habitat

Glint and Glare Assessment Report

Barnawartha North Solar Farm

Renewable Energy Facility & Battery Energy Storage System

Murray Valley Highway, Barnawartha North

SEPTEMBER 2023

Submitted to Minister for Planning
On behalf of **BE Pro BWN Pty Ltd**

Contact

David Hunter, Director
Shannon O'Brien, Senior Consultant

Habitat Planning
409 Kiewa Street
Albury NSW 2640
02 6021 0662
habitat@habitatplanning.com.au
habitatplanning.com.au

Habitat Planning Pty Ltd
ABN 29 451 913 703
ACN 606 650 837

PROJECT NUMBER
21281

REVISION NO	REVISION DATE	VERSION STATUS	AUTHOR	APPROVED
01	5/09/2023	Final	SOB	DH

Contents

List of Figures

List of Tables

1. Introduction

1.1. Overview

BE Pro BWN Pty Ltd proposes to construct and operate a 4.95MW Renewable Energy Facility (Solar Facility) at Crown Allotment 10, Section 29 in the Parish of Barnawartha North, along the Murray Valley Highway, Barnawartha North. This facility is to comprise of the installation of solar photovoltaic panels mounted in arrays on single axis trackers.

A Planning Permit Application has been made for the development and requires consideration of suitable Glint and Glare management.

This report has been prepared by planning and urban design consultants, Habitat Planning. This report details the key inputs, methodology and the results of this glare assessment and includes mitigation measures which are to be adhered to by the development. The assessment and recommendations have been demonstrated by use of Solar Glare Analysis Tool, modelling the design and operation of the proposal.

The objectives of this study are as follows:

- Carry out an analysis of glare from the proposed single axis tracking system;
- Identify observation points surrounding the proposed solar facility
- Identify and summarise potential glare impacts at various observation points;
- Recommend any mitigation to reduce glare issues.

1.2. Glint and Glare

Glint refers to the momentary flash of bright light that can be caused by the reflectivity of solar panels and glare refers to the continuous source of light and is generally associated with stationary objects. Glint and glare from PV panels can have potential safety or amenity impacts to surrounding sensitive receivers, including potential to impair observers through inducing an after image.

The Solar Energy Facilities Design and Development Guideline require proponents to prepare a glint and glare assessment using an accepted methodology based on best practice.

1.3. PV Panels Reflectivity

As construction of PV panels primarily utilises glass and steel there is a perception of glint and glare from the reflectivity of solar panels. This leads to potential issues of distractions to motorists, aircraft and eye damage.

Generally, solar panels will not create significant glint or glare compared with other surfaces. PV panels are designed to collect sunlight to convert to energy and therefore absorb the majority of light received. The panels are designed using anti-reflective coatings during manufacture to reduce reflection and will typically absorb 80-90% of the light received.

PV panels are also generally less reflective than other naturally occurring elements such as soils and crops and have been found to be generally less reflective that general rural environments and far less reflective that open water[1].

The angle of incidence of the sunlight is also relevant in considering the reflection of solar development. A fixed axis solar facility will have panels that do not move throughout the day and therefore the angle incidence varies with the time of day. A tracking system, such as that proposed for this development, will follow the sun through the day and can have the angle of incidence reduced. It is also possible to 'back track' panels at certain periods of the day to reduce potential impacts.

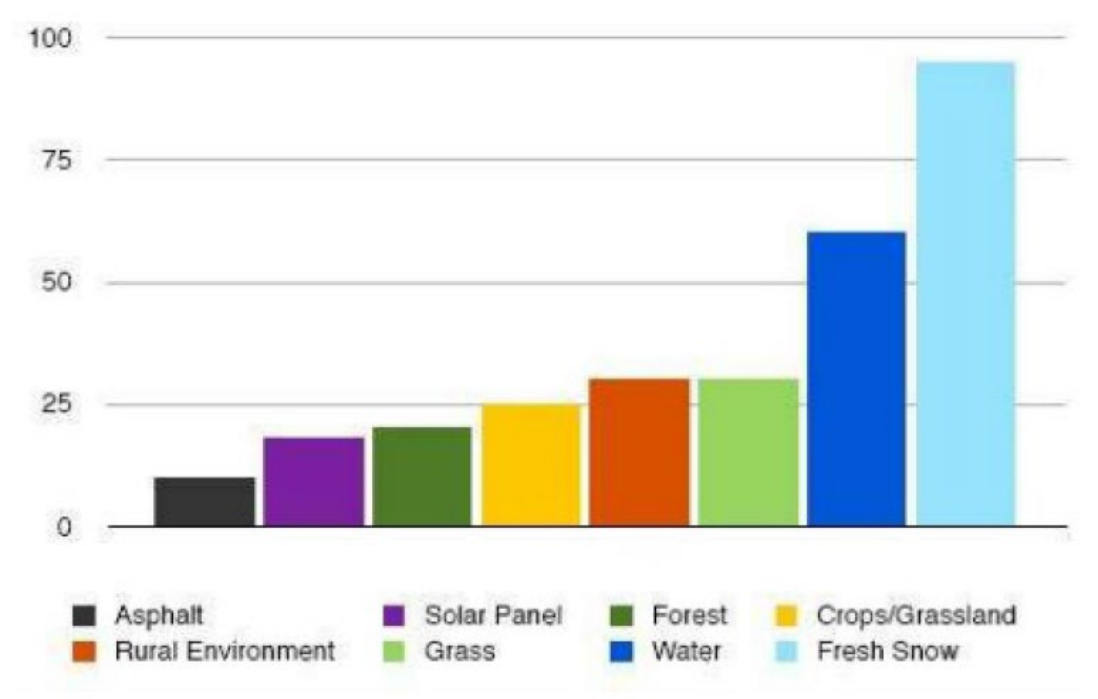

Figure 1 | Comparative reflection analysis of PV panels to other surfaces (Spaven Consulting 2011, p.5)

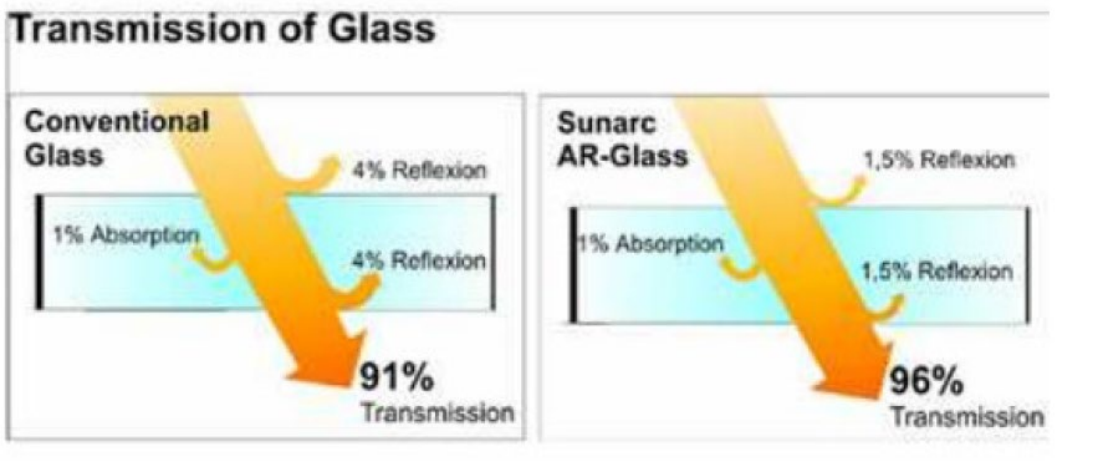

Figure 2 | Reflective values of conventional glass and typical treated glass (Spaven Consulting 2011, p.5)

2. Site Analysis

2.1. Site Location and Context

The subject site ('the site') is described as Crown Allotment 10, Section 29 in the Parish of Barnawartha North, and is addressed along the Murray Valley Highway, Barnawartha North. Vehicular access to the proposed facility is provided via an access track through the adjoining Crown Allotment 6, Section 30 in the Parish of Barnawartha North, from Old Barnawartha Road.

The subject site is located in Barnawartha North on the western outskirts of the Wodonga Local Government Area and is approximately 1 kilometre north of the Logic Precinct.

A copy of the certificate of title and title plan is attached within this application. There are no covenants or Section 173 agreements registered on the title.

Figure 1 below indicates the subject land in context to the surrounds.

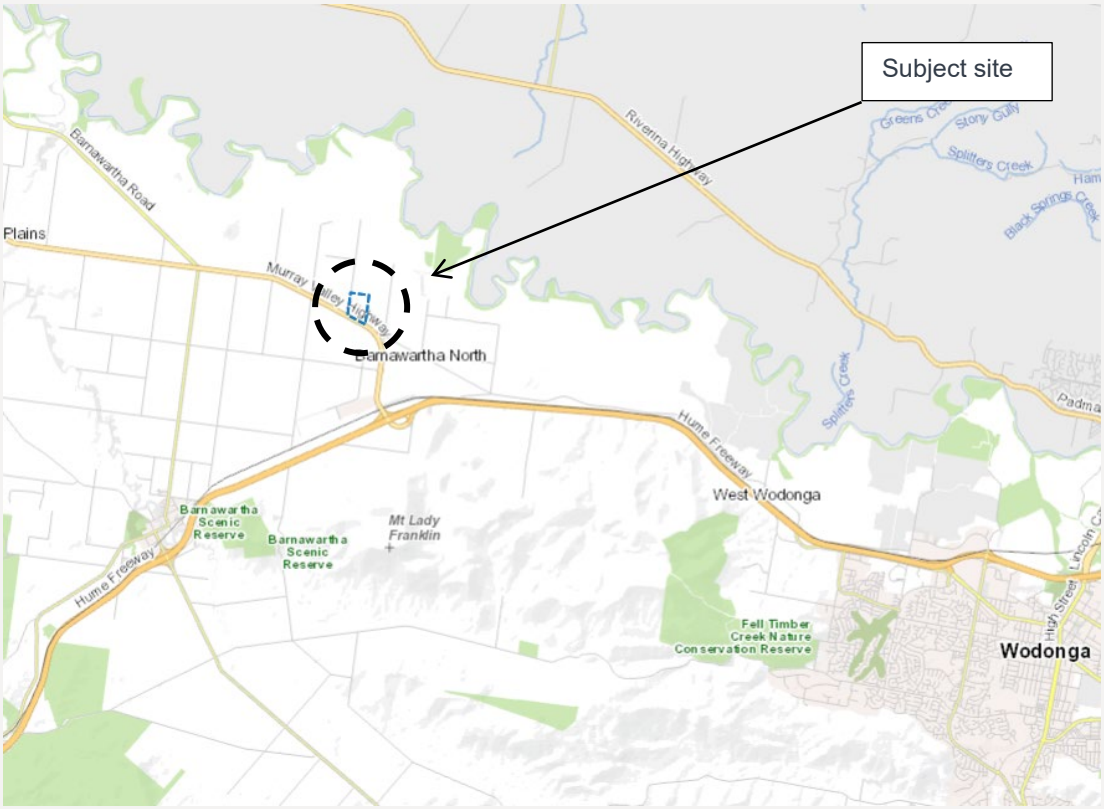

Figure 3 | Context Map

2.2. Site Description

The subject site forms two rectangular parcels. Allotment 10~29\PP2076 has a width of 399 metres and a depth of 630 metres with a total area of 22.08 hectares. The parcel is located on the corner of the Murray Valley Highway to the south and Margery's Road to the west. Allotment 6~30\PP2076 has a width of 496 metres and a depth of 785 metres with a total area of 28.75 hectares. The Murray Valley Highway and Old Barnawartha Road intersect along the southern boundary of this parcel, and Richardsons Road is located along the eastern boundary.

The site is part of a rural property and is vacant of development with the exception of a small rural shed on the northern boundary. The site otherwise consists of managed rural pastures actively used for cattle grazing.

A drainage depression with a dam traverses the site diagonally from the northeast corner of Allotment 10, to the southwest. Some native scattered trees are sparsely distributed along this drainage line, with another patch located towards the western boundary. More trees are spread in linear strips along part of the western, northern and eastern boundaries.

Access is available to Allotment 10 from a rural accessway from Margerys Road. Similar arrangements are provided to Allotment 6 via Richardsons Road. The site does not have access to reticulated water or potable water.

The existing conditions of the property are illustrated by the images at the figures below.

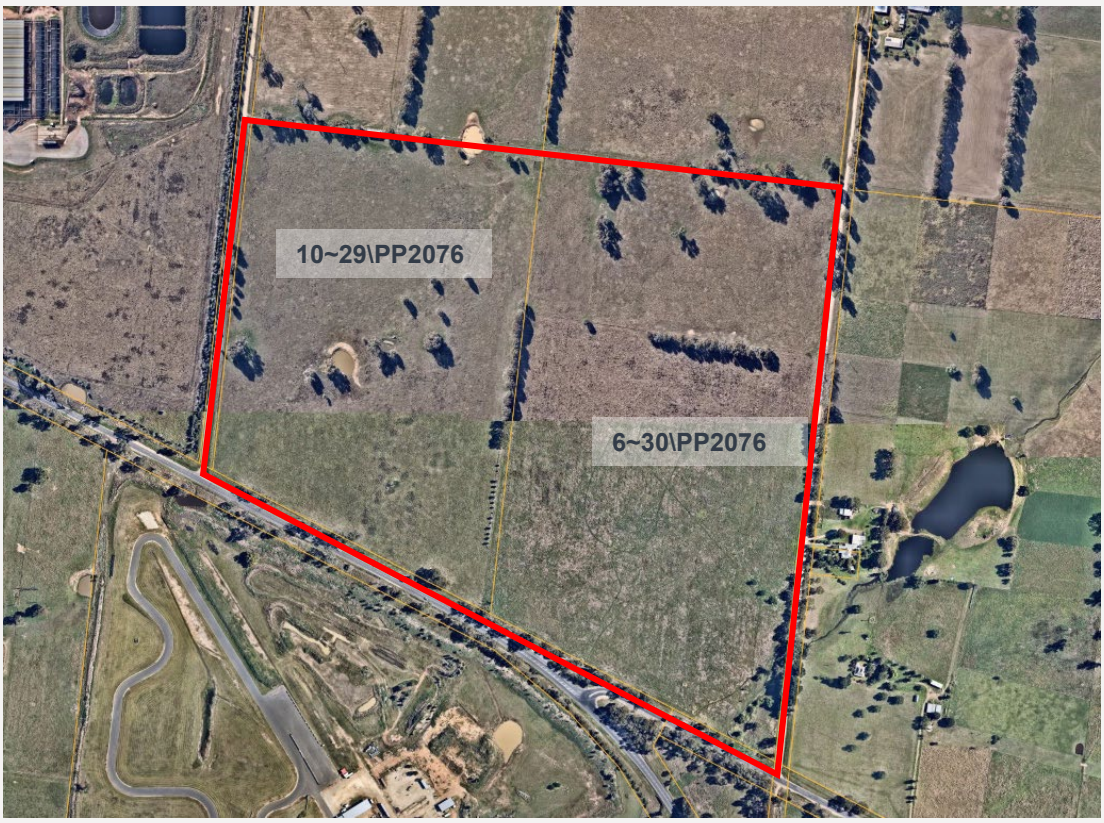

Figure 4 | Aerial view of site

Figure 5 | View facing northeast from the corner of the Murray Valley Highway and Margerys Road

Figure 6 | View facing northwest from the proposed access at Old Barnawartha Road

2.3. Surrounding Development

The surrounding context is predominantly rural, being located on the western fringe of the Wodonga LGA.

Land to the north includes more rural parcels associated with grazing activities. Further north towards the Murray River, land is generally use for agricultural purposes with improvements generally limited to rural dwellings.

Land to the east includes mostly farming properties that extend from along Old Barnawartha Road. Similar development extends along this roadway and the Hume Highway into the outer urban development of West Wodonga, approximately 12 kilometres from the site.

Land to the south includes a motorsport training complex which includes a track and associated facilities. The Logic precinct is located approximately 1 kilometre from the land, that includes a service station and large industrial distribution centres and railway line extending along the Hume Highway.

Land to the west includes the Northern Victoria Livestock Exchange, which is a saleyards facility . Land beyond this facility consists of other rural parcels extending from along the Murray Valley Highway.

Figure 7 | View away from the site at the corner of the Murray Valley Highway and Margerys Road

Figure 8 | View facing west away from the site at the corner of the Murray Valley Highway and Margerys Road

Figure 9 | View along the southern boundary of the site facing east along the Murray Valley Highway from the Margerys Road intersection

3. Glint and Glare Assessment

The assessment methodology in this instance is based on guidance documents for Solar Facility design, studies in relation to glint and glare along with industry best practice modelling. The broad methodology followed for this study comprises:

1. collate key data and model inputs for solar farm based on specifications and design;
2. identify primary receptors in the area surrounding the site;
3. consider visibility of the panels from the receptor's location and whether or not panels are likely to be visible;
4. plot the location of all receptors in a Solar Glare Analysis Tool and input data for the proposed facility to model the expected impacts;
5. based on modelling, determine whether a reflection can occur to receptors and the extent/period of impact;
6. determine whether a significant detrimental impact is expected;
7. Recommend appropriate mitigation measures as required.

3.1. Modelling Tool

This study has used the GlareGauge modelling tool by ForgeSolar. This is an industry standard technical modelling tool, which utilises the Solar Glare Hazard Analysis Tool (SGHAT) developed by Sandia National Laboratories, to assess the potential glare to receptors around solar arrays. This tool is required by a number of international authorities including the United States Federal Aviation Administration for glint and glare analyses near airports, and it recognised by the UK Civil Aviation Authority, and the Australian Government Civil Aviation Safety Authority.

The GlareGauge tool uses an interactive Google Maps interface to plot the arrangement of arrays and the location of sensitive receptors including static observation points, routes and flight paths. The elevation of the panels and receptors are automatically captured using ground elevation data of the respective locations. The modelling for consideration of this development utilises the specification and data of the proposed PV panels to be installed, the location of the panels relative to the receptors and the proposed angle of tilt for the panels.

If glare is found, the tool calculates the likelihood of the glare source to present a potential ocular hazard ranging from temporary after-image to retinal burn. The results are presented in a plot and graphs that specifies when glare will occur throughout the year and its duration, with colour codes indicating the potential ocular hazard. These hazard ratings are presented in the following section.

3.2. Glare Hazard Rating

The SGHAT defines three levels of ocular hazard as a result of glare. The hazards are defined as low, moderate or high, depending on the potential to impact vision through producing glare with a potential for afterimage. The following definitions are provided for the glare hazard levels referred to in this report.

No glare	No Glare - No glare predicted.
Green	**Low potential hazard** – Glare is present, however only a low potential for a temporary after-image. This hazard is shown green on the plots used by the GlareGauge tool, reproduced in **Figure 11** of this report.
Yellow	**Moderate potential hazard** – Glare present with the potential to leave temporary after-image of the glare. This hazard is shown green on the plots used by the GlareGauge tool, reproduced in **Figure 11** of this report.
High	**High potential hazard** – Glare is present with potential for permanent eye damage. This hazard is shown green on the plots used by the GlareGauge tool, reproduced in **Figure 11** of this report.

3.3. Model inputs

The proposed solar array associated with the Barnawartha North solar facility will consist of panels fixed single axis tracking. To accurately determine the potential glare impact of the array, the following array details were input into the Glare Gauge tool. The following summarises the model inputs and the details used for this site.

Name: The name of the proposal. This has no effect on the model output.

Description: Optional description of the proposal. This has no effect on the model output.

Axis tracking: Allows selection by the user of whether the proposal is a fixed-mount or utilize single- or dual-axis tracking.

Rated power (kW): Optional inputs that are 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. This does not alter the potential glare.

Module surface material: This input allows the materials of the proposed PV modules to be specified. It allows for selection of either Smooth glass or textured glass and with or without AR coating.

Reflectivity varies with incidence angle: This is a yes or no input. If this is checked 'yes', 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: This specifies 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. This is only used if reflectivity does not vary with incidence angle (as above).

Slope error (mrad): This 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.

Table 1 | Model Inputs

Input	Unit	Value
Time zone	UTC	UTC +10
Peak DNI	kW/m^2	1000
PV Panel surface material	-	Smooth glass with anti-reflective coating
Tracking axis tilt	Degrees	0
Resting angle	Degrees	60 (no backtracking)
Orientation of tracking axis	Degrees	180
Offset angle of panel	Degrees	0
Maximum tracking angle	Degrees	60
Backtracking		None proposed
Height above ground	Metres	2.364

3.4. Assessment of Impacts

As discussed, an assessment of the potential impact of the proposal has been undertaken using the GlareGauge Tool. The tool enables the proposed solar facility to be mapped along with relevant data inputs and then uses the data to consider the potential for temporary after-image or more significant retinal burn. The chart presented at **Figure 11** represents the possible severity of glare at receptor locations.

In summary, the red glare refers to potential for permanent eye damage from the observation location, yellow glare indicates the potential for after image effects and green glare refers to low potential for after image impacts.

[1] Spaven Consulting, Solar Photovoltaic Energy Facilities: Assessment of Potential for Impact on Aviation, January 2011

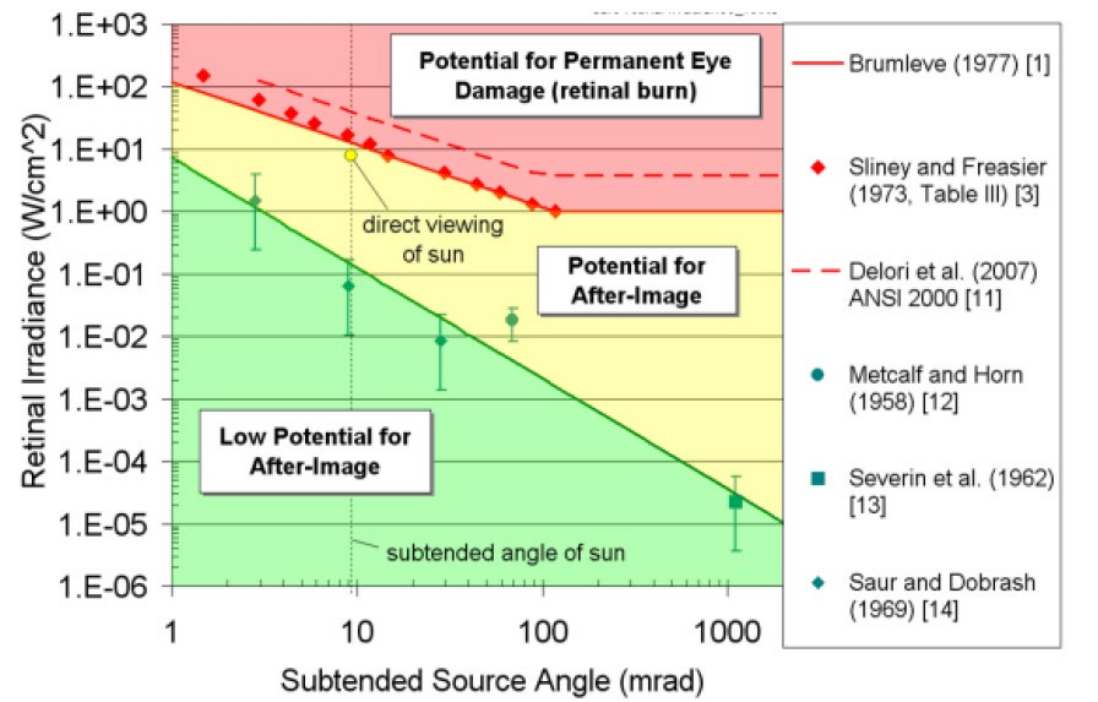

Figure 10 | Summary of potential glare impact with regard to total minutes of glare for receptor

The assessment relies on identifying the potential sensitive receptors surrounding the development and assessing the potential impacts on the receptors. The modelling for consideration of this development utilises the specification and data of the proposed PV panels to be installed, the location of the panels relative to the receptors and the proposed angle tilt for the panels.

By default, the glare assessment using Forge Solar analysis includes an assumption that the panel system would 'backtrack' to a flat resting position after sunset (when the sun left the angle of rotation of the panel) until sunrise (when the panel was in the angle of rotation of the panels). If backtracking to a flat resting position is enabled, glare would be experienced to the west of the site in the early morning, before the panels reset to being tracking for the day and for the properties to the east in the evening, when the panels had reset to rest. It is also observed that roads to the east and west experienced corresponding glare impacts dependent on which side of the facility they were located if backtracking is enabled.

If backtracking is disabled for the facility, the development will produce no glare on the receptor points. This is because the panels will track with the angle of the sun through the day and will remain in a tilted position west facing position from sunset to sunrise.

3.5. Identification of Receptors

In addition to the array inputs outlined above, the locations of the identified receptors were plotted into the GlareGauge tool on the same Google Maps interface. These receptors were input from within a capture area of a radius of approximately 2 kilometres around the location of the proposed facility.

A number of Observation Points (OP's) were identified within proximity to the site. These sites represent fixed locations where glint and glare could have an ongoing impact. These OP's consisted of dwellings surrounding the site, including those in adjacent properties and were measured from a height of 1.5 metres above the ground for a typical viewing angle. Glare was also measured from the commercial properties located immediately adjacent to the site. There is also no technical limit to the distance at which reflections could occur. However, the significance of a reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases. Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances. In this case, a total of 27 OP's were recorded surrounding the site at a radius of approximately 2 kilometres, as was deemed appropriate. **Figure 12** below illustrates the location of the nearest affected OP's within proximity of the site.

All surrounding routes were recorded for input into the GlareGauge tool similar to the OP's. These included Margerys Road, the Murray Valley Highway, the Hume Freeway and any other roads within the surrounds. The height above ground was also input as 1.5 metres, considered a typical viewing height for individuals in vehicles travelling these routes. The routes are indicated below in **Figure 13**.

There are also known to be two key flight paths proximate to the site, to the east. These flight paths are used for approximately 40% of the arrivals into Albury airport, with 3-5 plane movements per day. The height above ground was input as 1000 metres, which is considered the typical altitude for planes in this location as they approach their landing zone.

Figure 11 | Observation points assessed for glint and glare within the immediate context of the subject site

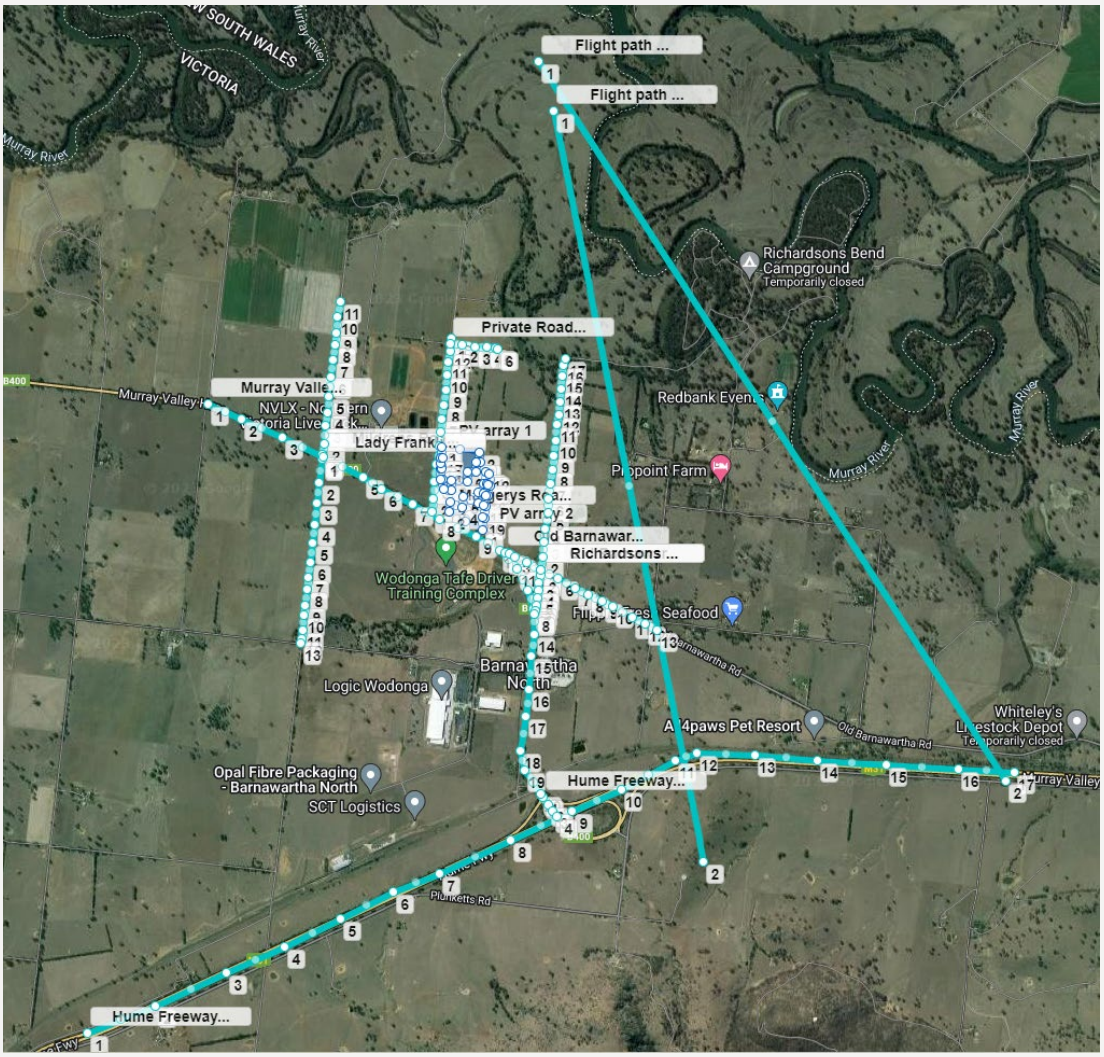

Figure 12 | Routes assessed for glint and glare within the immediate context of the subject site

4. Results

Of the dwellings assessed, zero were calculated to receive “yellow glare” or “green glare”, for being subject to potential after image. There were no routes that were calculated to receive yellow glare or green glare.

Notwithstanding, it is proposed that the facility will operate with backtracking disabled. Under this scenario, the modelling by this report identifies that under normal operation, with backtracking disabled, no glare hazard is geometrically possible.

5. Proposed Mitigation

The assessment undertaken within this report determines that under normal operation of the solar farm tracking system, being with a backtracking operation and minimum limit of 10 degree resting angle, no additional mitigation measures are required to manage the potential impacts of glare on receivers. While the proposal can also avoid significant glare impact through this design, a number of other recommendations are made for the proposed facility and are detailed below.

- The proposal must be operated in accordance with all conditions and endorsed plans associated with the planning permit issued by the Minister for Planning. Any amendments to this Permit must ensure that the proposal does not change the operational requirements of the facility unless further assessment of glare impact is carried out.
- The proposed facility must not be allowed to operate with backtracking, whereby Panels would be allowed to 'backtrack' to a horizontal position when the sun is out of tracking range. All panels must be limited to a minimum resting angle of 10 degrees.
- Given that no glare impact is expected from the proposal, no 'mesh screen' is recommended. However, a process for monitoring of glare hazard potential and managing complaints, including rectification, should be included in the operational procedures associated with the development.
- A landscaped area is to be established surrounding the proposed facility in accordance with the landscape plans submitted. Monitoring of glare hazard potential would no longer be required once the screen planting is sufficiently established to block line of sight to the solar farm.

6. Conclusion

Overall, the assessment of the facility determines the following results:

- There will be no glare potential to the observation points for a fixed single axis tracking system when backtracking is limited to a minimum of 10 degrees. It is noted that this outcome can be achieved by way of compliance with conditions of the planning permit.
- There will be no glare potential to the road corridors surrounding the facility for a fixed single axis tracking system and when backtracking is limited to a minimum of 10 degrees. It is noted that this outcome can be achieved by way of compliance with conditions on the future planning permit.
- As a result of the modelled impact under normal operating conditions, being backtracking limited to 10 degrees, no mesh screening is required to be established for glare mitigation.
- A landscaped area is to be established surrounding the proposed facility in accordance with the landscape plans submitted.

As such, it is recommended that the facility be operated with backtracking limited to a minimum resting angle of 10 degrees, and configured to prevent the panels returning to a flat resting position. Under these configured options, there will be no glare potential to adjoining observation points or transport corridors.

To mitigate against potential unforeseen operational constraints (including panel and tracking malfunction), the recommended mitigation recommendations at Section 5 should be imposed to avoid any significant impacts.

Appendix A: ForgeSolar Report

FORGESOLAR GLARE ANALYSIS

Project: **Barnawartha North Solar Farm**
Proposed 4.95MW solar energy facility

Site configuration: **Barnawartha North Solar Farm**

Client: BE Pro BWN Pty Ltd

Site description: Barnawartha North Solar Farm

Created 04 Sep, 2023
Updated 04 Sep, 2023
Time-step 1 minute
Timezone offset UTC10
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 1 MW to 5 MW
Site ID 99378.17277

Ocular transmission coefficient 0.5
Pupil diameter 0.002 m
Eye focal length 0.017 m
Sun subtended angle 9.3 mrad
PV analysis methodology V2

Summary of Results No glare predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	SA tracking	SA tracking	0	0.0	0	0.0	-
PV array 2	SA tracking	SA tracking	0	0.0	0	0.0	-

Total glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Flight path 1	0	0.0	0	0.0
Flight path 2	0	0.0	0	0.0
Hume Freeway Ramp	0	0.0	0	0.0
Hume Freeway West	0	0.0	0	0.0
Lady Franklin Road	0	0.0	0	0.0
Margerys Road	0	0.0	0	0.0
Mildrens Road	0	0.0	0	0.0
Murray Valley Highway	0	0.0	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Old Barnawartha Road	0	0.0	0	0.0
Old Barnawartha Road East	0	0.0	0	0.0
Private Road	0	0.0	0	0.0
Richardsons Road	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0
OP 15	0	0.0	0	0.0
OP 16	0	0.0	0	0.0
OP 17	0	0.0	0	0.0
OP 18	0	0.0	0	0.0
OP 19	0	0.0	0	0.0
OP 20	0	0.0	0	0.0
OP 21	0	0.0	0	0.0
OP 22	0	0.0	0	0.0
OP 23	0	0.0	0	0.0
OP 24	0	0.0	0	0.0
OP 25	0	0.0	0	0.0
OP 26	0	0.0	0	0.0
OP 27	0	0.0	0	0.0

Component Data

PV Arrays

Name: PV array 1
Axis tracking: Single-axis rotation
Backtracking: None
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking 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	-36.059244	146.719130	156.84	2.36	159.21
2	-36.059561	146.722158	155.39	2.36	157.76
3	-36.060202	146.722225	155.45	2.36	157.82
4	-36.060170	146.721871	155.50	2.36	157.86
5	-36.060853	146.721898	155.48	2.36	157.84
6	-36.060799	146.721179	156.04	2.36	158.40
7	-36.061450	146.721174	155.92	2.36	158.28
8	-36.061369	146.719943	156.48	2.36	158.85
9	-36.061998	146.719962	156.09	2.36	158.45
10	-36.061953	146.719286	156.70	2.36	159.07
11	-36.061320	146.719270	157.02	2.36	159.38
12	-36.061307	146.719055	156.98	2.36	159.34
13	-36.060634	146.719044	156.96	2.36	159.32
14	-36.060639	146.719130	156.98	2.36	159.35
15	-36.060290	146.719106	156.77	0.00	156.77
16	-36.059941	146.719093	156.94	2.36	159.31
17	-36.059945	146.719221	156.95	2.36	159.32

Name: PV array 2
Axis tracking: Single-axis rotation
Backtracking: None
Tracking axis orientation: 0.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking 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	-36.064570	146.722415	156.69	2.36	159.06
2	-36.063423	146.719728	156.63	2.36	158.99
3	-36.062768	146.719798	155.95	2.36	158.31
4	-36.063132	146.720793	156.93	2.36	159.30
5	-36.062428	146.720878	156.68	2.36	159.04
6	-36.062870	146.722072	156.79	2.36	159.15
7	-36.062128	146.722083	156.39	2.36	158.75
8	-36.062241	146.722480	156.54	2.36	158.90
9	-36.061556	146.722464	156.03	2.36	158.40
10	-36.061623	146.722718	155.96	2.36	158.32
11	-36.060830	146.722692	156.01	2.36	158.38
12	-36.060947	146.722968	156.02	2.36	158.39
13	-36.061699	146.722973	156.12	2.36	158.48
14	-36.061669	146.722847	155.95	2.36	158.32
15	-36.062360	146.722820	156.54	2.36	158.90
16	-36.062324	146.722681	156.30	2.36	158.67
17	-36.063052	146.722692	156.51	2.36	158.87
18	-36.062998	146.722539	156.56	2.36	158.92
19	-36.063811	146.722555	156.93	2.36	159.29
20	-36.063763	146.722431	156.83	2.36	159.20

Route Receptors

Name: Flight path 1
Path type: One-way (toward increasing index)
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.037585	146.728107	143.31	1000.00	1143.31
2	-36.085911	146.740038	228.78	1000.00	1228.78

Name: Flight path 2
Path type: One-way (toward increasing index)
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.034358	146.726863	142.16	1000.00	1142.16
2	-36.080709	146.764113	165.07	1000.00	1165.07

Name: Hume Freeway Ramp
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.081788	146.727233	183.22	1.50	184.72
2	-36.082238	146.727620	185.73	1.50	187.23
3	-36.082707	146.728006	183.15	1.50	184.65
4	-36.083053	146.728306	179.43	1.50	180.93

Name: Hume Freeway West
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.096965	146.690894	193.43	1.50	194.93
2	-36.095231	146.696301	190.30	1.50	191.80
3	-36.093081	146.701966	192.31	1.50	193.81
4	-36.091417	146.706601	192.96	1.50	194.46
5	-36.089613	146.711064	196.69	1.50	198.19
6	-36.087879	146.715270	194.12	1.50	195.62
7	-36.086700	146.718960	188.51	1.50	190.01
8	-36.084550	146.724625	179.98	1.50	181.48
9	-36.082677	146.729518	178.89	1.50	180.39
10	-36.081290	146.733466	178.73	1.50	180.23
11	-36.079417	146.737757	174.75	1.50	176.25
12	-36.078931	146.739474	176.60	1.50	178.10
13	-36.079070	146.744109	178.12	1.50	179.62
14	-36.079417	146.749087	174.73	1.50	176.23
15	-36.079694	146.754580	168.15	1.50	169.65
16	-36.079972	146.760331	165.22	1.50	166.72
17	-36.080180	146.764794	163.79	1.50	165.29

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.059982	146.709599	159.44	1.50	160.94
2	-36.061491	146.709363	160.08	1.50	161.58
3	-36.062862	146.709213	160.11	1.50	161.61
4	-36.064232	146.709020	161.40	1.50	162.90
5	-36.065377	146.708848	160.88	1.50	162.38
6	-36.066660	146.708677	162.75	1.50	164.25
7	-36.067597	146.708548	161.08	1.50	162.58
8	-36.068412	146.708419	162.44	1.50	163.94
9	-36.069418	146.708290	161.16	1.50	162.66
10	-36.070077	146.708162	163.64	1.50	165.14
11	-36.071048	146.708076	163.42	1.50	164.92
12	-36.071603	146.708012	163.31	1.50	164.81
13	-36.071829	146.707926	163.19	1.50	164.69

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.063378	146.718370	156.98	1.50	158.48
2	-36.062563	146.718499	157.03	1.50	158.53
3	-36.061436	146.718563	157.29	1.50	158.79
4	-36.060343	146.718757	156.96	1.50	158.46
5	-36.059163	146.718950	156.85	1.50	158.35
6	-36.058279	146.719078	156.70	1.50	158.20
7	-36.057394	146.719143	156.22	1.50	157.72
8	-36.056492	146.719314	155.76	1.50	157.26
9	-36.055555	146.719465	154.82	1.50	156.32
10	-36.054584	146.719550	154.90	1.50	156.40
11	-36.053751	146.719679	154.59	1.50	156.09
12	-36.053022	146.719808	153.76	1.50	155.26
13	-36.052207	146.719915	153.69	1.50	155.19

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.059737	146.709621	159.09	1.50	160.59
2	-36.059026	146.709771	158.92	1.50	160.42
3	-36.057846	146.709900	158.44	1.50	159.94
4	-36.057031	146.710029	158.54	1.50	160.04
5	-36.055938	146.710179	157.79	1.50	159.29
6	-36.054707	146.710350	157.38	1.50	158.88
7	-36.053614	146.710501	156.14	1.50	157.64
8	-36.052642	146.710672	156.08	1.50	157.58
9	-36.051896	146.710737	155.65	1.50	157.15
10	-36.050821	146.710865	155.74	1.50	157.24
11	-36.049866	146.711080	154.65	1.50	156.15

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.056436	146.700563	159.13	1.50	160.63
2	-36.057407	146.703224	159.97	1.50	161.47
3	-36.058621	146.706442	158.78	1.50	160.28
4	-36.059836	146.709704	159.01	1.50	160.51
5	-36.061154	146.712880	159.25	1.50	160.75
6	-36.061952	146.714382	158.92	1.50	160.42
7	-36.062888	146.716828	158.33	1.50	159.83
8	-36.063895	146.718974	158.08	1.50	159.58
9	-36.065005	146.721892	157.07	1.50	158.57
10	-36.065872	146.723780	157.60	1.50	159.10
11	-36.067086	146.725153	157.25	1.50	158.75
12	-36.068474	146.726012	158.50	1.50	160.00
13	-36.069618	146.726484	158.76	1.50	160.26
14	-36.071318	146.726570	159.10	1.50	160.60
15	-36.072671	146.726312	160.69	1.50	162.19
16	-36.074870	146.726089	163.69	1.50	165.19
17	-36.076570	146.725875	164.99	1.50	166.49
18	-36.078790	146.725445	170.00	1.50	171.50
19	-36.080073	146.725746	177.44	1.50	178.94
20	-36.081599	146.727076	182.74	1.50	184.24

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.066031	146.724208	157.62	1.50	159.12
2	-36.066066	146.724551	157.33	1.50	158.83
3	-36.066291	146.724981	156.93	1.50	158.43
4	-36.066673	146.725925	155.95	1.50	157.45
5	-36.067141	146.727062	156.90	1.50	158.40
6	-36.067714	146.728414	156.97	1.50	158.47
7	-36.068286	146.729809	157.42	1.50	158.92
8	-36.068702	146.730796	156.89	1.50	158.39
9	-36.069171	146.731976	157.42	1.50	158.92
10	-36.069517	146.732770	157.43	1.50	158.93
11	-36.070177	146.734358	158.53	1.50	160.03
12	-36.070610	146.735345	158.67	1.50	160.17
13	-36.071026	146.736353	159.02	1.50	160.52

Name: Old Barnawartha Road East
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.067161	146.727050	156.95	1.50	158.45
2	-36.067465	146.727028	157.23	1.50	158.73
3	-36.067951	146.726910	158.17	1.50	159.67
4	-36.068480	146.726835	157.40	1.50	158.90
5	-36.068939	146.726750	159.32	1.50	160.82
6	-36.069416	146.726696	158.90	1.50	160.40
7	-36.069763	146.726642	158.22	1.50	159.72
8	-36.069989	146.726514	158.68	1.50	160.18

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.052537	146.719851	153.90	1.50	155.40
2	-36.052623	146.720774	153.89	1.50	155.39
3	-36.052762	146.721846	155.04	1.50	156.54
4	-36.052797	146.722748	154.52	1.50	156.02
5	-36.052866	146.723413	154.69	1.50	156.19
6	-36.052901	146.723649	154.17	1.50	155.67

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

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-36.067142	146.727061	156.90	1.50	158.40
2	-36.066327	146.727189	155.65	1.50	157.15
3	-36.065338	146.727318	156.10	1.50	157.60
4	-36.064506	146.727425	156.67	1.50	158.17
5	-36.063448	146.727619	157.55	1.50	159.05
6	-36.062529	146.727683	156.84	1.50	158.34
7	-36.061557	146.727812	155.24	1.50	156.74
8	-36.060655	146.728005	156.37	1.50	157.87
9	-36.059770	146.728112	156.12	1.50	157.62
10	-36.058782	146.728219	154.60	1.50	156.10
11	-36.057776	146.728348	152.16	1.50	153.66
12	-36.057116	146.728498	147.15	1.50	148.65
13	-36.056284	146.728563	145.40	1.50	146.90
14	-36.055451	146.728649	144.70	1.50	146.20
15	-36.054636	146.728756	145.02	1.50	146.52
16	-36.053942	146.728842	144.92	1.50	146.42
17	-36.053508	146.729013	144.64	1.50	146.14

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	-36.057593	146.729119	148.69	1.50
OP 2	2	-36.057697	146.735299	151.36	1.50
OP 3	3	-36.059813	146.734591	153.62	1.50
OP 4	4	-36.064219	146.728111	157.22	1.50
OP 5	5	-36.065728	146.728325	157.83	1.50
OP 6	6	-36.058321	146.714721	158.41	1.50
OP 7	7	-36.049665	146.723347	152.82	1.50
OP 8	8	-36.053325	146.723991	155.63	1.50
OP 9	9	-36.044807	146.715493	151.79	1.50
OP 10	10	-36.043922	146.722296	155.27	1.50
OP 11	11	-36.044243	146.712280	155.20	1.50
OP 12	12	-36.044083	146.713546	155.18	1.50
OP 13	13	-36.043770	146.714689	153.84	1.50
OP 14	14	-36.043137	146.703185	155.07	1.50
OP 15	15	-36.059757	146.692573	162.88	1.50
OP 16	16	-36.072137	146.697466	167.20	1.50
OP 17	17	-36.070982	146.713192	161.62	1.50
OP 18	18	-36.069612	146.735502	159.00	1.50
OP 19	19	-36.069967	146.738399	159.35	1.50
OP 20	20	-36.059326	146.739987	151.24	1.50
OP 21	21	-36.058927	146.742605	153.22	1.50
OP 22	22	-36.061252	146.741135	155.81	1.50
OP 23	23	-36.062075	146.740770	155.09	1.50
OP 24	24	-36.058511	146.745373	152.10	1.50
OP 25	25	-36.056898	146.745791	149.18	1.50
OP 26	26	-36.052162	146.717585	155.93	1.50
OP 27	27	-36.068502	146.720568	157.97	1.50

Glare Analysis Results

Summary of Results No glare predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	SA tracking	SA tracking	0	0.0	0	0.0	-
PV array 2	SA tracking	SA tracking	0	0.0	0	0.0	-

Total glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Flight path 1	0	0.0	0	0.0
Flight path 2	0	0.0	0	0.0
Hume Freeway Ramp	0	0.0	0	0.0
Hume Freeway West	0	0.0	0	0.0
Lady Franklin Road	0	0.0	0	0.0
Margerys Road	0	0.0	0	0.0
Mildrens Road	0	0.0	0	0.0
Murray Valley Highway	0	0.0	0	0.0
Old Barnawartha Road	0	0.0	0	0.0
Old Barnawartha Road East	0	0.0	0	0.0
Private Road	0	0.0	0	0.0
Richardsons Road	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 15	0	0.0	0	0.0
OP 16	0	0.0	0	0.0
OP 17	0	0.0	0	0.0
OP 18	0	0.0	0	0.0
OP 19	0	0.0	0	0.0
OP 20	0	0.0	0	0.0
OP 21	0	0.0	0	0.0
OP 22	0	0.0	0	0.0
OP 23	0	0.0	0	0.0
OP 24	0	0.0	0	0.0
OP 25	0	0.0	0	0.0
OP 26	0	0.0	0	0.0
OP 27	0	0.0	0	0.0

PV: PV array 1 no glare found

Receptor results ordered by category of glare

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Flight path 1	0	0.0	0	0.0
Flight path 2	0	0.0	0	0.0
Hume Freeway Ramp	0	0.0	0	0.0
Hume Freeway West	0	0.0	0	0.0
Lady Franklin Road	0	0.0	0	0.0
Margerys Road	0	0.0	0	0.0
Mildrens Road	0	0.0	0	0.0
Murray Valley Highway	0	0.0	0	0.0
Old Barnawartha Road	0	0.0	0	0.0
Old Barnawartha Road East	0	0.0	0	0.0
Private Road	0	0.0	0	0.0
Richardsons Road	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0
OP 15	0	0.0	0	0.0
OP 16	0	0.0	0	0.0
OP 17	0	0.0	0	0.0
OP 18	0	0.0	0	0.0
OP 19	0	0.0	0	0.0
OP 20	0	0.0	0	0.0
OP 21	0	0.0	0	0.0
OP 22	0	0.0	0	0.0
OP 23	0	0.0	0	0.0
OP 24	0	0.0	0	0.0
OP 25	0	0.0	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 26	0	0.0	0	0.0
OP 27	0	0.0	0	0.0

PV array 1 and Route: Flight path 1

No glare found

PV array 1 and Route: Flight path 2

No glare found

PV array 1 and Route: Hume Freeway Ramp

No glare found

PV array 1 and Route: Hume Freeway West

No glare found

PV array 1 and Route: Lady Franklin Road

No glare found

PV array 1 and Route: Margerys Road

No glare found

PV array 1 and Route: Mildrens Road

No glare found

PV array 1 and Route: Murray Valley Highway

No glare found

PV array 1 and Route: Old Barnawartha Road

No glare found

PV array 1 and Route: Old Barnawartha Road East

No glare found

PV array 1 and Route: Private Road

No glare found

PV array 1 and Route: Richardsons Road

No glare found

PV array 1 and OP 1

No glare found

PV array 1 and OP 2

No glare found

PV array 1 and OP 3

No glare found

PV array 1 and OP 4

No glare found

PV array 1 and OP 5

No glare found

PV array 1 and OP 6

No glare found

PV array 1 and OP 7

No glare found

PV array 1 and OP 8

No glare found

PV array 1 and OP 9

No glare found

PV array 1 and OP 10

No glare found

PV array 1 and OP 11

No glare found

PV array 1 and OP 12

No glare found

PV array 1 and OP 13

No glare found

PV array 1 and OP 14

No glare found

PV array 1 and OP 15

No glare found

PV array 1 and OP 16

No glare found

PV array 1 and OP 17

No glare found

PV array 1 and OP 18

No glare found

PV array 1 and OP 19

No glare found

PV array 1 and OP 20

No glare found

PV array 1 and OP 21

No glare found

PV array 1 and OP 22

No glare found

PV array 1 and OP 23

No glare found

PV array 1 and OP 24

No glare found

PV array 1 and OP 25

No glare found

PV array 1 and OP 26

No glare found

PV array 1 and OP 27

No glare found

PV: PV array 2 no glare found

Receptor results ordered by category of glare

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Flight path 1	0	0.0	0	0.0
Flight path 2	0	0.0	0	0.0
Hume Freeway Ramp	0	0.0	0	0.0
Hume Freeway West	0	0.0	0	0.0
Lady Franklin Road	0	0.0	0	0.0
Margerys Road	0	0.0	0	0.0
Mildrens Road	0	0.0	0	0.0
Murray Valley Highway	0	0.0	0	0.0
Old Barnawartha Road	0	0.0	0	0.0
Old Barnawartha Road East	0	0.0	0	0.0
Private Road	0	0.0	0	0.0
Richardsons Road	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	0	0.0	0	0.0
OP 14	0	0.0	0	0.0
OP 15	0	0.0	0	0.0
OP 16	0	0.0	0	0.0
OP 17	0	0.0	0	0.0
OP 18	0	0.0	0	0.0
OP 19	0	0.0	0	0.0
OP 20	0	0.0	0	0.0
OP 21	0	0.0	0	0.0
OP 22	0	0.0	0	0.0
OP 23	0	0.0	0	0.0
OP 24	0	0.0	0	0.0
OP 25	0	0.0	0	0.0
OP 26	0	0.0	0	0.0
OP 27	0	0.0	0	0.0

PV array 2 and Route: Flight path 1

No glare found

PV array 2 and Route: Flight path 2

No glare found

PV array 2 and Route: Hume Freeway Ramp

No glare found

PV array 2 and Route: Hume Freeway West

No glare found

PV array 2 and Route: Lady Franklin Road

No glare found

PV array 2 and Route: Margerys Road

No glare found

PV array 2 and Route: Mildrens Road

No glare found

PV array 2 and Route: Murray Valley Highway

No glare found

PV array 2 and Route: Old Barnawartha Road

No glare found

PV array 2 and Route: Old Barnawartha Road East

No glare found

PV array 2 and Route: Private Road

No glare found

PV array 2 and Route: Richardsons Road

No glare found

PV array 2 and OP 1

No glare found

PV array 2 and OP 2

No glare found

PV array 2 and OP 3

No glare found

PV array 2 and OP 4

No glare found

PV array 2 and OP 5

No glare found

PV array 2 and OP 6

No glare found

PV array 2 and OP 7

No glare found

PV array 2 and OP 8

No glare found

PV array 2 and OP 9

No glare found

PV array 2 and OP 10

No glare found

PV array 2 and OP 11

No glare found

PV array 2 and OP 12

No glare found

PV array 2 and OP 13

No glare found

PV array 2 and OP 14

No glare found

PV array 2 and OP 15

No glare found

PV array 2 and OP 16

No glare found

PV array 2 and OP 17

No glare found

PV array 2 and OP 18

No glare found

PV array 2 and OP 19

No glare found

PV array 2 and OP 20

No glare found

PV array 2 and OP 21

No glare found

PV array 2 and OP 22

No glare found

PV array 2 and OP 23

No glare found

PV array 2 and OP 24

No glare found

PV array 2 and OP 25

No glare found

PV array 2 and OP 26

No glare found

PV array 2 and OP 27

No glare found

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.
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.
Several V1 calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects V1 analyses of path receptors.
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.
The analysis does not automatically 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.
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.)
The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
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.
The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.
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.
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Refer to the Help page at **www.forgesolar.com/help/** for assumptions and limitations not listed here.

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

Appendix B: Development Plans