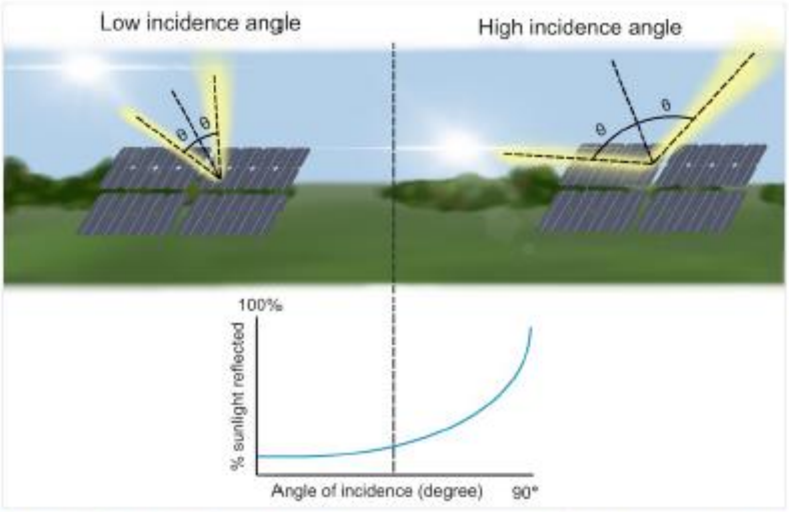
2.1.1 Reflectivity

While the concept of reflectivity and light diffusion is explained within **Section 4.1** in relation to its effects as glare, reflectivity is relative to many variables within PV placement and this effects the inputs and outputs of the FSGAT tool.

A panel that absorbs 90% of direct sunlight may reflect up to 60% when not directly facing the sun. This situation is common for low-tilt panels during sunset and sunrise. The oft-repeated claim that PV panels reflect less than 5% of sunlight only holds true when the panels directly face the sun**.** For fixed-mount panels, this claim only applies during a few minutes of the day, at most.

In relation to Viewbank Solar Farm, the PV panel mounting structure that has been specified in the design is a single axis tracker. This tracker will follow the sun so that panels directly face the sun throughout the day". This means that the panels reflect the minimal amount of sunlight throughout the entire day. If a fixed panel were to be chosen this would result in a portion of the day to produce a high level of glare due to high incidence angle, as outlined in **Figure 2-2.**

A rotating panel throughout the day maintains a low level of glare incidence due to the consistent low angle. Inputting this variable into FSGAT produces low levels of surrounding glare at sensitive receptors in comparison to fixed panels.



PV panel reflectance depends on incidence angle between panel normal (i.e. facing) and sun position. Large incidence angle yields more reflected sunlight.

Figure 2-2 Difference in reflectivity due to angle incidence

Within this parameter the variable of panel surface is also an important input to note. There exist multiple options for the face of a panel which effects the amount of reflected light at a certain angle of incidence. There are light textured glass options and anti-reflective coatings. **Figure 2-3** illustrates the reflectance of each material profile as a function of incidence angle, where an angle of 0° implies the panels are directly facing the sun. For example, a high glancing angle near 90° for panels with 0° tilt (lying flat) occurs daily at sunrise and sunset. Anti-reflective coatings (ARC) and surface texturing can reduce panel reflectivity, but this reduction is typically less than 8%. In addition, greater surface texturing can increase the size of the subtended source angle (i.e. glare spot).

For the Viewbank Solar Farm, the PV module material chosen that is input into the FSGAT tool consists of smooth glass with an ARC. This will produce lower potential reflectivity throughout the day as compared to smooth glass without ARC.

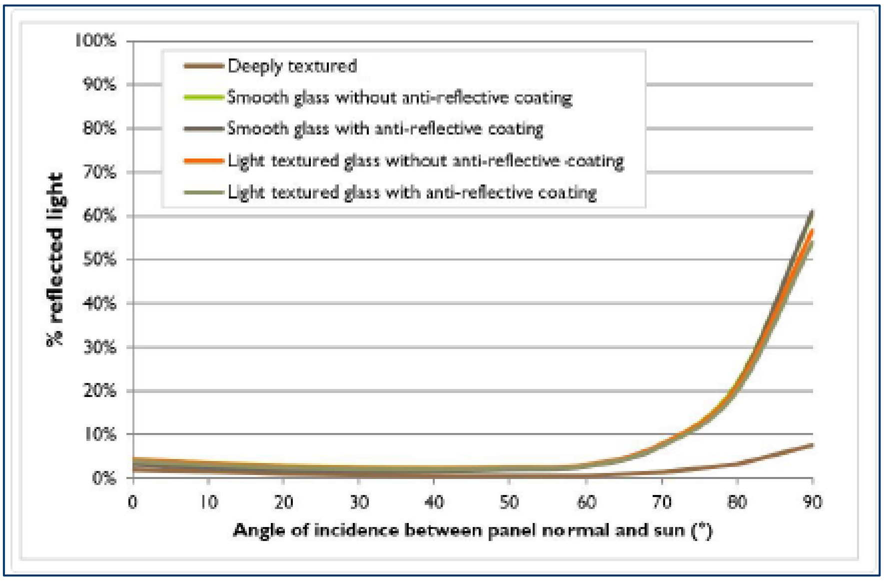


Figure 2-3 Reflectance profiles of typical PV module materials

2.1.2 Observation points and route analysis

The FSGAT allows for observation points and routes surrounding the analysed sites and array to be assessed. The FSGAT tool allows for simulations of an observer at a single discrete location defined by longitude and latitude, elevation, and height above ground. The route receptor allows for simulations of observers travelling along continuous paths such as roads, railways, helicopter paths, and multi-segment flight tracks.

The observation points and route analysis do not take into account any land coverage that isn't topographical. As such, the FSGAT tool outputs results based on unimpeded view at that specific location. This is critical to note as areas with dense vegetation, buildings and infrastructure that would impede glare visibility would not be considered in the output. Typically, visual verification of an observation point is needed where glare might be a problem but there is a frontage obscuring the view of the glare source (e.g. a house with a large frontage of vegetation may receive significant glare but in reality the glare is blocked from the sensitive receptor by in place vegetation.

Route parameters can also vary determining the outputs of the FSGAT analysis. For example, route direction is a variable that can alter the outcome as you can input a one-way direction or travel in both directions. View angle can also be altered as an input and defines the left and right field-of-view of observers along the route. A view of 180º would imply the observer can see potential glare in all directions. A view angle of 50° (default) implies the observer has a field-of-view of 50° to their left and right, i.e. a total FOV of 100°. This default is based on FAA research which determined that the impact of glare that appears beyond 50° is mitigated.

The Viewbank Solar Farm identifies 3 routes that need assessment using the FSGAT tool. The input variables chosen were a two-way travel direction using a view angle of 50º (a total FOV of 100º).

3. PROJECT DESCRIPTION

The Viewbank Solar Farm (the Project) involves the construction of a solar farm including the photovoltaic (PV) plant array, substation, battery energy storage (BESS), inverter buildings (either containerised or in an outdoor configuration), underground cable network, internal access tracks, and a site office building and associated car parking, over a 217ha Development Area The 75 MW grid connected solar farm is expected to generate enough power to supply 37,400 typical Victorian homes. The Viewbank Solar Farm will be connected to PowerCor's Service's existing 66kV distribution network, which is located to the south of the site. The proposed access to the site for construction vehicles is off Poole Road which can be accessed by Midland Highway.

PV modules will be fixed to and supported by a ground-mounted framing structure, aligned in rows oriented in a north-south direction. Single axis tracking technology will be used for the project so that the panels can change their orientation throughout the day to follow the sun and maximise the energy captured. The rows of PV modules will be spaced out approximately 3.5 - 8 meters apart along the east-west axis. The use of single axis tracking technology would enable the PV modules to rotate from east to west during the day, tracking the sun's movement.

The construction period of the project is expected to be up to 18 months. During construction, a site office compound and temporary laydown areas will be established. The lifespan of the project is estimated to be 30 years. At the end of its useful life, the solar farm can be decommissioned and traditional agricultural use will resume back on site.

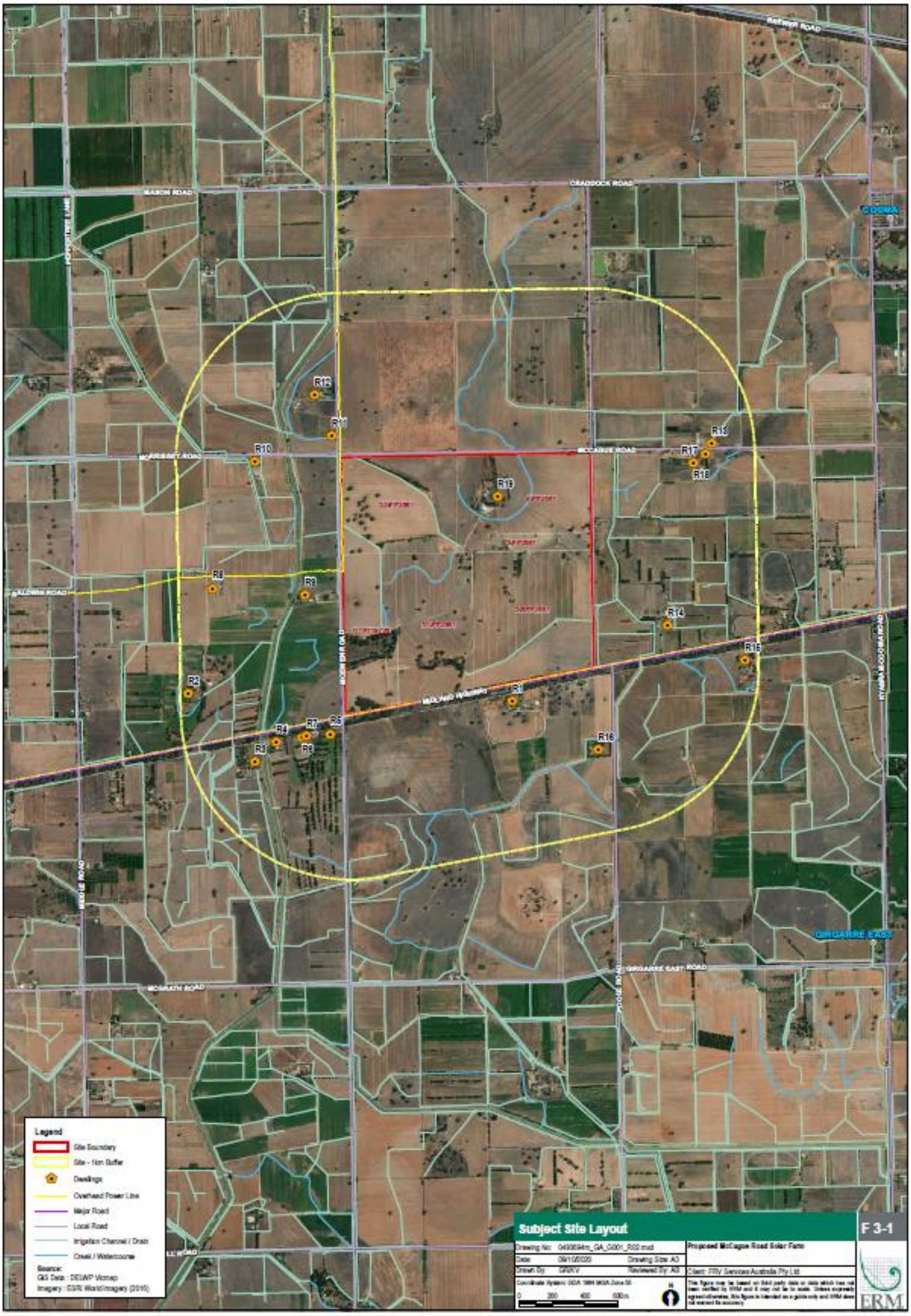


Figure 3-1 Project Site

4. GLARE EFFECTS

Glint and glare (referred to collectively in this report as glare) are caused by a significant contrast between a light source and background illuminance. Glare occurs over a continuous period while glint is a brief flash of light. Glint and glare can be hazardous when they affect critical operations like aviation. Aside from causing discomfort to the viewer, glare can be a source of distraction and can leave after-images in the viewer's vision.

It is important to note that the Forge Solar Glare Gauge Assessment Tool (FSGAT) utilised in this report assesses glint and glare effects, there are no separate analysis of either glint or glare. Both of these aspects of 'glare hazard' are assessed utilising the FSGAT methodology.

Glare hazard is the human impact caused by exposure to reflected light. Factors that contribute to glare hazard for a solar farm include:

- Reflectivity of surfaces;
- Angle of incidence;
- Strength of the light source;
- Receptors; and
- Distance

Photovoltaic efficiency describes the efficiency or percentage of radiation (sun) energy that can be converted into electrical energy. The more light that can be absorbed by a solar panel, the more efficient the process.

For these reasons, photovoltaic panel surfaces are designed to absorb as much light as possible and limit reflection. However, glare or reflection can still occur at various times throughout the day.

For these reasons, solar panels are designed to reduce glare and reflectance.

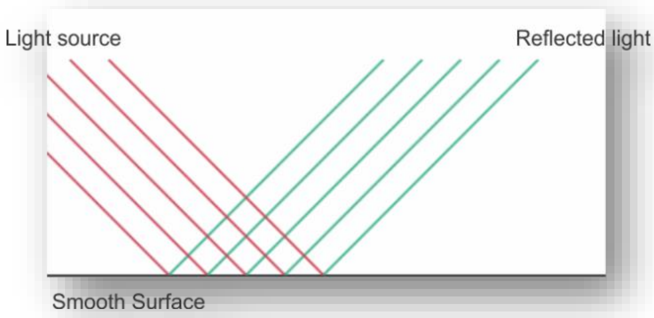
4.1 Reflectivity

Specular and Diffuse reflection are the two main types of light reflection caused by the sun reflecting off the surface of solar panels.

Specular reflection occurs when light is reflected from a smooth surface. In specular reflection, reflected light is usually parallel and the angle of reflected light is similar to that of the incoming light source.

Specular reflection is experienced as a flash similar to that of a moving car windscreen.

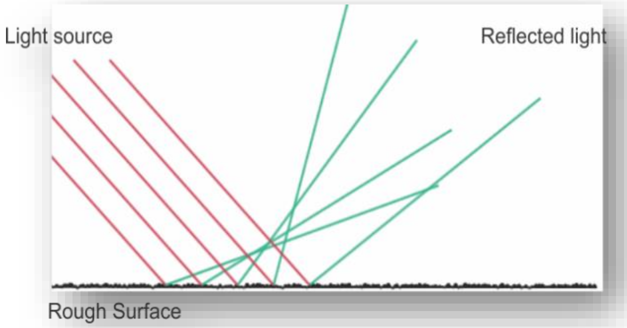
Figure 4-1 Specular reflection



Diffuse reflection occurs when light is reflected from a dull or matt surface. The reflected light is scattered with inconsistent angles. The rougher the surface, the more diffused the reflection.

Diffuse light is usually experienced as a glow, and although usually less intense than specular reflection, the glare effects of diffuse reflection can be longer lasting than Specular reflection.

Figure 4-2 Diffuse reflection



The amount of light reflected from a PV panel depends on the amount of sunlight hitting the surface as well as the surface reflectivity. The amount of sunlight exposure will vary based on geographic location, time of year, cloud cover, and solar panel orientation.

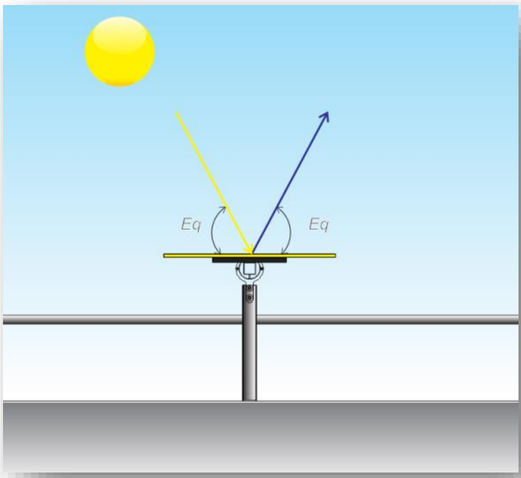
4.2 Reflection and Angle of Incidence

Angle of incidence describes the angle at which a line or trajectory (in this case light) deviates from perpendicular to a surface.

The angle of incidence alters as the sun moves across the sky and during various times of the year. The angle of incidence for the sun is at its lowest around noon where the sun is directly overhead and at its highest at dawn and at dusk.

At a simple level, a single-axis tracking PV array, as is being proposed for the Project, is designed to optimise the efficiency by reducing the angle of incidence over the course of the day, which will also reduce the potential for glare. The tracking systems also utilise backtracking technology, to reduce shading-impacts of individual rows. This means that the angle of incidence will vary across individual rows early in the morning and later in the afternoon. These slight changes in angle have no significant impacts on glare.

Figure 4-3 Angle of incidence



4.3 Intensity

Glare effect can be described as the presence of light within the human field of vision that will result in visual discomfort or impairment. This can be experienced when looking at a reflection of the sun from a surface such as glass, water or metal. The assessment of the effect of glare varies depending on the intensity of the incoming light, relativity to the field of human vision, duration of exposure, size of the glare and distance of the receiver from the glare source.

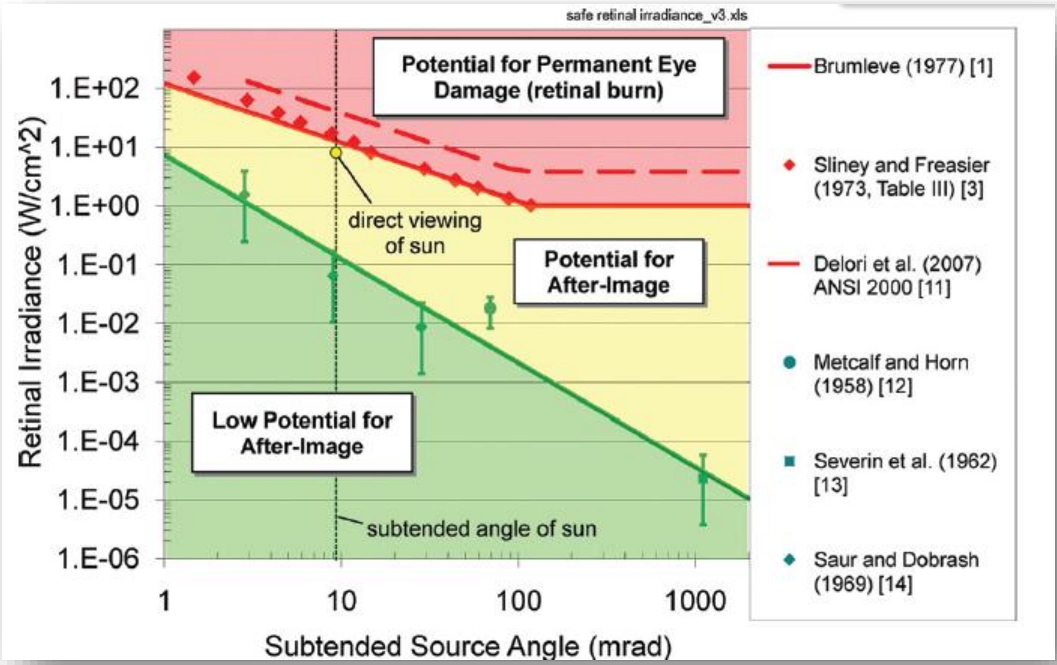
Glare is defined as either discomfort or disability glare. Discomfort glare creates difficulty in seeing the object(s) being focussed upon. Disability glare can impair vision for a short or sustained period. Disability glare is a primary and common cause of concern in relation to traffic safety.

The assessment of glare effects and associated scale of effects are primarily based on the assessment distance to the Project, viewer numbers based on location, and potential for after image.

- **Distance**: The distance of the viewer from the Project. The level of impact decreases as distance increases.
- **Number of viewers**: The level of impact is less likely to occur where there are fewer people able to experience after image.

Visibility in terms of line of sight towards the Project also plays a factor in the potential for after image effect because if the Project is not visible from a specific location then there is no chance for after image.

Figure 4-4 Ocular Impacts and Hazard Ranges



4.4 Scale of Effects

This study uses the following scale of effects for assessing the glare impacts of the Project:

- Nil Potential for After-Image
- Low Potential for After-Image
- Potential for After-Image
- Potential for Permanent Eye Damage (retinal burn)

Nil effect:

No recorded glare effect at the specified location at any time of the year.

Low potential for after image:

Adverse effects that are noticeable however will not cause any significant adverse impacts and no mitigation measures are required.

Potential for After Image

Significant effects that may be require mitigation and / or remedied.

Potential for Permanent Eye Damage

Potential for permanent adverse effects that will require mitigation or design changes.

This scale is used when describing the overall Glare Assessment of the Project from indicative publicly accessible and residential observation points, discussed in the following sections. The FSGAT tool quantifies these ocular impact of solar glare into three (3) categories:

- Green – low potential to cause after-image (flash blindness)
- Yellow – potential to cause temporary after-image
- Red – potential to cause retinal burn (permanent eye-damage)

5. IMPACT ASSESSMENT

5.1 Identification of Observation Points

This section examines locations within the surrounding landscape that may be impacted by glare from the Project. Observation points have been chosen based on proximity to the Project site and potential visual impact. An initial GIS based topographic model was used to identify areas that may be visually impacted by the development, with 12 observation receptors, McCague Road, McEwan Road, Poole Road and Midland Highway and assessed using the FSGAT.

Table 5-1 and **Figure 5-2** provides a summary of Observation Points.

Table 5-1 Observation Point Locations

Observation Point	Latitude (º)		Longitude (º)	Elevation (m)	Height (m)
OP1	-36.436101		145.053835	111.97	1.80
OP2	-36.427054		145.056345	111.46	1.80
OP3	-36.425436		145.031685	111.79	1.80
OP4	-36.423165		145.031540	115.04	1.80
OP5	-36.426670		145.026197	110.82	1.80
OP6	-36.434029		145.029357	110.21	1.80
OP7	-36.433456		145.023172	109.00	1.80
OP8	-36.439329		145.021326	113.09	1.80
OP9	-36.441776		145.029287	110.66	1.80
OP10	-36.440140		145.043235	115.31	1.80
OP11	-36.442866		145.049033	111.00	1.80
OP12	-36.438149		145.059021	112.61	1.80
McCague Road	Vertex 1	-36.426489	145.031902	110.07	1.50
	Vertex 2	-36.426558	145.053445	113.94	1.50
McEwen Road	Vertex 1	-36.422328	145.031923	114.03	1.50
	Vertex 2	-36.442717	145.031923	109.45	1.50
Midland Highway	Vertex 1	-36.441612	145.026151	110.36	1.50
	Vertex 2	-36.436986	145.059432	111.66	1.50

Observation Point	Latitude (º)		Longitude (º)	Elevation (m)	Height (m)
Poole Road	Vertex 1	-36.422570	145.049047	111.03	1.50
	Vertex 2	-36.438453	145.049025	110.97	1.50

5.2 Solar Glare Hazard Assessment Tool

This Glare Assessment of the Project utilises the Forge Solar Glare Assessment Tool (FSGAT) to assess potential glare and ocular impact rating. This tool was developed by the US based Sandia National Laboratories and licenced to Forge Solar and is a globally recognised industry standard assessment tool for assessing glare from solar developments.

FSGAT uses latitude and longitudinal coordinates and elevation data from Google Earth in conjunction with proprietary algorithms software to predict the sun position and angle at various times throughout the year. Information such as the size and orientation of the PV panel orientation and surface reflectivity are project specific.

FSGAT will predict glare potential at a nominated observation point, the likely time and duration as well as the magnitude of potential glare impact based on the scale of effects identified in **Section 4.4** Scale of Effects.

Figure 5-12 Observation points and roads analysed utilising FSGAT

5.3 PV Array Configuration

It is understood that the PV array configuration for the proposed development will be a single axis tracker with smooth glass with an ARC applied. This is the configuration option being considered, and which has been assessed using the FSGAT. The variable within the PV array is the height of the panels being considered. The two options currently undergoing assessment and that were assessed with the FSGAT modelling tool are an approximate 2 m and 4.2 m peak height panel configuration. These two separate heights that were assessed with the FSGAT tool as the PV array can utilise the same sized panel but in configurations of rows of either 2 panels or 1 panel. This is detailed in the panel equipment schematic in **Appendix B**. This 'peak height' is only reached by the panel when they are at maximum tilt.

PV modules will be fixed to and supported by a ground-mounted framing structure, aligned in rows oriented in a north-south direction. Single axis tracking technology will be used for the project so that the panels can change their orientation throughout the day to follow the sun and maximise the energy captured. The rows of PV modules will be spaced out approximately 3.5 - 8 meters apart along the east-west axis. The use of single axis tracking technology would enable the PV modules to rotate from east to west during the day, tracking the sun's movement.

5.4 Civil Aviation Safety Authority Requirements

The Civil Aviation Safety Authority (CASA) Regulations require that air traffic control towers are protected from glare. Assessment of glare effects by nearby solar PV systems within or near airports are to follow guidelines issues by the US Federal Aviation Administration (FAA) when making assessments.

The FAA recommends that any proposed solar farms that are below the direct approach paths to an airport (aligned with a runway) and within a distance of around 5 nautical miles (approximately 10km) from a runway end should be referred for a specific assessment by the relevant authorities.

The FSGAT used for assessing glare effects in this report (and the related analysis in **Appendix A**) evaluates all inputs against the FAA policy for adherence of glare effects from solar PV systems in the following areas:

- No "yellow" glare (potential for after-image) for any flight paths from threshold to 2 miles;
- No glare of any kind for air traffic control towers at cab height; and
- Default analysis and observer characteristics (general analysis of glare effects at observation points).

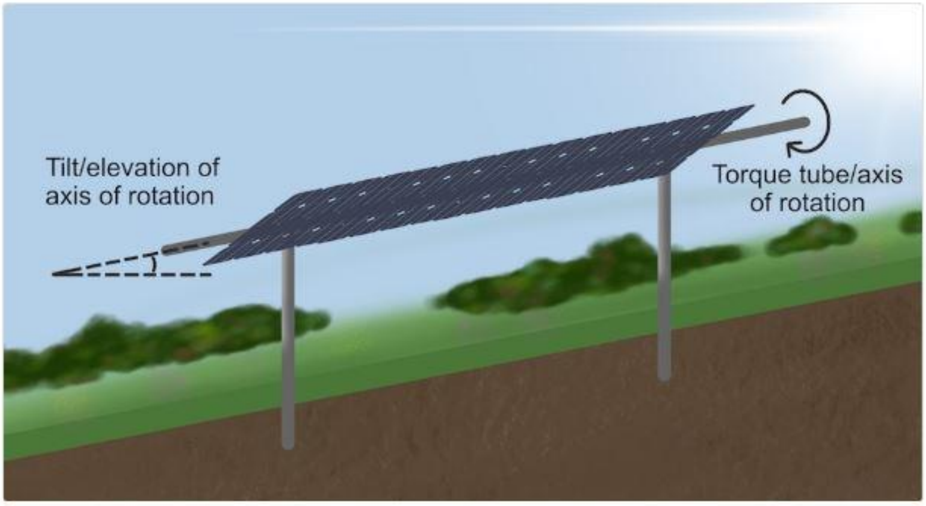
The nearest airstrip to Viewbank Solar Farm is the Shepparton Airport approximately 30 km from Project boundary. The physical distance from the Project makes it unlikely that the solar farm will cause any significant glare issues for pilots on approach or on departure from the airstrip. Inclusive of the fact that both runways do not align their approach and departure paths over the solar farm, and that there are significant geographical features between the Project and the nearest airstrip. It is not deemed necessary to perform a specific assessment of aircraft flight paths in this study.

5.5 Glare Assessment

An assessment of potential glare impacts on the nominated receptors has been undertaken for the parameters of a 2 m and 4.2 m peak height, single axis tracking mount with PV panels with smooth glass and with an ARC applied as outlined in Section 2.1.1. The FSGAT tool takes into account various models of PV panels and assesses all potential glare inputs including panel maximum tilt. A brief overview of how the FSGAT tool takes into account the direction of the PV panel and its tracking process is demonstrated below in **Figure 5-2.**

Tracking System Parameters

Single-axis module tracking systems are described by a unique set of parameters. These angular inputs model the tracking axis, rotation range and backtracking behavior. Dual-axis module tracking systems are assumed to track the sun at all times.



Single-axis tracking system with torque tube tilted due to geography

Tilt of tracking axis (°)
Tilt above flat ground of axis over which panels rotate (e.g. torque tube). System on flat, level ground would have axis tilt of 0°.

Orientation of tracking axis (°)
Azimuthal angle of axis over which panels rotate. Angle represents the facing of the axis and system. For example, typical tracking system in northern hemisphere has tracking axis oriented north-south with an orientation of 180°, allowing panels to rotate east-west with potential south-facing tilt. Typical tracking system in southern hemisphere runs south-north with axis orientation of 0°, yielding east-west rotation with potential north-facing tilt.

Offset angle of module (°)
Additional tilt angle of PV module elevated above tracking axis/torque tube. Offset angle is measured from the torque tube.

Maximum tracking angle (°)
Maximum angle of rotation of tracking system in one direction. For example, a typical system with a 120° range of rotation has a *max tracking angle* of 60° (east/west).

Resting angle (°)
Angle of rotation of panels when sun is outside tracking range. Used to model backtracking. Panels will revert to the position described by this rotation angle at all times when the sun is outside the rotation range. Setting this equal to the *maximum tracking angle* implies the panels do not backtrack.

ForgeSolar utilizes a simplified model of backtracking which assumes panels instantaneously revert to the *resting angle* whenever the sun is outside the rotation range. For example, panels with *max tracking angle* of 60° and *resting angle* of 0° would lie flat from sunrise until the sun enters the rotation range, and immediately after the sun leaves the rotation range until sunset daily.

Figure 5-2 FSGAT Tool Tracking System Parameters

Further information regarding the assessment methodology of the FSGAT tool, including assessment of glare and glint from tracking panels, is included in **Appendix C**.

The below **Table 5-3** provides a comparison of potential temporary after-image glare in minutes over a yearly period for each option.

It is evident from the outcomes of the assessment that single axis rotational PV array configuration results in no potential glare impacts.

Table 5-2 Potential Temporary After-Image Glare Minutes

Receptors	2 m high Single Axis smooth glass with ARC		4.2 m high Single Axis smooth glass with ARC	
	Annual Green Glare (min)	Annual Yellow Glare (min)	Annual Green Glare (min)	Annual Yellow Glare (min)
OP1	0	0	0	0
OP2	0	0	0	0
OP3	0	0	0	0
OP4	0	0	0	0
OP5	0	0	0	0
OP6	0	0	0	0
OP7	0	0	0	0
OP8	0	0	0	0
OP9	0	0	0	0
OP10	0	0	0	0
OP11	0	0	0	0
OP12	0	0	0	0
McCague Road	0	0	0	0
McEwen Road	0	0	0	0
Midland Highway	0	0	0	0
Poole Road	0	0	0	0

Assessment of potential glare impacts at each observation is traditionally undertaken on a point by point basis in an assessment table. As there are no glare impacts from the 2 m or the 4.2 m options to any observation points an assessment is not necessary.

6. DISCUSSION & CONCLUSION

The Glare Assessment has identified that there are no potential glare impacts to any of the observation points or routes surrounding the Project. It is clear from the results that the use of single axis tracking avoids any potential glare impacts, irrespective of the height configurations analysed.

In analysing the locations which have the potential to experience glare impacts, it was evident that existing vegetation, buildings or the proposed landscape screening along the Project boundaries will largely obstruct any views of the facility and filter any potential glare impacts. The use of anti-reflective coating on the PV panels has further reduced the potential for glare impacts occurring from these locations.

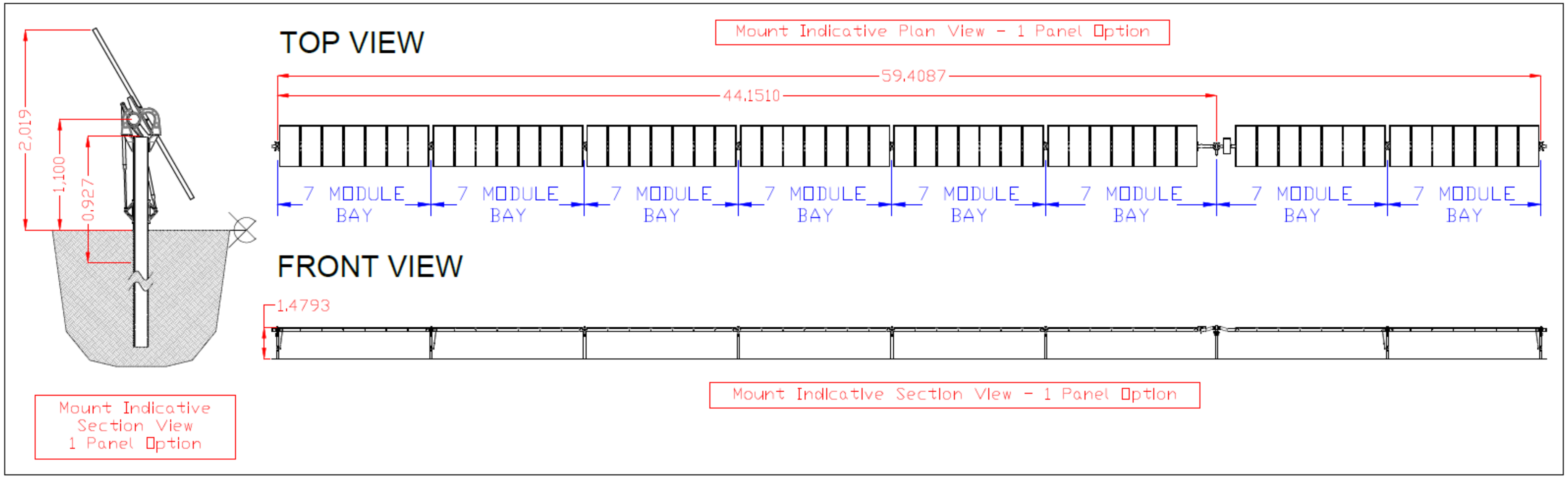
The modelling tool also included an analysis of potential glare impacts to McCague Road, McEwen Road, Midland Highway and Poole Road. No glare was detected for the road corridors.

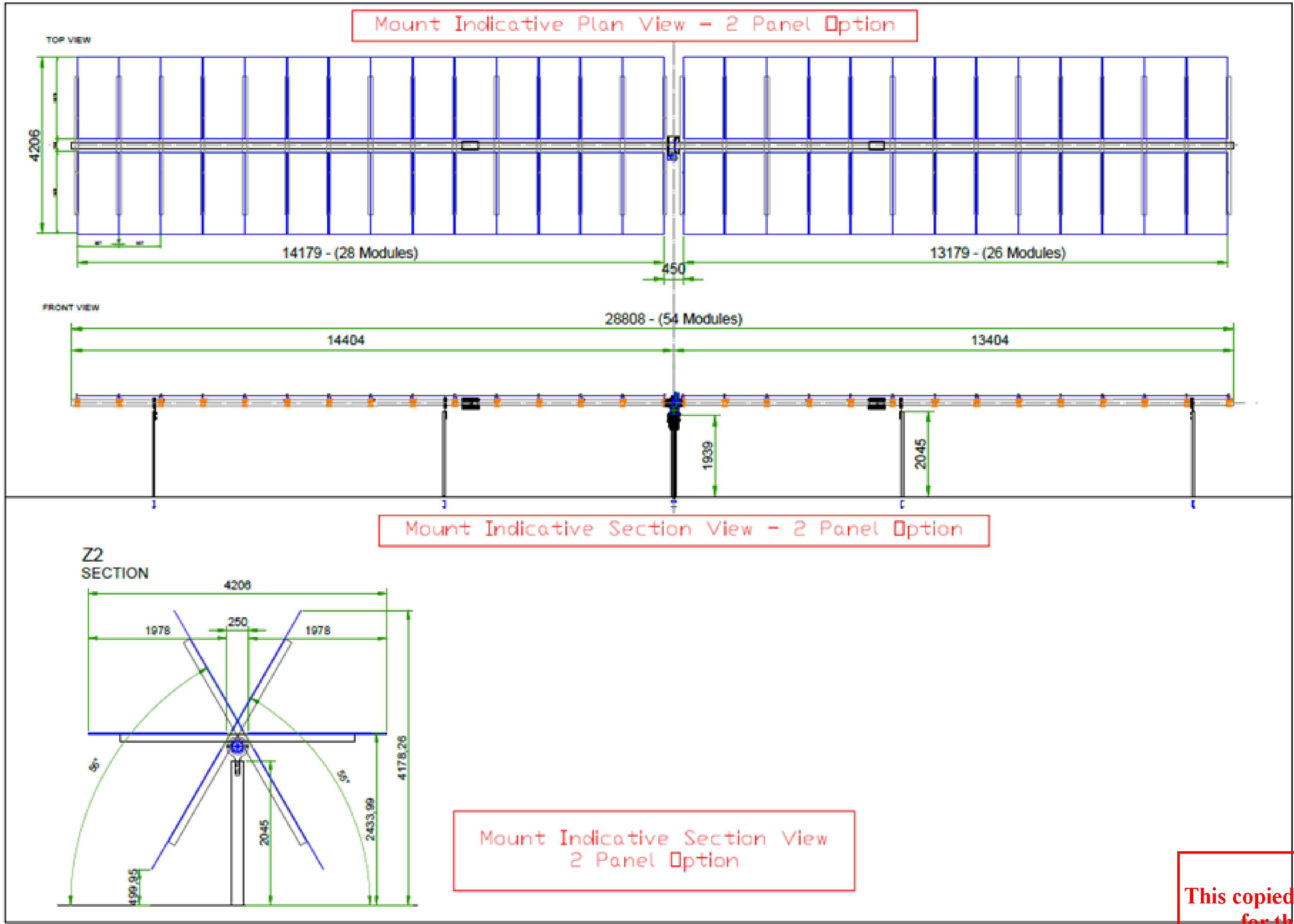
7. LIMITATIONS

- The Glare Assessment is based on the results from the Forge Solar Glare Analysis Tool.
- Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
- Glare analyses do not 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.
- 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; however the PV footprint for Viewbank SF is not considered large and has been analysed as 2 array sub-sections. Additional analyses of array sub-sections can provide additional information on expected glare.
- The FSGAT does not account for back-tracking of the PV panels. It is assumed the PV tracker will revert to 0 degrees following sunset and revert to 60 degrees before sunrise, having no glare impact associated with back-tracking.
- 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.
- 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.
- Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.

APPENDIX A FORGE SOLAR GLARE ANALYSIS RESULTS

APPENDIX B EQUIPMENT SCHEMATIC (PV ARRAY)


TOP VIEW
Mount Indicative Plan View - 1 Panel Option
59.4087
44.1510
7 MODULE BAY
FRONT VIEW
1.4793
Mount Indicative Section View - 1 Panel Option
2.019
1.100
0.927
Mount Indicative
Section View
1 Panel Option


Mount Indicative Plan View - 2 Panel Option
TOP VIEW
4206
14179 - (28 Modules)
13179 - (26 Modules)
450
FRONT VIEW
28808 - (54 Modules)
14404
13404
1939
2045
Mount Indicative Section View - 2 Panel Option
Z2
SECTION
4206
1978
250
1978
4178.26
2433.99
2045
499.95
Mount Indicative Section View
2 Panel Option

APPENDIX C GUIDANCE AND INFORMATION FOR FORGE SOLAR GLARE ANALYSIS TOOL

ERM has over 160 offices across the following countries and territories worldwide

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FORGESOLAR GLARE ANALYSIS

Project: **FRV Viewpoint Solar Farm**
Site configuration: **Viewpoint 1_0**
Analysis conducted by Alan Simonic (alan.simonic@erm.com) at 23:16 on 09 May, 2020.

U.S. FAA 2013 Policy Adherence

The following table summarizes the policy adherence of the glare analysis based on the 2013 U.S. Federal Aviation Administration Interim Policy 78 FR 63276. This policy requires the following criteria be met for solar energy systems on airport property:

- No "yellow" glare (potential for after-image) for any flight path from threshold to 2 miles
- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics (see list below)

ForgeSolar does not represent or speak officially for the FAA and cannot approve or deny projects. Results are informational only.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
2-mile flight path(s)	N/A	No flight paths analyzed
ATCT(s)	N/A	No ATCT receptors designated

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

FAA Policy 78 FR 63276 can be read at https://www.federalregister.gov/d/2013-24729

SITE CONFIGURATION

Analysis Parameters

DNI: peaks at 1,000.0 W/m^2
Time interval: 1 min
Ocular transmission coefficient: 0.5
Pupil diameter: 0.002 m
Eye focal length: 0.017 m
Sun subtended angle: 9.3 mrad
Site Config ID: 39042.7117

PV Array(s)

Name: PV array 1
Axis tracking: Single-axis rotation
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 60.0°
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.438043	145.048792	110.45	4.20	114.65
2	-36.438967	145.042741	112.90	4.20	117.10
3	-36.438958	145.040284	114.28	4.20	118.48
4	-36.438596	145.040080	115.40	4.20	119.60
5	-36.437034	145.040488	109.89	4.20	114.09
6	-36.437318	145.037805	115.66	4.20	119.86
7	-36.436317	145.037730	110.22	4.20	114.42
8	-36.434107	145.040863	108.08	4.20	112.28
9	-36.433745	145.044135	108.88	4.20	113.08
10	-36.432744	145.044511	109.84	4.20	114.04
11	-36.432770	145.048824	111.59	4.20	115.79

Name: PV array 2
Axis tracking: Single-axis rotation
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 60.0°
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.426675	145.032119	109.67	4.20	113.87
2	-36.426762	145.048802	114.03	4.20	118.23
3	-36.430189	145.048792	112.35	4.20	116.55
4	-36.431043	145.044983	109.58	4.20	113.78
5	-36.431173	145.042580	111.70	4.20	115.90
6	-36.431941	145.039565	111.15	4.20	115.35
7	-36.432821	145.039372	110.61	4.20	114.81
8	-36.434366	145.037108	107.64	4.20	111.84
9	-36.434841	145.037065	108.00	4.20	112.20
10	-36.435126	145.034640	110.00	4.20	114.20
11	-36.436205	145.033535	110.64	4.20	114.84
12	-36.436196	145.032076	110.02	4.20	114.22
13	-36.432019	145.032162	110.00	4.20	114.20
14	-36.431880	145.033310	109.44	4.20	113.64
15	-36.431104	145.034168	110.63	4.20	114.83
16	-36.429955	145.034308	112.38	4.20	116.58
17	-36.428712	145.034254	112.33	4.20	116.53
18	-36.428738	145.033203	113.36	4.20	117.56
19	-36.427823	145.032119	110.81	4.20	115.01

Discrete Observation Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	-36.436101	145.053835	111.97	1.80
OP 2	2	-36.427054	145.056345	111.46	1.80
OP 3	3	-36.425436	145.031685	111.79	1.80
OP 4	4	-36.423165	145.031540	115.04	1.80
OP 5	5	-36.426670	145.026197	110.82	1.80
OP 6	6	-36.434029	145.029357	110.21	1.80
OP 7	7	-36.433546	145.023172	109.00	1.80
OP 8	8	-36.439329	145.021326	113.09	1.80
OP 9	9	-36.441776	145.029287	110.66	1.80
OP 10	10	-36.440140	145.043235	115.31	1.80
OP 11	11	-36.442866	145.049033	111.00	1.80
OP 12	12	-36.438149	145.059021	112.61	1.80

Route Receptor(s)

Name: McCague Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.426489	145.031902	110.07	1.50	111.57
2	-36.426558	145.053445	113.94	1.50	115.44

Name: McEwen Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.422328	145.031923	114.03	1.50	115.53
2	-36.442717	145.031923	109.45	1.50	110.95

Name: Midland Highway
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.441612	145.026151	110.36	1.50	111.86
2	-36.436986	145.059432	111.66	1.50	113.16

Name: Poole Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.422570	145.049047	111.03	1.50	112.53
2	-36.438453	145.049025	110.97	1.50	112.47

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt (°)	Orient (°)	"Green" Glare min	"Yellow" Glare min	Energy kWh
PV array 1	SA tracking	SA tracking	0	0	-
PV array 2	SA tracking	SA tracking	0	0	-

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Results for: PV array 1

Receptor	Green Glare (min)	Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0

Receptor	Green Glare (min)	Yellow Glare (min)
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Point Receptor: OP 1

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Route: McCague Road

0 minutes of yellow glare
0 minutes of green glare

Route: McEwen Road

0 minutes of yellow glare
0 minutes of green glare

Route: Midland Highway

0 minutes of yellow glare
0 minutes of green glare

Route: Poole Road

0 minutes of yellow glare

0 minutes of green glare

Results for: PV array 2

Receptor	Green Glare (min)	Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Point Receptor: OP 1

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Route: McCague Road

0 minutes of yellow glare
0 minutes of green glare

Route: McEwen Road

0 minutes of yellow glare

0 minutes of green glare

Route: Midland Highway

0 minutes of yellow glare
0 minutes of green glare

Route: Poole Road

0 minutes of yellow glare
0 minutes of green glare

Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
Glare analyses do not account for physical obstructions between reflectors and receptors. This includes buildings, tree cover and geographic obstructions.
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.
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.)
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual results and glare occurrence may differ.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
Refer to the Help page at **www.forgesolar.com/help/** for assumptions and limitations not listed here.

FORGESOLAR GLARE ANALYSIS

Project: **FRV Viewpoint Solar Farm**
Site configuration: **Viewpoint 2_0**
Analysis conducted by Alan Simonic (alan.simonic@erm.com) at 23:49 on 09 May, 2020.

U.S. FAA 2013 Policy Adherence

The following table summarizes the policy adherence of the glare analysis based on the 2013 U.S. Federal Aviation Administration Interim Policy 78 FR 63276. This policy requires the following criteria be met for solar energy systems on airport property:

- No "yellow" glare (potential for after-image) for any flight path from threshold to 2 miles
- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics (see list below)

ForgeSolar does not represent or speak officially for the FAA and cannot approve or deny projects. Results are informational only.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
2-mile flight path(s)	N/A	No flight paths analyzed
ATCT(s)	N/A	No ATCT receptors designated

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

FAA Policy 78 FR 63276 can be read at https://www.federalregister.gov/d/2013-24729

SITE CONFIGURATION

Analysis Parameters

DNI: peaks at 1,000.0 W/m^2
Time interval: 1 min
Ocular transmission coefficient: 0.5
Pupil diameter: 0.002 m
Eye focal length: 0.017 m
Sun subtended angle: 9.3 mrad
Site Config ID: 39047.7117

PV Array(s)

Name: PV array 1
Axis tracking: Single-axis rotation
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 60.0°
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.438043	145.048792	110.45	2.00	112.45
2	-36.438967	145.042741	112.90	2.00	114.90
3	-36.438958	145.040284	114.28	2.00	116.28
4	-36.438596	145.040080	115.40	2.00	117.40
5	-36.437034	145.040488	109.89	2.00	111.89
6	-36.437318	145.037805	115.66	2.00	117.66
7	-36.436317	145.037730	110.22	2.00	112.22
8	-36.434107	145.040863	108.08	2.00	110.08
9	-36.433745	145.044135	108.88	2.00	110.88
10	-36.432744	145.044511	109.84	2.00	111.84
11	-36.432770	145.048824	111.59	2.00	113.59

Name: PV array 2
Axis tracking: Single-axis rotation
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 60.0°
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.426675	145.032119	109.67	2.00	111.67
2	-36.426762	145.048802	114.03	2.00	116.03
3	-36.430189	145.048792	112.35	2.00	114.35
4	-36.431043	145.044983	109.58	2.00	111.58
5	-36.431173	145.042580	111.70	2.00	113.70
6	-36.431941	145.039565	111.15	2.00	113.15
7	-36.432821	145.039372	110.61	2.00	112.61
8	-36.434366	145.037108	107.64	2.00	109.64
9	-36.434841	145.037065	108.00	2.00	110.00
10	-36.435126	145.034640	110.00	2.00	112.00
11	-36.436205	145.033535	110.64	2.00	112.64
12	-36.436196	145.032076	110.02	2.00	112.02
13	-36.432019	145.032162	110.00	2.00	112.00
14	-36.431880	145.033310	109.44	2.00	111.44
15	-36.431104	145.034168	110.63	2.00	112.63
16	-36.429955	145.034308	112.38	2.00	114.38
17	-36.428712	145.034254	112.33	2.00	114.33
18	-36.428738	145.033203	113.36	2.00	115.36
19	-36.427823	145.032119	110.81	2.00	112.81

Discrete Observation Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	-36.436101	145.053835	111.97	1.80
OP 2	2	-36.427054	145.056345	111.46	1.80
OP 3	3	-36.425436	145.031685	111.79	1.80
OP 4	4	-36.423165	145.031540	115.04	1.80
OP 5	5	-36.426670	145.026197	110.82	1.80
OP 6	6	-36.434029	145.029357	110.21	1.80
OP 7	7	-36.433546	145.023172	109.00	1.80
OP 8	8	-36.439329	145.021326	113.09	1.80
OP 9	9	-36.441776	145.029287	110.66	1.80
OP 10	10	-36.440140	145.043235	115.31	1.80
OP 11	11	-36.442866	145.049033	111.00	1.80
OP 12	12	-36.438149	145.059021	112.61	1.80

Route Receptor(s)

Name: McCague Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.426489	145.031902	110.07	1.50	111.57
2	-36.426558	145.053445	113.94	1.50	115.44

Name: McEwen Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.422328	145.031923	114.03	1.50	115.53
2	-36.442717	145.031923	109.45	1.50	110.95

Name: Midland Highway
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.441612	145.026151	110.36	1.50	111.86
2	-36.436986	145.059432	111.66	1.50	113.16

Name: Poole Road
Path type: Two-way
Observer view angle: 50.0°

Note: Route receptors are excluded from this FAA policy review. Use the 2-mile flight path receptor to simulate flight paths according to FAA guidelines.

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.422570	145.049047	111.03	1.50	112.53
2	-36.438453	145.049025	110.97	1.50	112.47

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt (°)	Orient (°)	"Green" Glare min	"Yellow" Glare min	Energy kWh
PV array 1	SA tracking	SA tracking	0	0	-
PV array 2	SA tracking	SA tracking	0	0	-

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Results for: PV array 1

Receptor	Green Glare (min)	Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0

Receptor	Green Glare (min)	Yellow Glare (min)
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Point Receptor: OP 1

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Route: McCague Road

0 minutes of yellow glare
0 minutes of green glare

Route: McEwen Road

0 minutes of yellow glare
0 minutes of green glare

Route: Midland Highway

0 minutes of yellow glare
0 minutes of green glare

Route: Poole Road

0 minutes of yellow glare

0 minutes of green glare

Results for: PV array 2

Receptor	Green Glare (min)	Yellow Glare (min)
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
McCague Road	0	0
McEwen Road	0	0
Midland Highway	0	0
Poole Road	0	0

Point Receptor: OP 1

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Route: McCague Road

0 minutes of yellow glare
0 minutes of green glare

Route: McEwen Road

0 minutes of yellow glare

0 minutes of green glare

Route: Midland Highway

0 minutes of yellow glare
0 minutes of green glare

Route: Poole Road

0 minutes of yellow glare
0 minutes of green glare

Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
Glare analyses do not account for physical obstructions between reflectors and receptors. This includes buildings, tree cover and geographic obstructions.
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.
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.)
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual results and glare occurrence may differ.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
Refer to the Help page at **www.forgesolar.com/help/** for assumptions and limitations not listed here.

ForgeSolar Help

Guidance and information on using ForgeSolar analysis tools

Under Construction! We're enhancing the Help pages with new content and guidance. If a section isn't completed yet, stay tuned as we add new info over the coming weeks.

These help pages include documentation and guidance on the ForgeSolar tools. This includes detailed descriptions of the editor, analysis methodology and results. ForgeSolar was built with the Solar Glare Hazard Analysis Tool technology (SGHAT), licensed from Sandia National Laboratories. Portions of the Help content is taken from the SGHAT User's and Technical Manuals which were originally written by Dr. Clifford K. Ho, Cianan Sims, Dr. Julius Yellowhair and Evan Bush.

Introduction

With growing numbers of solar energy installations throughout the United States, glare from photovoltaic (PV) arrays has received increased attention as a real hazard for pilots, air-traffic control personnel, motorists, and others. The ForgeSolar suite of tools provide a quantified assessment of:

1. when and where glare will occur throughout the year for a prescribed solar installation
2. potential effects on the human eye at locations where glare occurs, and
3. annual energy production from the PV system so that alternative designs can be compared to maximize energy production while mitigating the impacts of glare

ForgeSolar employs an interactive Google map where the user can quickly locate a site, draw an outline of the proposed PV array(s), and specify observer locations or paths. Latitude, longitude, and elevation are automatically queried from Google, providing necessary information for sun position and vector calculations. Additional information regarding the orientation and tilt of the PV panels, reflectance, environment, and ocular factors are entered by the user.

If glare is found, the tool calculates the retinal irradiance and subtended 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 color codes indicating the potential ocular hazard. The tool can also predict relative energy production while evaluating alternative designs, layouts, and locations to identify configurations that maximize energy production while mitigating the impacts of glare.

ForgeSolar currently includes two tools for glare analysis, which are both accessed via the editor:

- **GlareGauge** - annual glare hazard analysis of PV arrays and receptors
- **GlaReduce** - optimization analysis of a single PV array over a range of module configurations (tilts and orientations)

For questions or feedback on Help content, please contact us.

Requirements

ForgeSolar is built and optimized for the following browsers:

- Mozilla Firefox
- Google Chrome

Fundamentals

Background and theory regarding solar glare and regulatory policies

About Glint & Glare

Glint is typically defined as a momentary flash of bright light, often caused by a reflection off a moving source. A typical example of glint is a momentary solar reflection from a moving car. Glare is defined as a continuous source of bright light. Glare is generally associated with stationary objects, which, due to the slow relative movement of the sun, reflect sunlight for a longer duration.

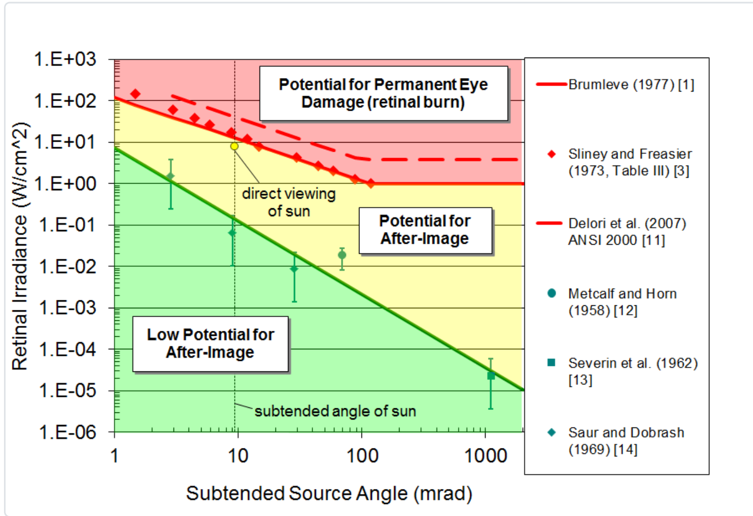
The difference between glint and glare is **duration**. Industry-standard glare analysis tools evaluate the occurrence of glare on a minute-by-minute basis; accordingly, they generally refer to solar hazards as 'glare'.

The ocular impact of solar glare is quantified into three categories (Ho, 2011):

- Green - low potential to cause after-image (flash blindness)
- Yellow - potential to cause temporary after-image
- Red - potential to cause retinal burn (permanent eye damage)

These categories assume a typical blink response in the observer. Note that retinal burn is typically not possible for PV glare since PV modules do not focus reflected sunlight.

The ocular impact of glare is visualized with the Glare Hazard Plot. This chart displays the ocular impact as a function of glare subtended source angle and retinal irradiance. Each minute of glare is displayed on the chart as a small circle in its respective hazard zone. For convenience, a reference point is provided which illustrates the hazard from viewing the sun without filtering, i.e. staring at the sun. Each plot includes predicted glare for one PV array and one receptor.

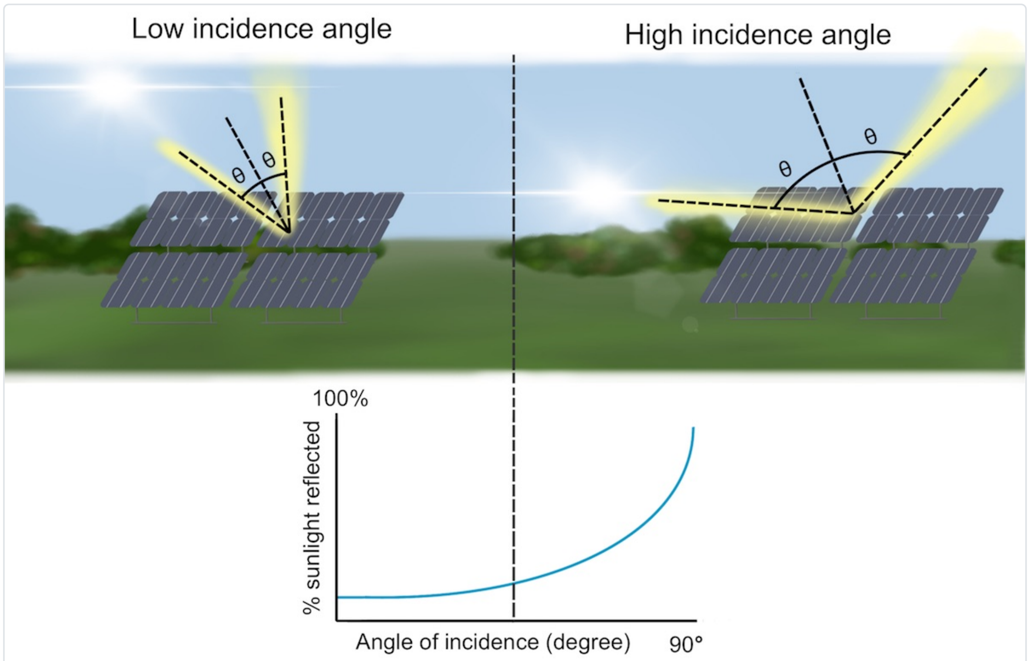


Sample glare hazard plot defining ocular impact as function of retinal irradiance and subtended source angle (Ho, 2011)

About Reflectivity

Reflections from PV panels may impair observers. Studies have found that 7 W/m^2 is enough to cause an after-image lasting 4 to 12 seconds (Ho, 2009). This represents a reflection of only 1-2% of typical solar irradiance (incoming sunlight) for a given location, which typically ranges between 800-1000 W/m^2.

A key factor of reflectance is the position of PV modules relative to the sun. A panel that absorbs 90% of direct sunlight may reflect up to 60% when not directly facing the sun. This situation is common for low-tilt panels during sunset and sunrise (Yellowhair, 2015). **The oft-repeated claim that PV panels reflect less than 5% of sunlight only holds true when the panels directly face the sun.** For fixed-mount panels, this claim only applies during a few minutes of the day, at most.



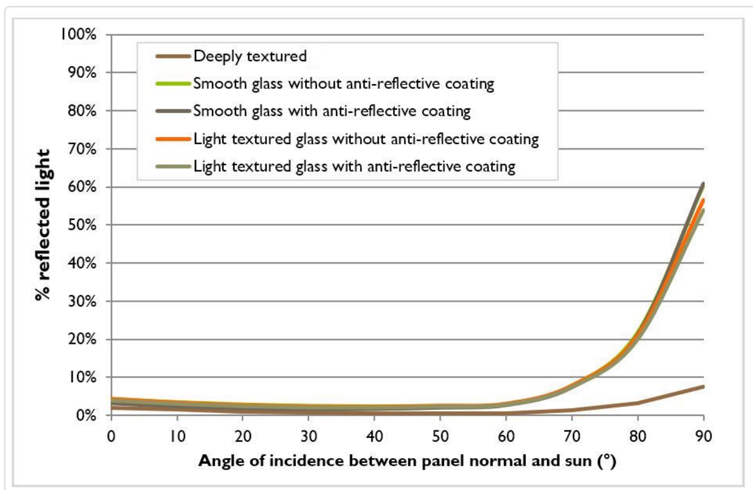
PV panel reflectance depends on incidence angle between panel normal (i.e. facing) and sun position. Large incidence angle yields more reflected sunlight.

Module Reflectance Profiles

Sandia National Laboratories developed five generic PV module material reflectance profiles by analyzing over twenty PV module samples. These profiles are available in ForgeSolar and allow for customizing the material properties of the PV array during analysis.

The figure to the right illustrates the reflectance of each material profile as a function of incidence angle, where an angle of 0° implies the panels are directly facing the sun. For example, a high glancing angle near 90° for panels with 0° tilt (lying flat) occurs daily at sunrise and sunset.

Anti-reflective coatings (ARC) and surface texturing can reduce panel reflectivity, but this reduction is typically less than 8% (Yellowhair, 2015). In addition, greater surface texturing can increase the size of the subtended source angle (i.e. glare spot).



Reflectance profiles of typical PV module materials (Yellowhair, 2015).

Workflow

Guidance on conducting glare analyses and optimizations

Projects

Project Settings

Project name
Unique name to distinguish a particular project. For example, "LAX parking rooftop PV" or "Main street solar farm"

Description
Optional description for user convenience.

Timezone offset
Numerical +/- offset from UTC/GMT of the site location. For example, a site in New York, USA would utilize a timezone offset of -5. Options range from -12 to +14.

Distance units
Whether the distances, including heights and elevations, should be displayed in feet or meters.

Site Configurations

Site Settings

Site name
Alphanumeric name describing this site and configuration

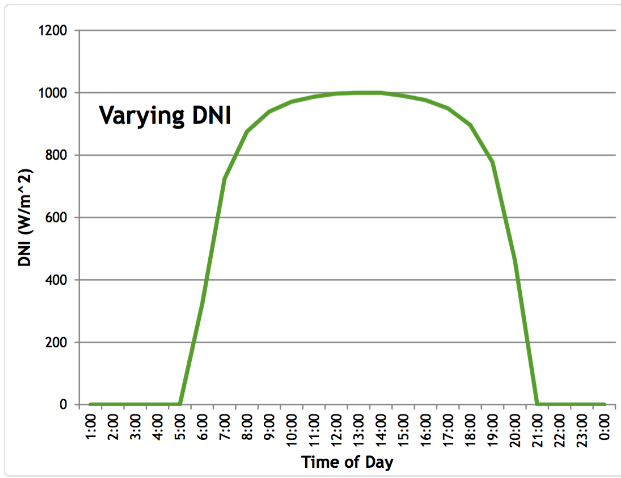
Configuration description
Optional description of this particular site and configuration

Time interval (min)
The time step, or sampling interval, for the annual glare hazard analysis. The sun position will be determined at each time step throughout the year. Regulatory authorities such as the FAA typically require a time step of 1 minute. Other values can be used to conduct faster analyses or "spot check" alternative configurations. The time interval must evenly divide 1440 (i.e. number of minutes in a day); suitable alternatives are 2, 4, 5, 10, 15, 20.

Sun angle (mrad)
The average subtended angle of the sun as viewed from earth is ~9.3 mrad or 0.5°.

Peak DNI (W/m^2 or Wh/m^2)
The maximum Direct Normal Irradiance at the given location at solar noon. DNI is the amount of solar radiation received in a collimated beam on a surface normal to the sun during a 60-minute period. On a clear sunny day at solar noon, a typical peak DNI is ~1,000 W/m^2. More accurate values for a specific site location may be available from other data sources. The Typical Meteorological Year 3 (TMY3) data sets from the U.S. National Solar Radiation Database contain similar values for locations throughout the U.S.

If seeking an alternative DNI, verify the data type and format are valid



Daily DNI scaling using Peak DNI value of 1000 W/m^2

DNI varies?
If checked, the peak DNI will be scaled at each time step according to the changing position of the sun and reduced DNI in the mornings and evenings. If unchecked, the DNI at every step will be set to the **Peak DNI**.

Ocular transmission coefficient
Coefficient accounting for radiation that is absorbed in the eye before reaching the retina. A value of 0.5 is typical (Ho, 2011; Sliney, 1973).

Pupil diameter (m)
Defines the diameter of the pupil of the observer receiving predicted glare. 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 nighttime vision (Ho, 2011; Sliney, 1973).

Eye focal length (m)
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. A typical eye focal length is 0.017 m (Ho, 2011; Sliney, 1973).

Components & Receptors

Information on creating and editing PV arrays, flight paths, routes and observation points

PV Array Component

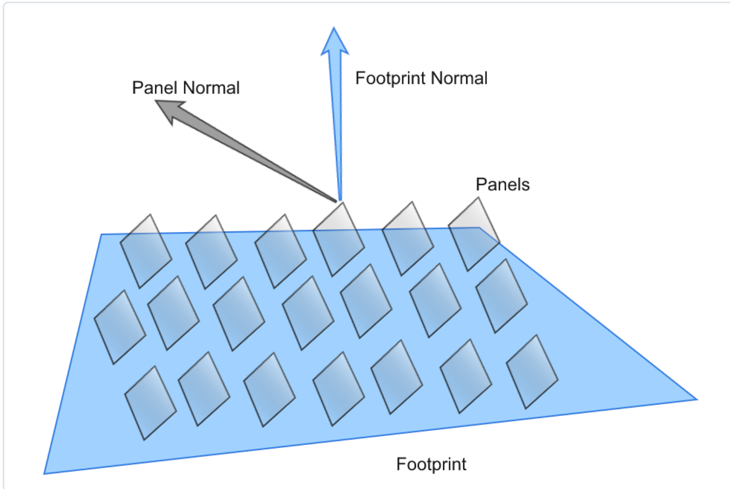
Photovoltaic systems are represented by a contiguous planar polygon footprint and a set of customizable parameters.

Each footprint comprises three or more vertices, defined by a latitude, longitude, elevation and height. Each distinct PV installation should be modeled with it's own PV array footprint in the editor. During analysis, sunlight is reflected over each PV array on a minute-by-minute basis according to the user-specified module tilt and orientation or axis tracking parameters if the system is not fixed-mount. The system then checks whether the resulting solar reflections intersect (impact) the receptors.

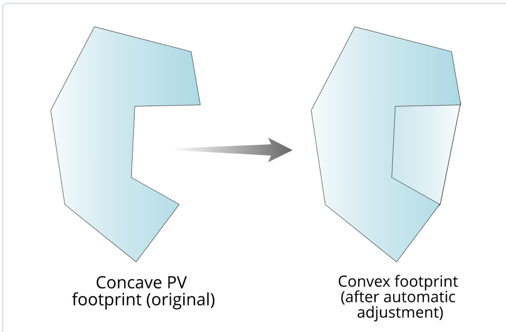
PV Array Footprint

PV arrays are simulated spatially with a contiguous planar convex polygon. This polygonal footprint comprises three or more vertices which are defined by a latitude, longitude, elevation and height. The footprint should encompass all planned PV modules in a given area. Non-contiguous PV systems, or those with substantial concavities, should be modeled with multiple PV array footprints.

ForgeSolar will modify the vertex elevations if they do not initially reside on a single planar surface. For example, if a user attempts to model a non-planar footprint, such as multiple sides of a hill, the system would smooth the footprint and effectively flatten the hill. (In this example, a more accurate approach would be to model each hillside as a separate PV array.)



PV array footprint and modules and their corresponding normal vectors



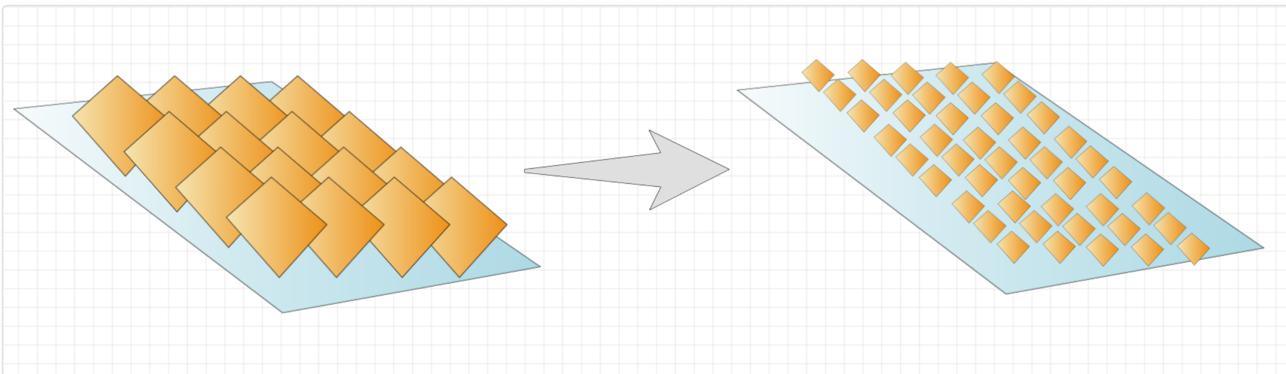
Analysis automatically fills in concavities in PV footprints

Note that ForgeSolar will convert the footprint polygon into a convex polygon during analysis by filling in any concavities. For example, a 'C'-shaped footprint would be modified into a half-circle. This adjustment is currently required by the glare-check algorithm during analysis.

Large PV array sites with many concavities should typically be modeled with multiple PV array footprints, instead of one large PV footprint. This can yield more accurate results which do not over-predict glare by over-estimating the size of the PV array after the required gap-filling.

PV footprint vertex coordinates, including elevation, are independent of the orientation and tilt. The vertices establish the tilt of the PV-array plane and do not influence the tilt or orientation of the individual panels themselves. For example, panels mounted flush on a 30° pitched roof will have PV-array vertices with different elevations to accommodate the pitched roof and resulting tilted PV-array plane (e.g., two vertices at 15 feet and two vertices at 10 feet). However, the panels should still be prescribed with a tilt of 30° (if they are flush mounted against the 30° pitched roof) and the appropriate orientation. A tilt of 0° indicates that the panels are parallel with the earth's surface and facing upward, regardless of the prescribed vertex elevations.

ForgeSolar 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. The PV array is simulated as a footprint filled with infinitesimally small panels reflecting sunlight in the trajectory of the tilt and orientation.



PV array panels are approximated with simplified geometry. Blocking and shading are not considered.

PV Array Parameters

General PV array parameters are described below. Module configuration, tracking and vertex parameters are described in subsequent sections.

Name
Descriptive alphanumeric name of this PV array

Description
Optional textual description of array

Axis tracking
Whether PV array modules are fixed-mount or utilize single- or dual-axis tracking

Rated power (kW)
Used to calculate the approximate maximum annual energy produced (kWh) from the system in the prescribed configuration (assuming clear sunny days). This is useful for comparing alternative configurations to determine which one has the maximum energy production. ForgeSolar system output calculations are approximate and should not supercede more accurate calculations conducted elsewhere.

Module surface material

The type of material comprising the PV modules. The reflectivities of the material choices have been characterized to generate scaled values for each time step. Refer to the Module Reflectance Profiles section for additional information.

Reflectivity varies with incidence angle
If checked, the reflectivity of the modules at each time step will be calculated as a function of module surface material and incidence angle between the panel normal and sun position.

Reflectivity
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); for example, at sunrise and sunset for low-tilt panels. Based on evaluation of several different PV modules, an average reflectance of 10% is provided as a default value. Only used if reflectivity does not vary with incidence angle.

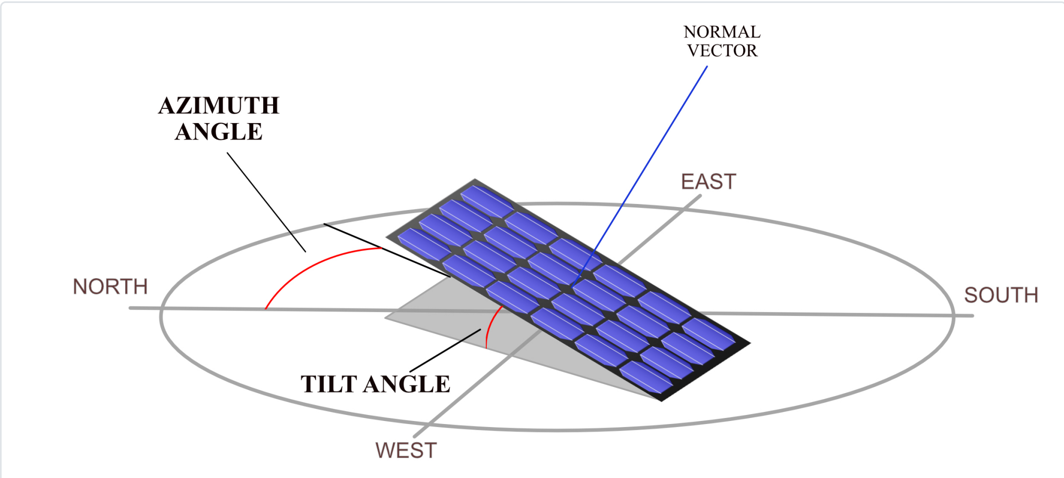
Slope error (mrad)
Specifies the amount of scatter that occurs from the PV module. Mirror-like surfaces that produce specular reflections will have a slope error closer to zero, while rough surfaces that produce more scattered (diffuse) reflections have higher slope errors. Based on observed glare from 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. Not used if **correlate slope error to module surface type** is checked.

Correlate slope error with surface type
If checked, the slope error value will be set per the table below, based on the selected material.

PV Cover Type	Average RMS Slope Error (mrad)	Average Beam Spread (mrad)	Standard deviation of slope error	Standard deviation of beam error
Smooth glass without anti-reflection coating	6.55	87.9	4.43	53.3
Smooth glass with anti-reflection coating	8.43	110	2.58	30.9
Light textured glass without anti-reflection coating	9.70	126	2.78	33.3
Light textured glass with anti-reflection coating	9.16	119	3.17	38.0
Deeply textured	82.6	1000	N/A	N/A

Fixed-Mount Parameters

Fixed-mount PV panels are described by a tilt and orientation. These parameters are referred to as the **module configuration** of the PV array.



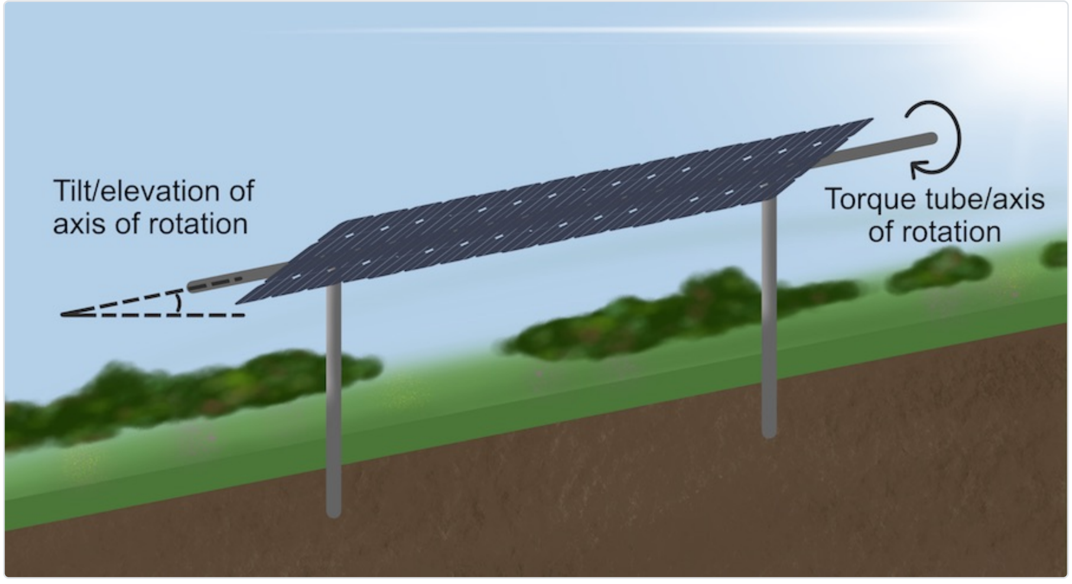
PV module orientation/azimuth and tilt. Sample illustrates south-facing module typical in northern hemisphere

Module orientation/azimuth (°)
The azimuthal facing or direction toward which the PV panels are positioned. Orientation is measured clockwise from true north. Panels which face north, which is typical in the southern hemisphere, have an orientation of 0°. Panels which face south, which is typical in the northern hemisphere, have an orientation of 180°. If a known orientation is based on magnetic north, the location-specific declination must be used to determine the orientation from true north.

Module tilt (°)
The elevation angle of the panels, measured up from flat ground. Panels lying flat on the ground (facing up) have a tilt of 0°. Tilt values between 0° and 40° are typical.

Tracking System Parameters

Single-axis module tracking systems are described by a unique set of parameters. These angular inputs model the tracking axis, rotation range and backtracking behavior. Dual-axis module tracking systems are assumed to track the sun at all times.



Single-axis tracking system with torque tube tilted due to geography

Tilt of tracking axis (°)
Tilt above flat ground of axis over which panels rotate (e.g. torque tube). System on flat, level ground would have axis tilt of 0°.

Orientation of tracking axis (°)
Azimuthal angle of axis over which panels rotate. Angle represents the facing of the axis and system. For example. typical tracking system in northern hemisphere has tracking axis oriented north-south with an orientation of 180°, allowing panels to rotate east-west with potential south-facing tilt. Typical tracking system in southern hemisphere runs south-north with axis orientation of 0°, yielding east-west rotation with potential north-facing tilt.

Offset angle of module (°)
Additional tilt angle of PV module elevated above tracking axis/torque tube. Offset angle is measured from the torque tube.

Maximum tracking angle (°)
Maximum angle of rotation of tracking system in one direction. For example, a typical system with a 120° range of rotation has a *max tracking angle* of 60° (east/west).

Resting angle (°)
Angle of rotation of panels when sun is outside tracking range. Used to model backtracking. Panels will revert to the position described by this rotation angle at all times when the sun is outside the rotation range. Setting this equal to the *maximum tracking angle* implies the panels do not backtrack.

ForgeSolar utilizes a simplified model of backtracking which assumes panels instantaneously revert to the *resting angle* whenever the sun is outside the rotation range. For example, panels with *max tracking angle* of 60° and *resting angle* of 0° would lie flat from sunrise until the sun enters the rotation range, and immediately after the sun leaves the rotation range until sunset daily.

Vertex Parameters

Latitude (°)
North-south measurement of location relative to the equator, with range of [-90° to 90°]. Latitude is measured in decimal degrees and assumes the WGS84 datum.

Longitude (°)
Measurement of east-west position relative to Prime Meridian, with range of [-180°, 180°]. Longitude is measured in decimal degrees and assumes the WGS84 datum.

Elevation/altitude (ft or m)
Elevation above mean sea level at specified location. ForgeSolar automatically queries the Google Elevation services for an approximate value.

Height above ground (ft or m)
User-specified height above ground of point. The height of a rooftop PV system should measure from the ground to the PV panel centroid above the roof. A ground-mount system would have a height measured to the PV panel centroid.

Total elevation (ft or m)
Sum of the elevation and height above ground. The system will automatically calculate the height or total elevation when the other is provided. During analysis, the total elevation determines the Cartesian Z value of the point. For more accuracy, the user should perform analyses using minimum and maximum values for the vertex heights, based on the PV panel dimensions, 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.

Vertices describing a level rooftop should share an identical total elevation.

2-Mile Flight Path Receptor

The 2-Mile Flight Path receptor ("FP") simulates an aircraft following a straight-line approach path toward a runway, by default, including a restricted field-of-view to filter unrealistic glare. In addition, it can be modified to represent a worst-case approach and takeoff path.

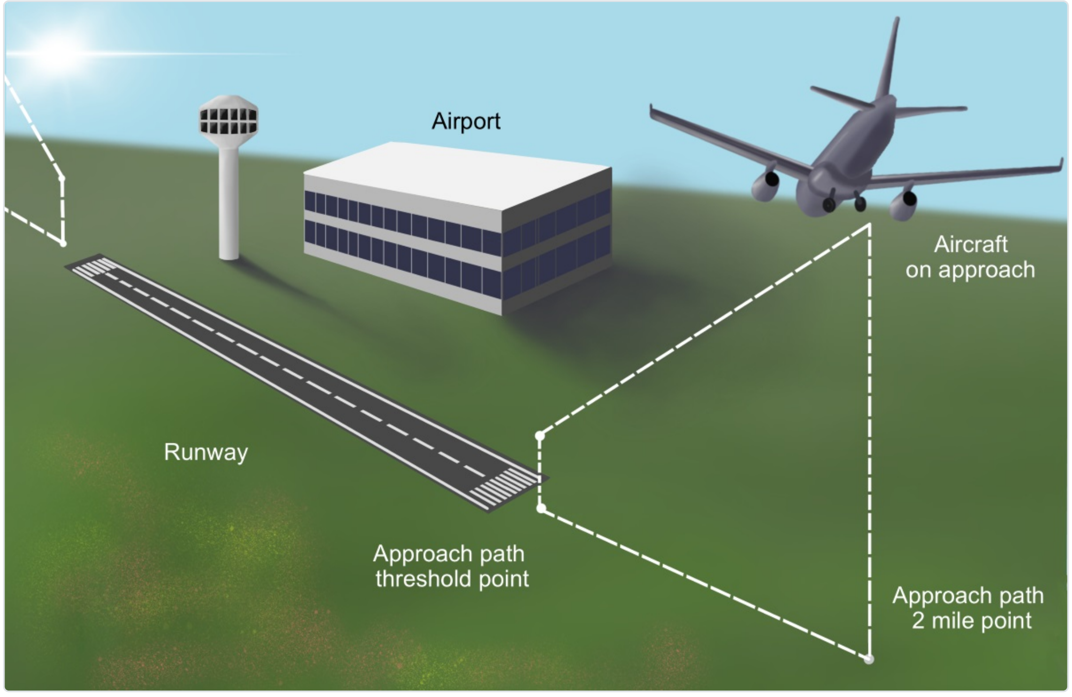


Illustration of aircraft utilizing 2-mile approach path toward airport

The FP receptor should be used to satisfy FAA requirements for runway glare analysis.

Usage

Follow these steps to create FPs in the map editor:

1. Activate the FP drawing mode by clicking the **FP** button above the map.
2. In the map, click once on the runway threshold location to set the FP threshold point. A marker will be placed and a line will extend from the marker to the mouse cursor.
3. Click a second time in the direction of the flight path, away from the runway, to set the FP direction. The system will automatically create the 2-mile point in the specified direction.
4. Modify the FP glide slope, direction, or elevation values in the FP data section to the right of the map.

Example of runway threshold with FP extending southwest

FP Parameters

Name
Descriptive alphanumeric label of receptor

Direction (°)
Azimuthal angle of approach of aircraft which defines the straight path toward the runway. Measured clockwise from true north.

Glide slope (°)
Angle of descent of aircraft toward runway. Default value of 3°.

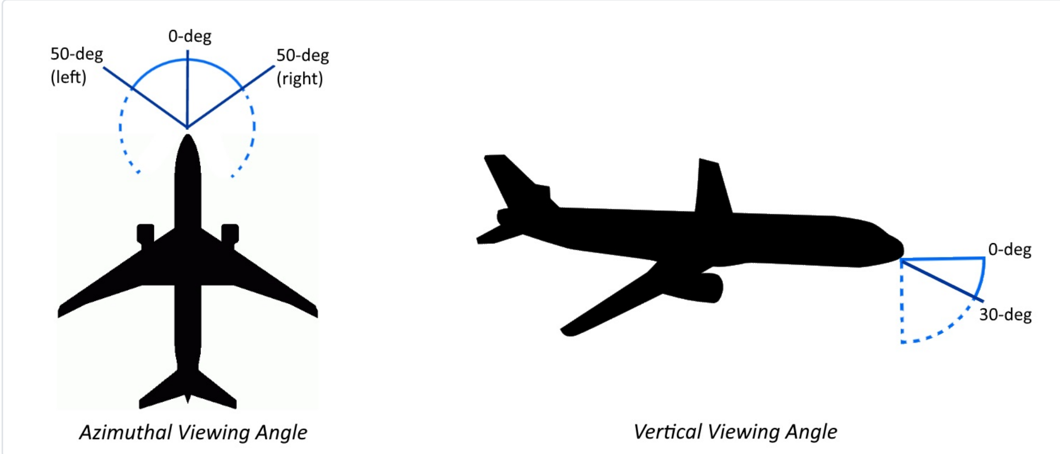
Threshold crossing height
Height above ground of aircraft when it crosses the runway threshold. (Typically 50 ft.).

Consider pilot visibility from cockpit
Check to display viewing angle parameters for modification. If unchecked, system assumes the default visibility constraints of 50° azimuthal, 30° downward.

Max downward viewing angle (°)
The vertical field-of-view of the pilot, measured positive downward from the XY plane (i.e. flat). A default value of 30° assumes glare appearing beyond that FOV is not visible to the pilot, and is acceptable to FAA. A value of 90° assumes the pilot can see glare appearing directly underneath the aircraft.

Azimuthal viewing angle (°)
The left and right field-of-view of the pilot during approach. A view angle of 180° implies the pilot can see glare emanating from behind the plane. A view angle of 50° (default) implies the pilot has a field-of-view of 50° to their left and right during approach, i.e. a total FOV of 100°. This default is based on FAA research which determined that the impact of glare that appears beyond 50° is mitigated (Rogers, 2015).

Point coordinates
The threshold and 2-mile point ground elevation parameters can be modified in the FP Advanced dialog. The 2-mile point height is calculated from the point elevations and *threshold crossing height* to ensure a smooth 2-mile descent path.



Aircraft field-of-view defined by azimuthal and downward viewing angle parameters.

Observation Point Receptor

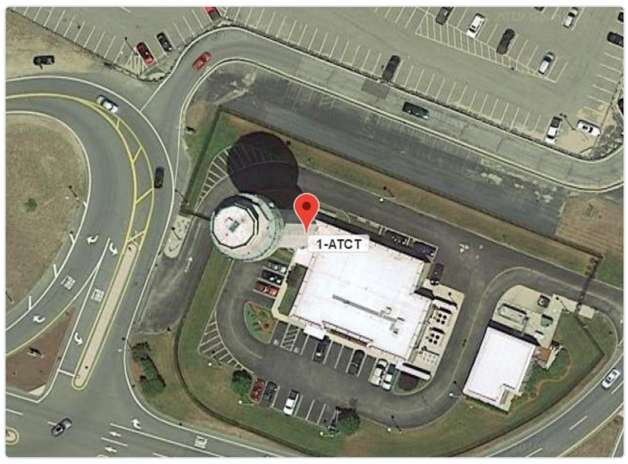
The Observation Point receptor ("OP") simulates an observer at a single, discrete location, defined by a latitude, longitude, elevation, and height above ground. In addition, it can be marked to represent an Air Traffic Control Tower ("ATCT") for aviation purposes.

The OP receptor should be used to satisfy FAA requirements for assessing Air Traffic Control Towers.

Usage

Follow these steps to create an Observation Point in the map editor:

1. Activate the OP drawing mode by clicking the **OP** button above the map.
2. Click once on the desired map location to place an OP at that location.
3. Modify location coordinates, including height above ground, in OP data section to right of map. For example, a height of ~5-6 ft. to simulate a stationary observer at ground level.
4. To simulate an ATCT, ensure the *Is ATCT?* checkbox is checked.



Example of OP representing ATCT

OP Parameters

Latitude
Geodetic coordinate defined by WGS-84 datum in decimal degrees with range of -90° to 90°

Longitude
Geodetic coordinate defined by WGS-84 datum in decimal degrees with range of -180° to 180°

Elevation
Location altitude above sea level. By default, elevation value is provided by Google Elevation service. If marker is moved manually, elevation will be re-queried.

Height
Height above ground of observer receptor. Examples: large height for ATCT or 5-6 ft. for person at ground level.

Is ATCT?
Check to mark OP as representing an Air Traffic Control Tower. System will review ATCT results for policy adherence when generating aviation PDF.

Route Receptor

The Route receptor is a generic multi-line representation which can simulate observers traveling along continuous paths such as roads, railways, helicopter paths, and multi-segment flight tracks.

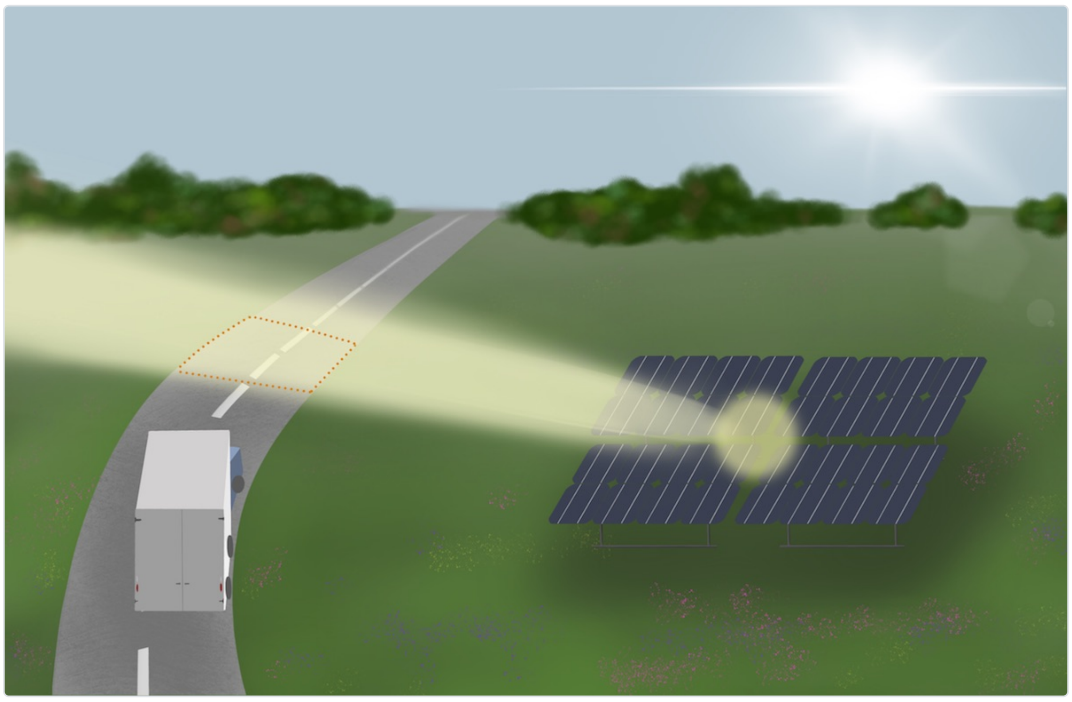


Illustration of reflected glare impacting a route (road)

The Route receptor should **not** be used to satisfy FAA requirements for runway approach path glare analysis. Use the standard 2-mile flight path receptor instead.

Usage

Routes can be created quickly in the Map Editor:

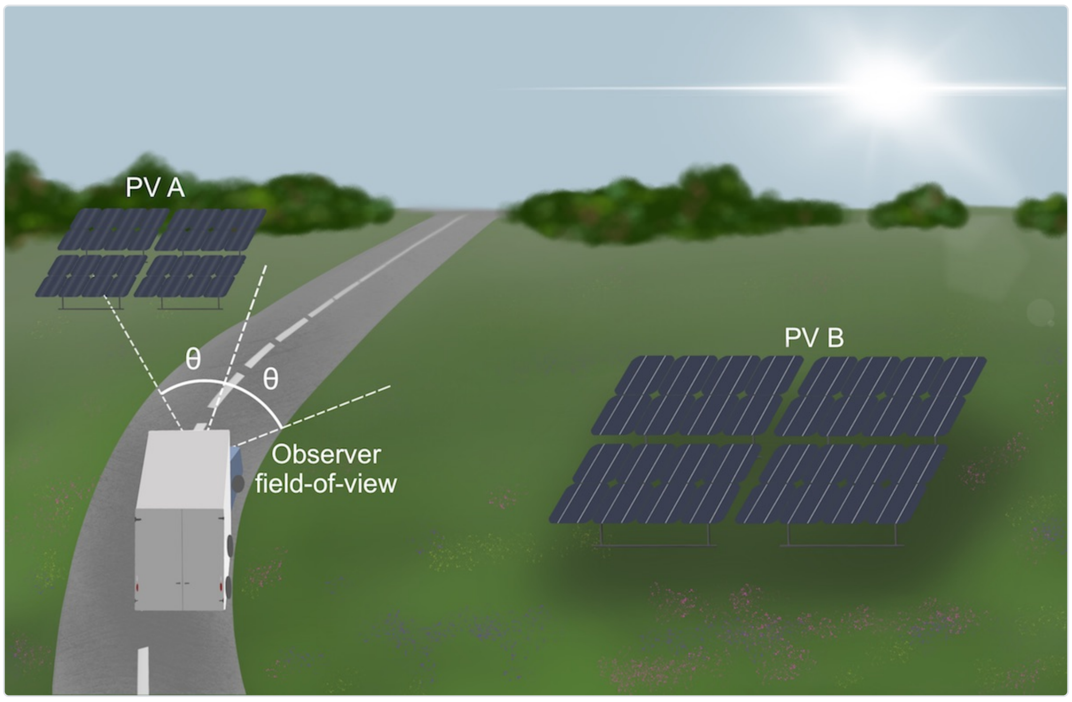
1. Activate the Route drawing mode by clicking the **Route** button above the map.
2. Click once on a location in the map to begin drawing a route
3. Click once to add a vertex to the route. Repeat as many times as is necessary; routes can include many line segments
4. Double-click on final position to end the Route
5. To add an additional vertex to the Route after it has already been completed, click and drag one of the "ghost" points within the polyline in the map.

Route Parameters

Name
Descriptive alphanumeric label of receptor

Is route one-way?
If checked, the system will assume observers travel along the route in the direction it was drawn (i.e. order of increasing vertex #). Together with the *view angle* parameter, this will filter out glare appearing behind the path of travel. If unchecked (default), the system will assume observers travel in both directions.

View angle (°)
Defines the left and right field-of-view of observers traveling along the Route. A view angle of 180° implies the observer sees glare in all directions. A view angle of 50° (default) implies the observer has a field-of-view of 50° to their left and right, i.e. a total FOV of 100°. This default is based on FAA research which determined that the impact of glare that appears beyond 50° is mitigated (Rogers, 2015).



*Route receptor field-of-view is defined by view angle (theta) to left and right. Default FOV is 100° (i.e. 2 * 50° view angle).*

Assumptions & Limitations

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. 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.
3. 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.
4. 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.
5. 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.)
6. 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.
7. 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.
8. The variable direct normal irradiance (DNI) feature (if selected) scales the userprescribed 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.
9. 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.
10. 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.
11. Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
12. Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
13. PV array tracking assumes the modules move instantly when tracking the sun, and when reverting to the rest position.

References

Additional resources and research on solar glare

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2. Federal Aviation Administration (2013). Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports. Federal Register: 63276-63279 (link)
3. Rogers, J. A., et al. (2015). Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach, Federal Aviation Administration (link)
4. Ho, C. K. and Sims, C. A., 2013, Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 3.0. (Download)
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13. Ho, C. K. and Khalsa, S. S., 2010, Hazard Analysis and Web-Based Tool for Evaluating Glint and Glare from Solar Collector Systems, in proceedings of SolarPACES 2010, Perpignan, France, Sept. 21-24. (Paper) (Presentation)

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16. Sliney, D.H. and B.C. Freasier, 1973, Evaluation of Optical Radiation Hazards, Applied Optics, 12(1), p. 1-24.

Appendix

Miscellaneous links and information

User's Manual (PDF)

Technical Manual (PDF)

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