BOMEN SOLAR FARM

Reflective Glare Assessment

Prepared for:

Bomen Solar Farm Pty Ltd
as Trustee for
Bomen Solar Farm Trust

SLR Ref: 610.30070-R01
Version No: -v1.0
September 2020

PREPARED BY

SLR Consulting Australia Pty Ltd
ABN 29 001 584 612
Tenancy 202 Submarine School, Sub Base Platypus, 120 High Street
North Sydney NSW 2060 Australia

T: +61 2 9427 8100
E: sydney@slrconsulting.com   www.slrconsulting.com

BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Bomen Solar Farm Pty Ltd (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
610.30070-R01-v1.0	10 September 2020	Peter Hayman	Dr Peter Georgiou	Dr Neihad Al-Khalidy

EXECUTIVE SUMMARY

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Bomen Solar Farm Pty Ltd, as Trustee for Bomen Solar Farm Trust, to carry out a Reflective Glare Assessment of Bomen Solar Farm (SF). The facility is located in Bomen, NSW - refer Figure 1.

- Bomen SF comprises a 100 MWac solar facility;
- The facility incorporates Jinko Swan Bifacial HC 72m 380-390W photovoltaic (PV) panels, measuring approximately 2.0 m by 1.0 m;
- The panels are mounted (portrait-style) on single-axis ±60° tracking structures which are aligned in a north-south direction and spaced 4.8 m apart.

Section 2 describes the footprint and envelope of Bomen SF.

The following potential glare conditions have been considered:

- Daytime Reflective glare (and glint) arising from the solar PV panels within the facility

In terms of potential glare calculation methodologies, the following have been considered:

- SOLAR GLARE HAZARD ANALYSIS TOOL (SGHAT) Reflective Glare – normally applied to Aviation Glint & Glare studies; and
- THRESHOLD INCREMENT (TI) Reflective Glare – normally applied to Motorist “Disability” Glare and Pedestrian “Discomfort” Glare (the latter relevant to pedestrian crossing situations).

The present study has found the following:

- It is noted that there are no Australian guidelines covering reflective glare in relation to “Residence Nuisance” glare, as opposed to guidelines covering Aviation Glint and Glare, Motorist Disability Glare and Pedestrian Discomfort Glare. These latter guidelines have been used to characterise the level of glare being experienced by surrounding residential receivers.
- Under current “back-tracking” operational conditions, labelled as the SIM-1 scenario, reflections from Bomen SF may be visible to receivers located to the east of the facility during late afternoon periods at different months of the year, depending upon relative position of the receiver. Note that the present analysis does not take into account any shielding of reflections from intervening vegetation, trees, etc, including those found within the facility itself.
- The SIM-1 analysis suggests that reflections become visible only once the panels have “back-tracked” to their horizontal rest position after the sun has passed a solar zenith angle of 60° to the west.
- This was confirmed by running a “±60° Tilt / No Back-Tracking” scenario (SIM-2) which confirmed the absence of visible reflections at all surrounding receivers assessed in the study.
- A theoretical “Equivalent Bifacial Underside Panel” mode (SIM-3) was run aimed at simulating the diffuse reflections that may occur from the underside of west-facing panels towards the east. The outcome of this simulation suggests that such reflections may potentially be visible, but at negligible lux levels.
- Simulations involving panels being tilted towards the west (with even a small 5° tilt angle, ie almost horizontal) resulted in no reflections being created towards the east (all-year-round).

EXECUTIVE SUMMARY

- The results of the TI Value calculations for the SIM-1 to SIM-4 scenarios suggest that, while reflections may indeed be visible to east side receivers under certain circumstances, eg panels in a horizontal position close to sunset, they would not constitute a "glare" condition according to the criteria normally applied to Motorist Disability and Pedestrian Discomfort Glare.
- A final "SIM-5" scenario was modelled, representing a situation which may have existed on occasion at Bomen SF during construction and prior to panel tracking commencing, when panels were left in a fixed tilt position facing east. The results of the TI Value calculations for the SIM-5 scenario suggest the recommended TI Value criterion for Pedestrian Discomfort Glare may have been exceeded during this period. It is noted that, since the commencement of normal tracker operations, the SIM-5 scenario is highly unlikely to occur again.

CONTENTS

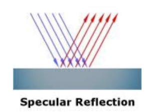
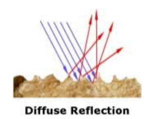
CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

Abbreviations and Definitions

Terms relevant to Daytime Reflective Glare	
PV Panel	Photovoltaic (PV) panels are designed to absorb solar energy and retain as much of the solar spectrum as possible in order to produce electricity.
Glare	Glare refers to the reflections of the sun off any reflective surface, experienced as a source of excessive brightness relative to the surrounding diffused lighting. Glare covers reflections: • Which can be experienced by both stationary and moving observers (the latter referred to as "glint"). • Which are either specular or diffuse.
Specular	A reflection which is essentially mirror-like – there is virtually no loss of intensity or angle dispersion between the incoming solar ray and outgoing reflection. 
Diffuse	A reflection in which the outgoing reflected rays are dispersed over a wide ("diffuse") range of angle compared to the incoming (parallel) solar rays, typical of "rougher" surfaces. 
KVP	Key View Points (KVPs) are offsite locations where receivers of interest have the potential to experience adverse reflective glare.

Terms relevant to Night-Time Illumination	
Luminous intensity	The concentration of luminous flux emitted in a specific direction. Unit: candela (Cd).
Luminance AS 1158.2:2005	This is the physical quantity corresponding to the brightness of a surface (e.g. a lamp, luminaire or reflecting material such as façade glazing) when viewed from a specified direction. Unit: Cd/m^2
Illuminance AS 1158.2:2005	This is the physical measure of illumination. It is the luminous flux arriving at a surface divided by the area of the illuminated surface – the unit is lux (lx) … 1 lx = 1 lm/m^2 The term covers both "Horizontal Illuminance" (the value of illuminance on a designated horizontal plane at ground level) and "Vertical Illuminance" (the value of illuminance on a designated vertical plane at a height of 1.5m above ground level).
Glare AS 1158.2:2005	Condition of vision in which there is a discomfort or a reduction in the ability to see, or both, caused by an unsuitable distribution or range of luminance, or to extreme contrast in the field of vision. Glare can include: (a) Disability Glare – glare that impairs the visibility of objects without necessarily causing discomfort. (b) Discomfort Glare – glare that causes discomfort without necessarily impairing the visibility of objects.
Threshold Increment (TI) AS 4282:2019	TI is the measure of disability glare expressed as the percentage increase in contrast required between an object and its background for it to be seen equally well with a source of glare present. Higher TI values correspond to greater disability glare.

1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Bomen Solar Farm Pty Ltd, as Trustee for Bomen Solar Farm Trust, to carry out a Reflective Glare Assessment of Bomen Solar Farm (SF). The facility is located several kms to the northeast of Bomen, NSW.

The following potential glare conditions have been considered:

- Daytime Reflective glare (and glint) arising from the solar PV panels within the facility.

1.1 Structure of Report

The remainder of this report is structured as follows:

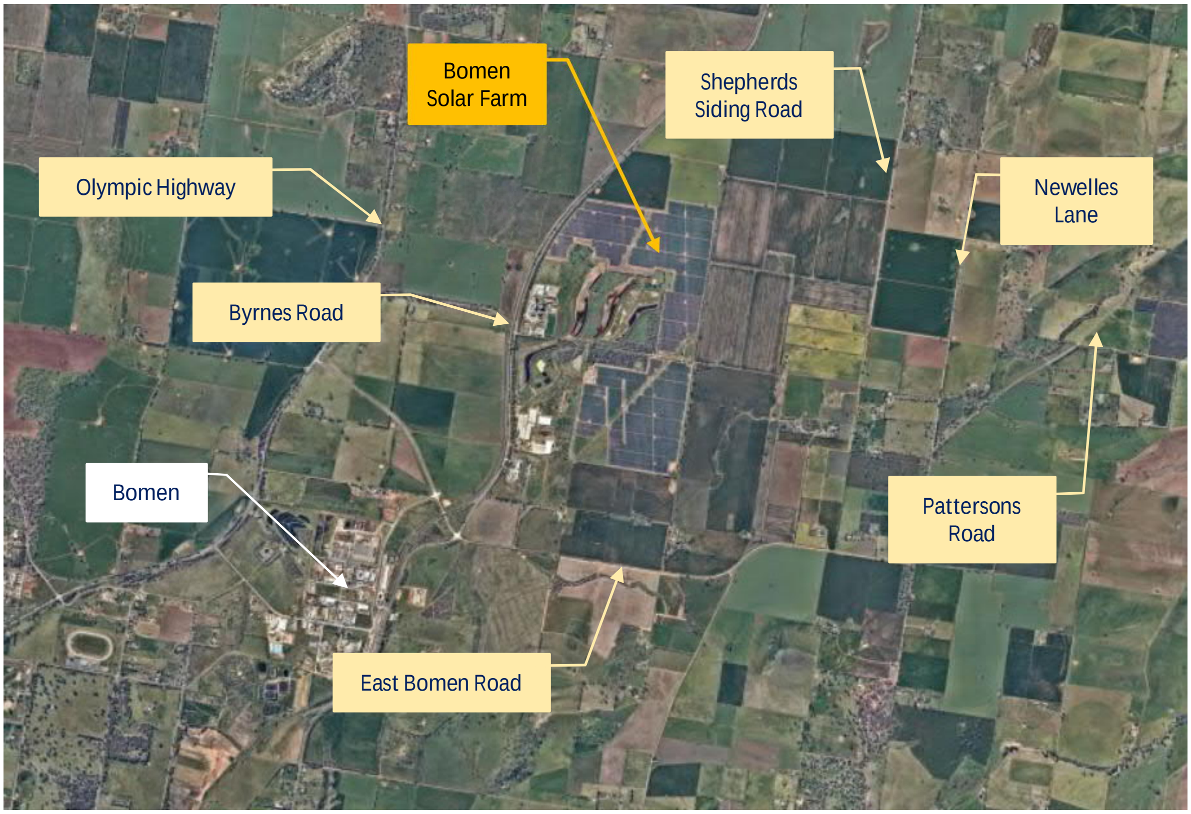
- Section 2 describes Bomen SF and the surrounding environment;
- Section 3 describes the range of receivers surrounding the site with the potential to experience adverse reflective glare;
- Section 4 presents the acceptability criteria used for the study;
- Section 5 addresses the assumptions made in the glare impact analysis;
- Section 6 presents a discussion of solar farm tracking modes of operation
- Section 7 presents the results of the glare impact analysis; and
- Section 8 presents the conclusions of the study.

2 BOMEN SOLAR FARM (SF)

2.1 Facility Location

Bomen SF comprises a 100 MWac solar facility. The perimeter of the facility ranges from 2.5 km to 5 km to the centre of Bomen, NSW – refer Figure 1.

Figure 1 Bomen Solar Farm - Location Map



2.2 Site Description and Key Project Components

From a Reflective Glare point of view, the key components of the Project are:

- the photovoltaic (PV) modules in relation to their daytime reflective glare potential

Facility Solar Array – refer Figure 2

Bomen SF comprises:

- A 100 MWac solar facility;
- Jinko Swan Bifacial HC 72m 380-390W photovoltaic (PV) panels, measuring approximately 2.0 m by 1.0 m;
- The panels are mounted on single-axis ±60° tracking structures which are aligned in a north-south direction and spaced 4.8 m apart.
- Elevations vary throughout the facility, generally rising towards the north and to the west.
- The nearest major thoroughfare is Byrnes Road to the west.

Figure 2 Bomen SF Layout and Selected Elevation Above Mean Sea Level RLs

Solar Panels & Trackers – refer Figure 3

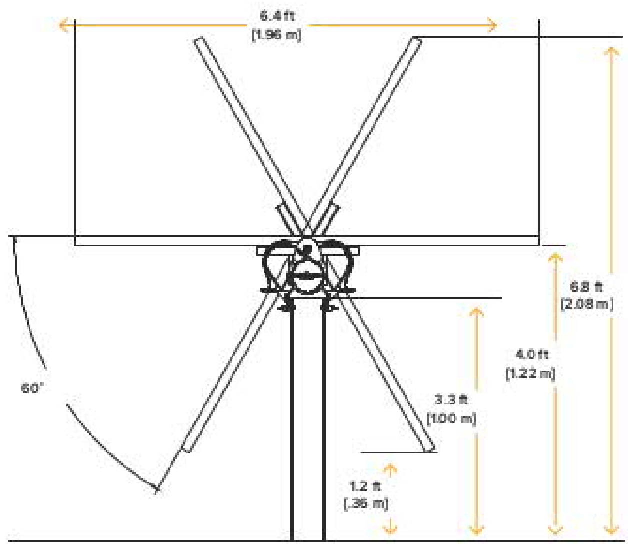
As noted above, the facility incorporates:

- Jinko Swan Bifacial HC 72m 380-390W photovoltaic (PV) panels, measuring approximately 2.0 m by 1.0 m;
- The panels are mounted on single-axis ±60° tracking structures which are aligned in a north-south direction and spaced 4.8 m apart.

Figure 3 Solar Panel and Tracking System Details

(a)
Jinko
Bifacial Panels

(b)
Single-Axis
Tracker Profile
(±60° **Tilt)**

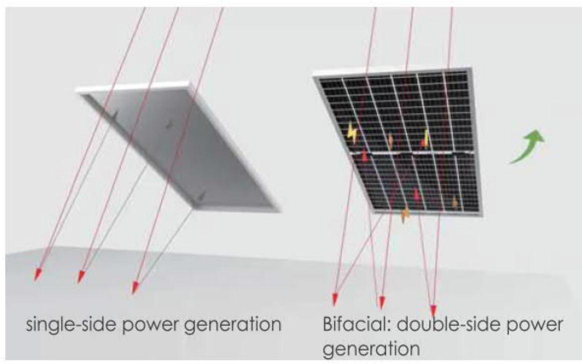


Solar Panels Characteristics – refer Figures 4-6

From a reflection point of view, the facility's bifacial panels have the ability to absorb (and reflect) incoming solar rays from both sides of the panel – refer Figure 4.

- Reflections off the "top" side of the panel (ie the side facing the sun) are assumed to be "specular" in nature, ie they respond to "direct" sunlight with an angle of reflection relative to the panel equal to the angle of incoming solar ray.
- Reflections off the "bottom" side of the panel (ie the side shielded from the sun) behave in a more "diffuse" manner as they respond to "indirect" sunlight coming from all directions – the reflections they create are also directed in all directions.

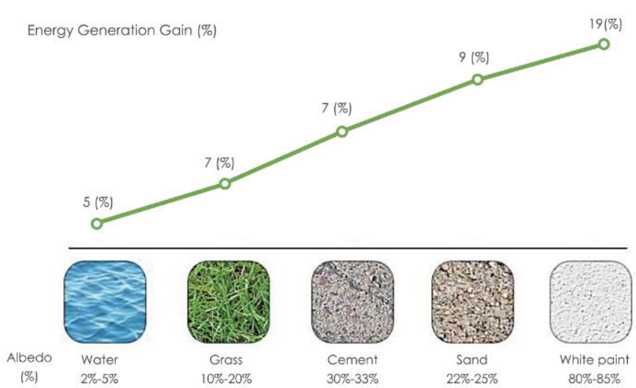
Figure 4 Bifacial Solar Panel Characteristics



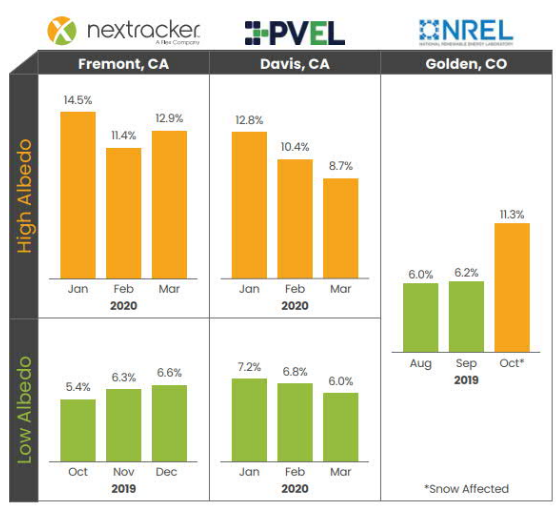
The "indirect/diffuse" nature of the "underside" of bifacial panels explains why the solar energy gain of such panels varies from between 5% to over 15% depending upon the albedo characteristics of the ground surface below the panels – refer Figure 5.

Figure 5 Solar Panel Energy Gain for Bifacial Panels

Typical Expected Gain versus Albedo



Actual Field Measurements (US Data)

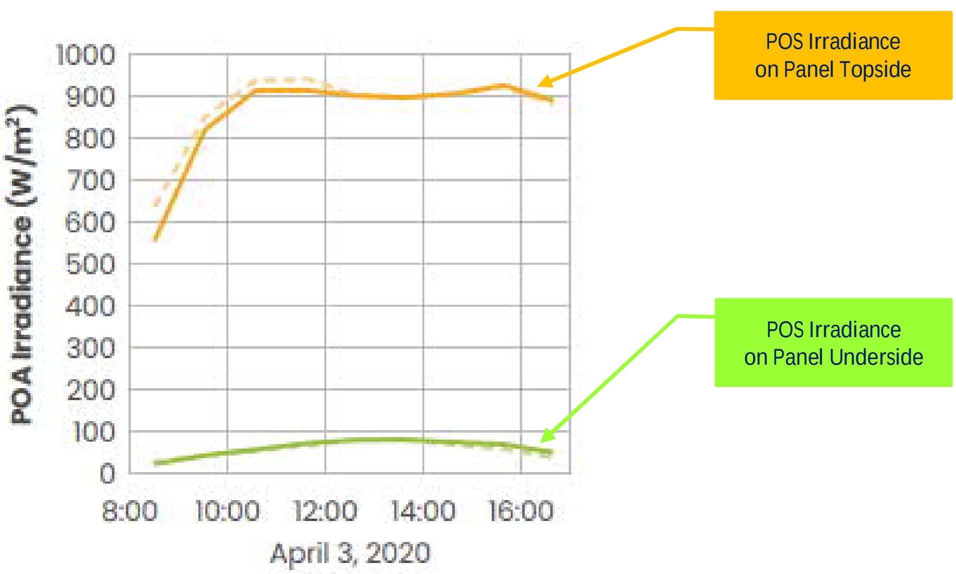


Magnitude of Reflections from Bifacial Panel Underside versus Topside

Figure 6 compares the POA (plane-of-array) irradiance levels measured at a mid-latitude US test facility on the front and back sides of a bifacial panel. The measurements were made on an average sunny day, with midday solar irradiance values of over 900 W/m^2. The POA data is the spatial average irradiance calculated from multiple sensors positioned on both sides of the panels.

- Importantly it can be seen that the W/m^2 "seen" by the underside of the bifacial panel is roughly 10 times lower than the topside.
- Moreover, the irradiance seen by the underside of the panel is "indirect" (refer Figure 4), ie arising from many directions.

Figure 6 Field Data Comparison of POA Irradiance of a Jinko Bifacial Panel



The above shows that the magnitude of reflections generated by the underside of a bifacial panel will be much more than 10 times lower compared to the levels being generated by the topside.

3 NEAREST RECEIVERS

3.1 Impacts of Interest

The issue of interest in relation to daytime reflective glare is:

- Residential Daytime "Nuisance" Glare on surrounding residential receivers;

3.2 Nearest Residential Receivers

The receivers analysed in this assessment include all residential receivers within 3 km of Bomen SF to the east and south and one additional residential receiver located approximately 4 km to the east (22 in total). Residential receivers to the west and north of the solar farm were not included in the assessment as they do not have views of the solar farm due to the intervening topography and landscape features.

The residential receivers analysed in the present assessment are shown in Figure 8. Their position relative to Bomen SF varies from northeast (NE) to south (S).

Figure 7 Nearest Residential Receivers Analysed in the Present Study

4 GLARE ACCEPTABILITY CRITERIA

In relation to daytime reflective glare impact, the Project contains the following elements of interest:

- PV modules using solar panels on the Project ground array

4.1 Residential "Nuisance" Glare

Instances of documented nuisance glare associated with solar PV panels (grid-scale, industrial or residential) and nearby residential receivers have been relatively infrequent globally, especially given the widespread and rapid increase in the take-up of residential solar panels in Australia and elsewhere.

> There are currently no national or state guidelines in Australia
> governing the acceptability or otherwise of residential nuisance glare specific to solar PV.

Existing guidance that exists in relation to solar panels from state governments typically covers installation audits and compliance checks. Additional guidance in relation to compliance with Australia Standards is provided by:

Clean Energy Council
Website: https://www.cleanenergycouncil.org.au/industry/products/modules

Accordingly, to assist in addressing residential nuisance glare, reference has been made of the concepts used for glare acceptability criteria outlined in the following sections.

4.2 Aviation Sector Reflective Glare

Note: although the present assessment has not assessed any potential glare impact on surrounding aviation operations, the criteria used for such assessments are of interest.

US FAA

In relation to the potential impact of solar PV systems on aviation activity, guidance is available from the US FAA which regulates and oversees all aspects of American civil aviation. On the basis of the above and other technical R&D references, the FAA issued a Technical Guidance Policy in 2010 and a subsequent (and over-riding) Interim Policy in 2013. The Technical Guidance Policy was updated in 2018.

- FAA, "Technical Guidance for Evaluating Selected Solar Technologies on Airports", Federal Aviation Administration, Washington, D.C., November 2010.
- FAA, "Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports", Federal Register, Oct. 23, 2013.
- FAA, "Technical Guidance for Evaluating Selected Solar Technologies on Airports", Federal Aviation Administration, Washington, D.C., Version 1.1, April 2018.

In support of the above, the FAA contracted Sandia Labs to develop their Solar Glare Hazard Analysis Tool (SGHAT) software as the standard tool for measuring the potential ocular impact of any proposed solar facility on a federally obligated airport. SGHAT utilises the Solar Glare Ocular Hazard Plot to determine and assess the potential for glare.

SGHAT is described in the following references:

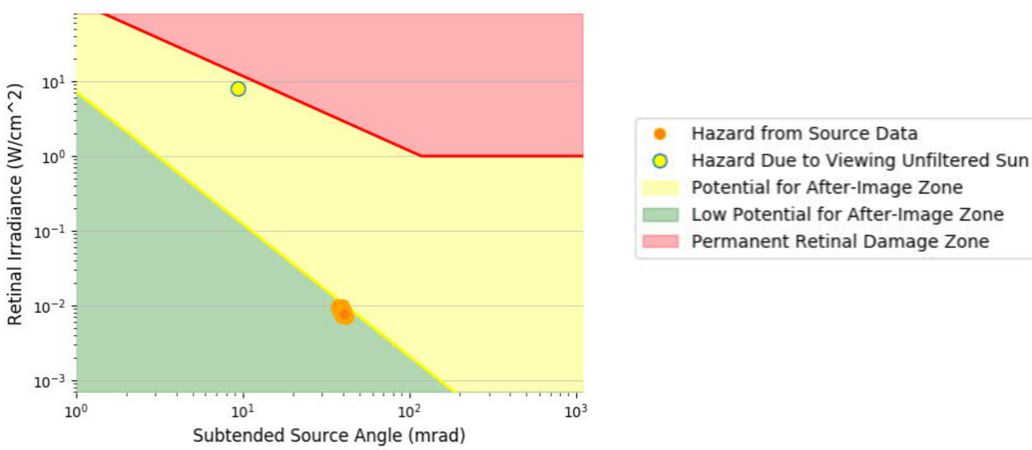
- Ho, C.K., Ghanbari, C.M. and Diver, R.B., "Methodology to Assess Potential Glint and Glare Hazards from Concentrating Solar Power Plants: Analytical Models and Experimental Validation", J. Solar Engineering, August 2011, Vol.133, 031021-1 to 031021-9.
- Ho, C.K. & Sims, C., "Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v2.0", Sandia National Laboratories, Albuquerque, NM. August 2013.

A sample Solar Glare Ocular Hazard Plot is shown in Figure 8. The analysis contained in this plot is derived from solar simulations that extend over the ENTIRE CALENDAR YEAR in 1-MINUTE intervals, sunrise to sunset.

The SGHAT criteria state that a proposed solar facility should satisfy the following:

- Airport Traffic Control Tower (ATCT) cab: NO Glare
- Final approach paths for landing aircraft: Glare to NOT exceed "Low Potential for After-Image"

Figure 8 Example Solar Glare Ocular Hazard Plot (SGHAT Software Output)



In Figure 8, the following is noted:

- SGHAT ocular impact is a function of both the "retinal irradiance" (ie the light seen by the eye) and "subtended source angle" (ie how wide an arc of view the light appears to be arriving from).
- SGHAT ocular impact falls into three categories:
  - GREEN: low potential to cause "after-image"
  - YELLOW: potential to cause temporary "after-image"
  - RED: potential to cause retinal burn (permanent eye damage)
- "After Image" is the term applied to a common retinal phenomenon that most people have experienced at some point or other, such as the effect that occurs when a photo with flash is taken in front of a person who then sees spots in front of their eyes for a few seconds. A more extreme example of "after-image" occurs when staring at the sun. "After-image" (also known as "photo bleaching") occurs because of the de-activation of the cells at the back of the eye's retina when subjected to a very bright light.

- The SGHAT plot provides an indication of the relative intensity of both the incoming reflection and the sources of light itself (ie the sun).
  . The occurrence of glare is shown in the plot as a series of orange circles,
  one circle for each minute that a reflection is visible.
  . A reference point is also shown in each SGHAT plot, the green circle,
  representing the hazard level of viewing the sun without filtering, ie staring at the sun.
- In Figure 8, it can be seen that the reflection visible by the receiver is roughly 1,000 times less intense than the light from the sun.
- Finally, in relation to PV Solar facilities, it is important to note that the third SGHAT Ocular Plot "RED" category is not possible, since PV modules DO NOT FOCUS reflected sunlight.

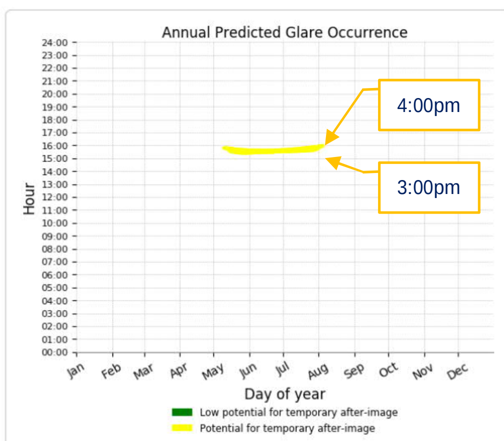
Additional Information Available with the SGHAT Analysis Tool

In addition to the above "assessment" output, the SGHAT software package also produces information which reveals the extent of visibility of reflections at any chosen receiver position, regardless of whether the reflections constitute a glare condition or not – an example is shown in Figure 9.

- Figure 9-A: shows the am/pm time periods when reflections occur at a specific position throughout the year, in this case typically between around 3:30pm and 4:00pm.
- Figure 9-B: shows the months during the year and the minutes per day when reflections occur at a specific position, in this case from early-May to the start of August.
- As noted above, this information is made possible because the SGHAT analysis covers the entire solar annual cycle in 1-minute intervals to ascertain any potential impacts on surrounding receivers.
- Finally, Figure 9-C shows WHERE within the solar farm panel array the reflection rays of interest are emanating from, in this case from panels near the southeast corner.

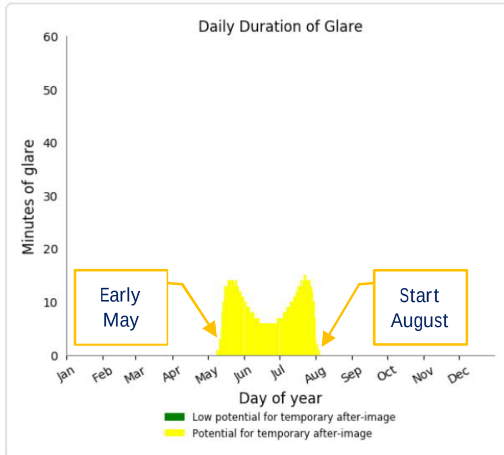
Figure 9 Example Solar Glare Output Plots (SGHAT Software Output)

A.

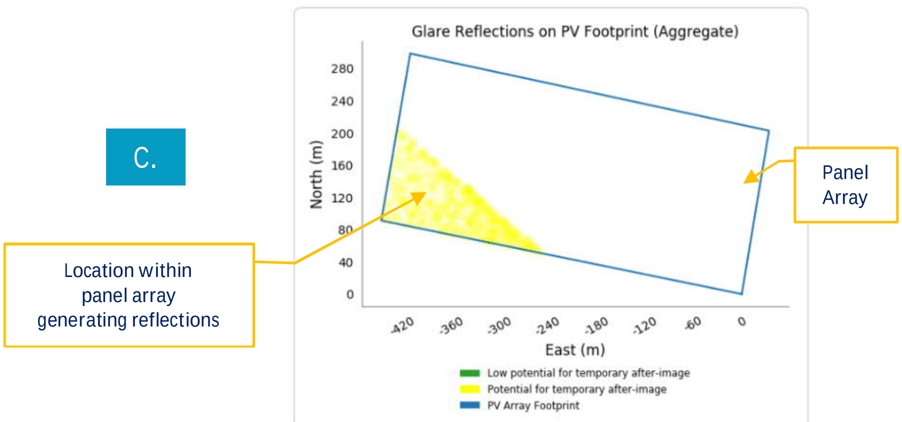


(Fig.9 cont'd)

B.



C.



4.3 Motorist "Disability" Glare and Pedestrian "Discomfort" Glare

The criteria commonly used by Australian Local Government Authorities to assess the acceptability or otherwise of potential adverse reflections from glazed façade systems onto surrounding roadways and pedestrian crossings utilise the so-called Threshold Increment (TI) Value of the reflection condition.

TI Value Definition

AS/NZS 4282:2019 defines Threshold Increment (TI) as:

> "the measure of disability glare expressed as the percentage increase in contrast required between an object and its background for it to be seen equally well with a source of glare present. Note: Higher values of TI correspond to greater disability glare."

The TI Value is calculated as the ratio of "veiling" luminance (eg from a reflection) to the overall average background ("adaptation") luminance, with the necessary constant and exponent parameters provided in AS 1158.2:2005.

The formula for calculating the TI Value is … $TI = 65 L_v / L_{tb}^{0.8}$, where:

- L_v = veiling luminance from a source of interest (eg reflection) – Cd/m^2
- L_{tb} = so-called "adaptation" luminance (total background) – Cd/m^2

TI Value Acceptability Criteria

The acceptability criteria adopted by Australian Local Government Authorities to assess the acceptability or otherwise of potential adverse reflections from glazed façade systems onto surrounding roadways and pedestrian crossings utilise the so-called Threshold Increment (TI) Value of the reflection condition (refer above for definition and calculation equations).

For (Motorist) Traffic Disability Glare, the TI Value should remain:

- Below 10 for major roads
- Below 20 for minor roads

For Pedestrian Discomfort Glare, the TI Value should remain:

- Below 2 at critical locations such as pedestrian crossings
- Below 3 for other locations

For the present study, Pedestrian Discomfort Glare is relevant to the potential for residential nuisance glare from surrounding receivers.

It should be noted that while Pedestrian Discomfort Glare can occur over a wide range of solar altitude angles, in most such instances, a pedestrian has the ability to adjust their line of sight to a more horizontal view away from the glare source, thereby rendering TI values essentially negligible.

5 GLARE IMPACT ASSESSMENT - ASSUMPTIONS

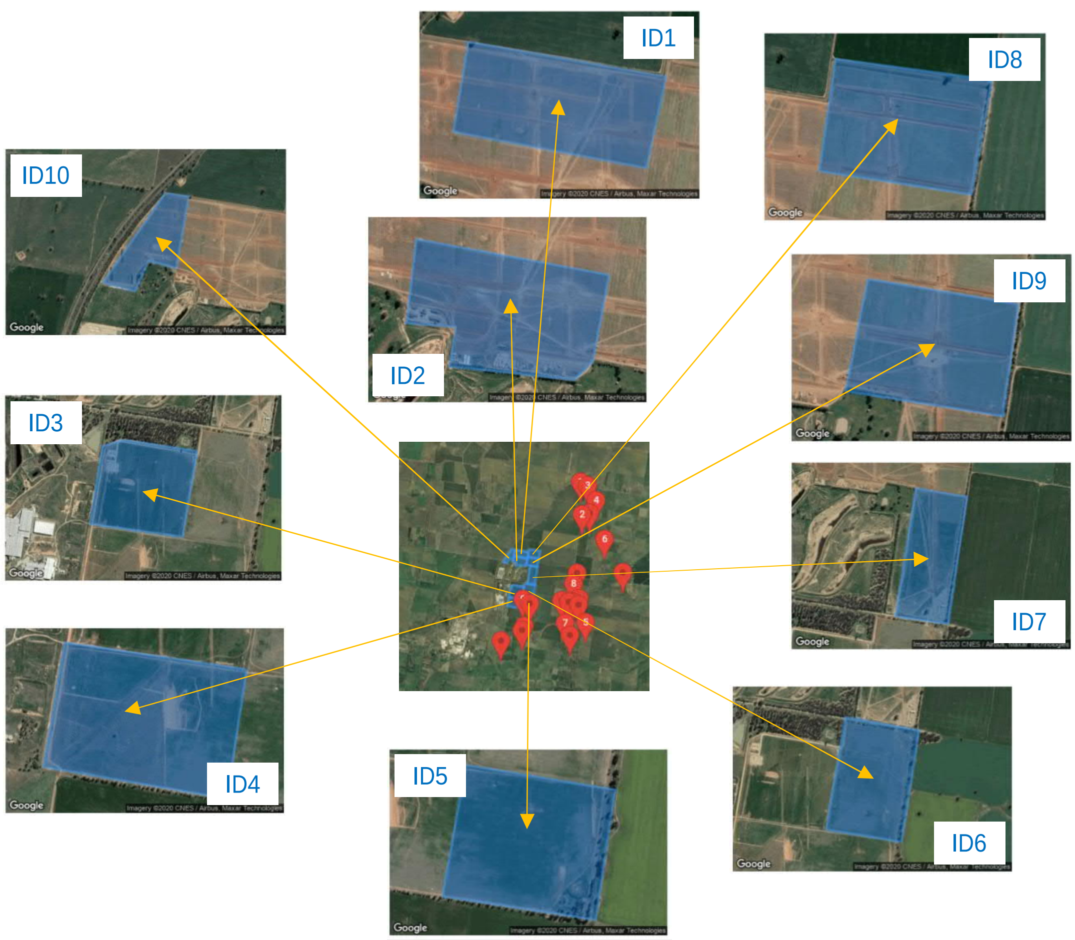
5.1 Assumptions – Solar Panel Geometry

The glare assessment discussed in detail in following sections is based on the following assumptions:

- The solar panel array trackers are "single-axis" capable of rotating solar panels to a maximum of ±60°;
- The trackers are oriented north-south and spaced 4.8 m apart; and
- Individual panels (2.0 m x 1.0 m) reach a maximum height above ground of around 2.5 m at their full 60° tilt angle.

Due to the irregular shape of Bomen SF's footprint, and the variation in elevation in different parts of the facility (ranging from just below RL200 to around RL250, south to north and east to west), the facility was divided into 10 segments for the subsequent analysis - these are shown in Figure 10.

Figure 10 Bomen Solar Farm Analysis Segments – Panel Array ID Identifiers



5.2 Receivers

The location (long, lat) and elevation above mean sea level (RL) of the receivers assessed in the present study (refer Figure 5) are detailed in Table 1. In SGHAT, receivers are denoted "Op" (observation points).

Table 1 Receiver Positions (Lat-Long)

Receiver ID	SGHAT ID	Longitude (deg)	Latitude (deg)	RL (m)
R57	Op-1	147.47048839100	-35.01702425500	270.6
R60	Op-2	147.47099321600	-35.02972871500	258.1
R64	Op-3	147.47384283800	-35.01838767600	275.7
R69	Op-4	147.47814274300	-35.02415924200	305.3
R133	Op-5	147.47263355200	-35.07318345400	217.4
R76	Op-6	147.48131107000	-35.03998982800	272.7
R132	Op-7	147.46287396600	-35.07295476500	203.2
R19	Op-8	147.46720555800	-35.05746083100	216.2
R08	Op-9	147.44279197100	-35.06373908600	203.6
R18	Op-10	147.46855679700	-35.05320818400	216.6
R09	Op-11	147.44623049100	-35.06568617800	195.7
R11	Op-12	147.44189836000	-35.07607673100	188.0
R10	Op-13	147.44266812200	-35.07446620630	193.5
R114	Op-14	147.43160080400	-35.08100175500	229.0
R131	Op-15	147.46950279300	-35.06607495040	220.8
R20	Op-16	147.46106325000	-35.06444834100	216.7
R128	Op-17	147.46427263400	-35.06492825100	220.0
R129	Op-18	147.46611069300	-35.06485089500	220.9
R134	Op-19	147.46536749600	-35.07788641300	194.7
R127	Op-20	147.47435019000	-35.02975378950	282.4
R130	Op-21	147.46933968600	-35.06348694480	223.4
R140	Op-22	147.49110407700	-35.05291452040	275.0

5.3 Project Site Solar Angles – Annual Variations

One of the challenging issues encountered with daytime solar panel glare is the varying nature of the reflections, whose duration will vary with time of day and day of the year as the sun's rays follow variable incoming angles between the two extremes of:

- summer solstice - sunrise incoming rays from just south of east, maximum angle altitude rays at midday, sunset incoming rays from just south of west
- winter solstice - sunrise incoming rays from the northeast, minimum angle altitude rays at midday, sunset incoming rays from the northwest

Any solar glare analysis should consider the complete cycle of annual reflection variations noted above.

The potential range of incoming solar angles at the Project site relevant to daytime glare is shown in Figure 11 with relevant critical angles summarised in Table 2.

Figure 11 Project Site Incoming Solar Angle Variations

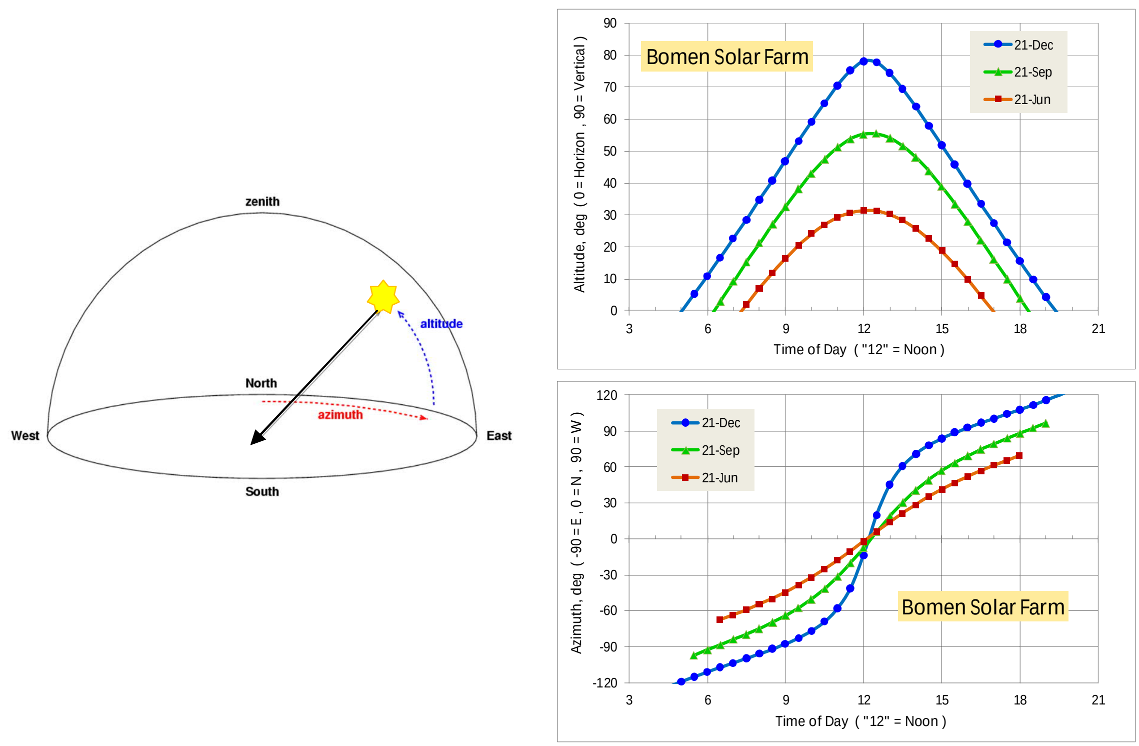


Table 2 Key Annual Solar Angle Characteristics for Project Site

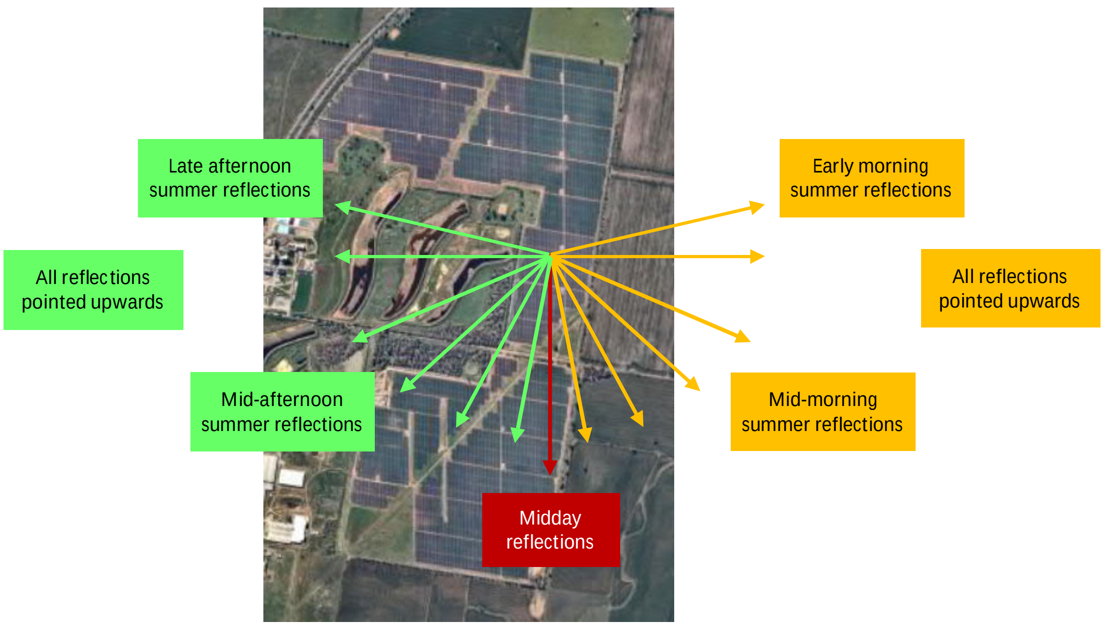
Day of Year	Sunrise	Sunset	Azimuth Range (sunrise-sunset)	Max Altitude
Summer Solstice	5:02 am	7:23 pm	119° E of North to 119° W of North	78.1°
Equinox	6:16 am	6:10 pm	91° E of North to 91° W of North	55.4°
Winter Solstice	7:20 am	4:59 pm	61° E of North to 61° W of North	31.5°

5.4 Project Solar Reflections

The project uses single-axis tracking panels (with a north-south axis of rotation) as described in Section 2.2. In "plan" view, reflections from the project's panels will be directed as shown in Figure 12 for a representative area of panels, with the direction of reflected rays shown for typical mid-summer days.

As a result of the tracking motion of the solar panels throughout the day, reflections will generally be directed upwards and hence not visible by ground-based receivers at a similar elevation. Where such reflections can be observed by surrounding elevated receivers they would generally be seen as "low incidence" reflections with corresponding low reflectivity. This is the inevitable outcome of the objective of maximising the solar gain of each panel (where the reflectivity would ideally be minimal) and justifying the additional cost of using a tracking system for the panels which follows the sun, rather than a fixed panel system.

Figure 12 Potential Solar PV Panel Reflection Angles from the Project (typical mid-summer)



5.5 Solar Panel Reflectivity

Solar PV panels are designed to capture (absorb) the maximum possible amount of light within the layers below the front (external) surface. Consequently, solar PV panels are designed to minimise reflections off the surface of each panel. Reflections are a function of:

- the angle at which the light is incident onto the panel (which will vary depending on the specific location, time of day and day of the year), and
- the index of refraction of the front surface of the panel and associated degree of diffuse (non-directional) versus specular (directional or mirror-like) reflection which is a function of surface texture of the front module (reflecting) surface.

Some typical reflectivity values (given in terms of the “n” refractive index value) are:

- Snow (fresh, flaky) n = 1.98
- Standard Window Glass n = 1.52
- Plexiglass, Perspex n = 1.50
- Solar Glass n = 1.33
- Solar Glass with AR Coating n = 1.25

Standard PV Solar Panels

Representative reflectivity curves are shown in Figure 13.

Figure 13 Typical Reflectivity Curves as a Function of Incidence Angle

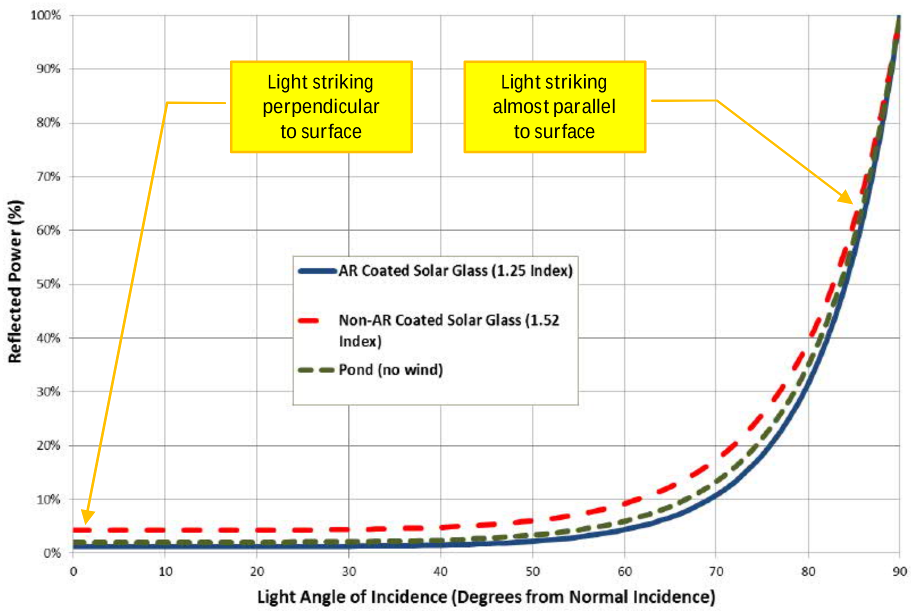


Figure 13 shows that:

- When an oncoming solar ray strikes the surface of a solar PV panel close to perpendicular to the panel surface (i.e. low “incident” angle), the reflectivity percentage is minimal (less than 5% for all solar panel surface types).
- It is only when an incoming solar ray strikes the panel at a large “incidence” angle, i.e. close to parallel to the panel, that reflectivity values increase. When this happens, reflections can become noticeable and potentially at “glare” level for all solar panel surface types.
- However, for very high incidence angle, it would almost always be the case that an observer would perceive reflections coming from virtually the same direction as the incoming solar rays themselves. Such a condition would not constitute a glare situation as the intensity of the incoming solar ray itself (ie the sun) would dominate the field of vision perceived by the observer.

6 SOLAR FARM OPERATIONAL MODES

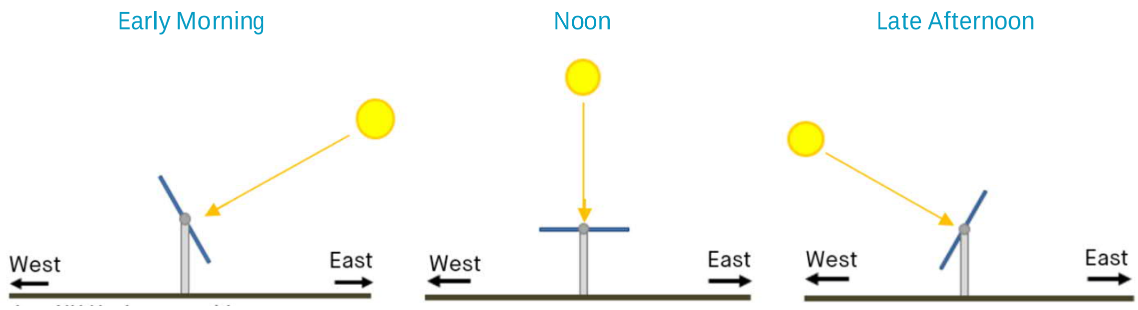
Solar Farm operations have evolved considerably over the past several decades. The first grid-scale solar facilities utilised PV modules that would typically be fixed, with a tilt angle towards the north (for southern hemisphere facilities). Subsequently, tracking systems were developed, involving either single-axis trackers and even dual-axis trackers, designed to maximise the absorption of solar rays throughout the day.

6.1 "Normal Tracking" Operational Mode

Figure 14 shows a simplified solar facility operation with a single-axis tracking system that consists of panels moving from an eastwards tilt position in the morning to a westwards tilt position in the afternoon.

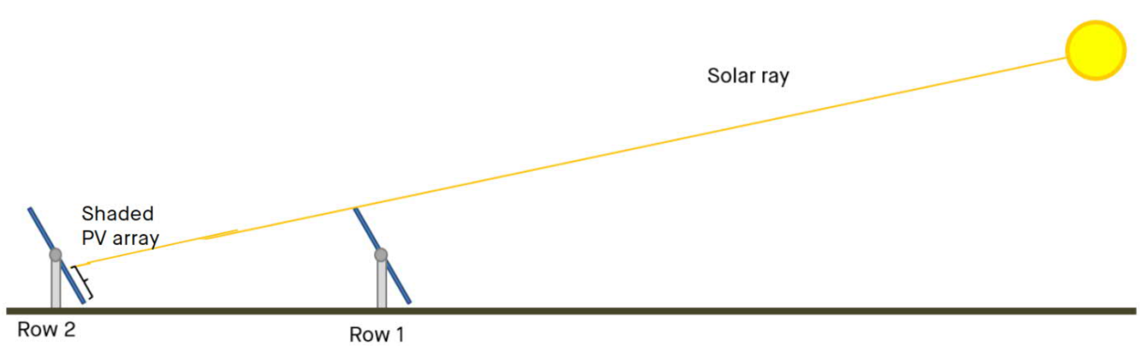
- At sunrise, panels are at their maximum eastwards tilt position (eg 60°East);
- They start tracking the sun once the solar altitude angle reaches 30° (to the east);
- Panels then follow the sun during the day until they reach their maximum westwards tilt position (eg 60°West); and
- They remain at that maximum westwards tilt position till sunset.

Figure 14 Single-Axis Tracking System – "Normal Tracking" Mode



The "normal tracking" mode shown in Figure 14 however encounters a "sheltering" issue in solar panel arrays as shown in Figure 15. It can be seen that at low altitude angles (just after sunrise and just before sunset) a row of panels can partially shade the row behind it. This adversely impacts the yield of the entire facility.

Figure 15 Solar Panel Array Sheltering Effect at Low Solar Altitude Angles

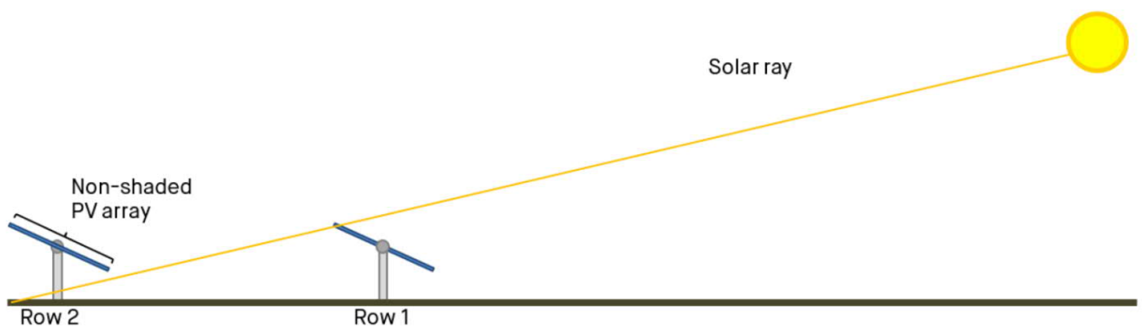


6.2 "Back-Tracking" Operational Mode

To avoid the sheltering effect shown in Figure 15, sophisticated "back-tracking" operational modes have been developed, typically by the manufacturers of the tracking systems that support solar panels.

- Algorithms are developed (usually fine-tuned during the commissioning stage of a solar facility) aimed at minimising inter-row shading. These algorithms are based on the location of a solar facility (ie its latitude), topography, panel row spacing, etc.
- They typically involve positioning panels in the early morning and late afternoon in a more horizontal position that "just" avoids inter-row shading – refer example Figure 16.
- During these early morning and late afternoon periods, panel motion is referred to as being in "back-tracking" mode;
- During the remaining hours in the middle of the day, solar panels follow the simplified "normal tracking" mode, ie moving between their maximum (±60°) tilt positions;
- There is typically a transition period between the two tracking modes (say 15-20 minutes), calculated according to the local site tracking system algorithms.

Figure 16 Solar Panel Positioning in "Back-Tracking" Mode – Used to Avoid Inter-Row Shading



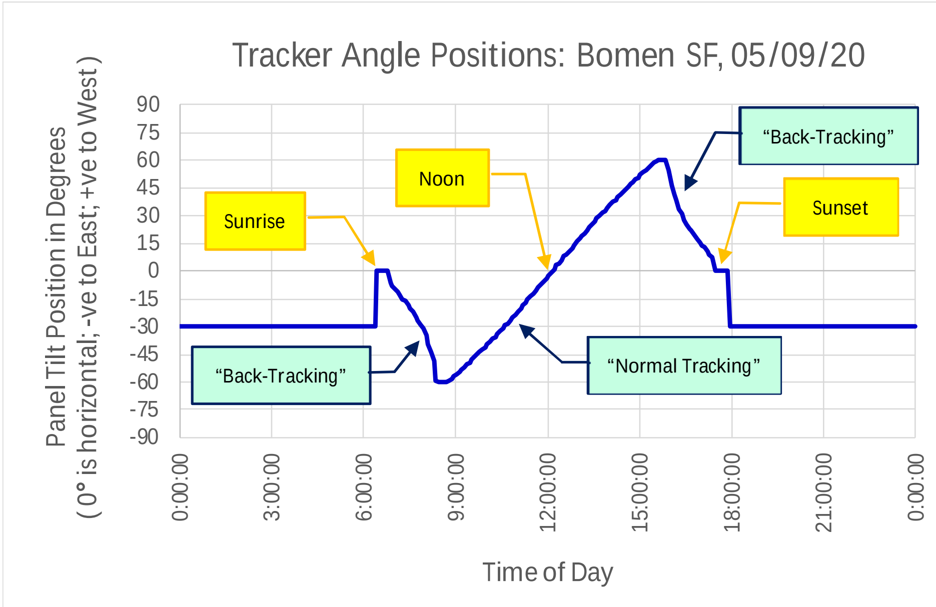
"Back-Tracking" Operational Mode Example

A real-world example of a "back-tracking" mode is shown in Figure 17.

In fact, this example shows the <u>actual</u> solar panel tilt positions at Bomen SF on 5 September 2020.

- The sun reaches an altitude angle of 30 in the morning at around 8:30am and again in the afternoon at around 3:45pm. During these hours (ie between around 8:30am and 3:45pm), the panels operate in "normal tracking" mode, ie from -60° facing East to +60° facing West;
- From sunrise till 8:30am and from 3:45pm to sunset, the panels operate in "back-tracking" mode, starting at sunrise and ending at sunset in a horizontal position;
- Overnight, the panels are "stowed" in a fixed (-30°) position to minimise wind loading and ensure any moisture (dew or rain) does not pool on the panel overnight and cause increased soiling.

Figure 17 Example 24-Hour “Back-Tracking” Operational Mode – Bomen SF, 5 September 2020



The tracking pattern shown in Figure 17 will vary throughout the year, continuously adapting to the annual cycle solar positions shown in Figure 11. However, the key elements remain the same:

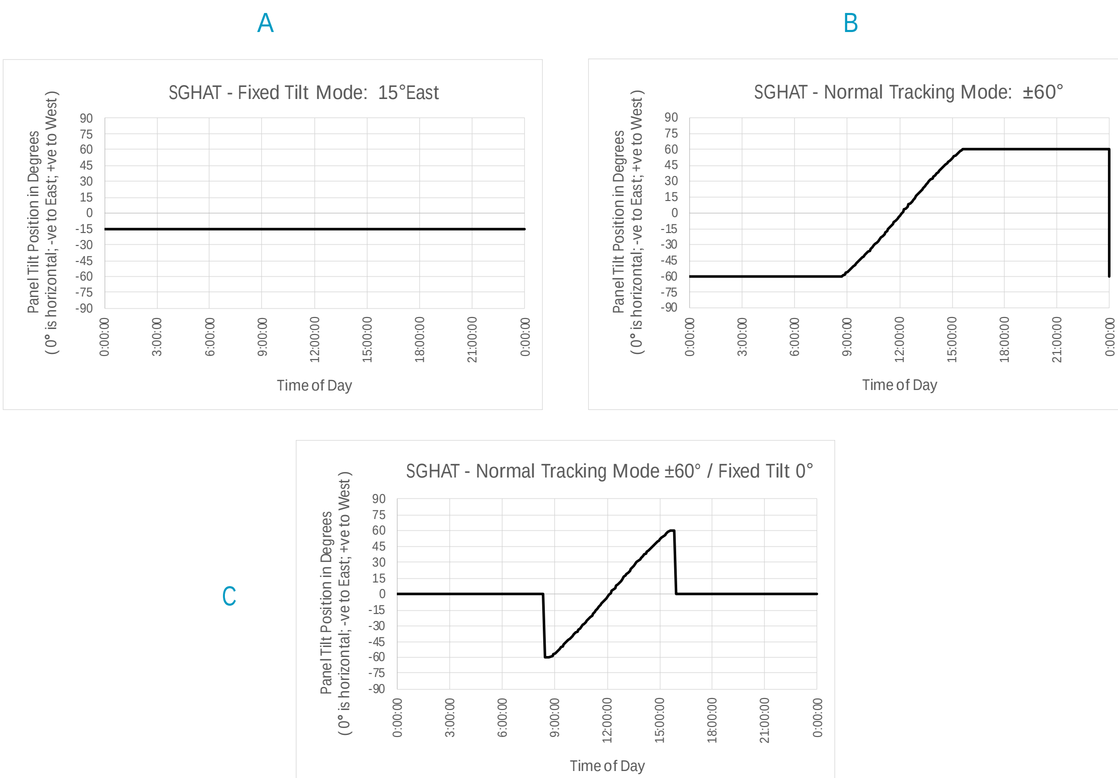
- During the night, panels are “stowed” in a fixed position (in the above case, at -30°), moving to a horizontal position at sunrise;
- From sunrise till around the time when the solar altitude angle reaches 30° (to the east), panels are in “back-tracking” mode slowly moving from a horizontal position to facing 60°East, all the time minimising inter-row shading;
- Panels then operate in “normal tracking” mode, following the sun from 60°East to 60°West;
- During the latter part of the day, once the solar altitude angle drops below 30° to the west, panels again operate in “back-tracking” mode, ending in a horizontal position just before sunset;
- Soon after sunset, the panels move to their overnight “stowed” position.

6.3 Modelling Real-World "Back-Tracking" Operational Modes

Currently available reflectivity software analysis tools, eg SGHAT, have not evolved yet to deal with sophisticated "back-tracking" operational modes of the type shown in Figure 17. They typically simulate solar farm panel positions in one of three simplified modes:

- Fixed Tilt Mode: in this mode, all panels are assumed to remain at a fixed angle all day long, eg horizontal, 15°East, 10°West, etc – refer Figure 18-A;
- Normal Tracking Mode: in this mode, panels move between maximum tilt angles once the sun is above the relevant altitude angle (eg an altitude angle of 30° for ±60° single-axis trackers). They remain at the maximum tilt angles at all other times, switching over during the night – refer Figure 18-B;
- Normal Tracking Mode / Fixed Tilt Stowed: in this mode, panels move during the day in "normal tracking": mode, but can then move (instantaneously) to any user-defined fixed tilt angle at all other times – refer Figure 18-C where the panels move to a horizontal position outside of "normal tracking" hours.

Figure 18 SGHAT Panel Mode Simulation Options



It will be appreciated that care must be taken when comparing the glare predictions of simplified SGHAT-type simulation modes, such as those shown in Figure 18, with the real-world reflectivity behaviour of operational panel modes as shown in Figure 17.

7 GLARE IMPACT ASSESSMENT

7.1 Analysis Scenarios

To assist in assessing the potential for residence nuisance glare from Bomen SF, a number of scenarios were simulated – as described in Table 3. Note that in these scenarios, the topography of the site is taken into account, but no shielding from any intervening terrain features, eg trees, vegetation, etc.

Table 3 Operational Mode Simulation Scenarios

Simulation Name	Description
SIM-1 SGHAT Normal Tracking / Instantaneous Back-Tracking to Fixed Tilt 0° Refer Figure 19-A Section 7.2	This is the closest mode available in SGHAT to the actual operational mode at Bomen SF: • The start point for all panels at sunrise is horizontal; • Once the solar altitude angle reaches 30° to the east, the panels instantaneously move to a 60°East position and start tracking the sun throughout the day until the panels reach 60° facing west; • Panels then "back-track" instantaneously to a horizontal position and remain horizontal till sunset; • Panels remain in a horizontal position in time for sunrise the next day.
SIM-2 SGHAT Normal Tracking ONLY Refer Figure 19-B Section 7.3	This mode is a simplified "normal tracking" mode: • It is the same as the mode described above, except that, once the panels reach 60° facing west, they remain in that position until sunset; • During the night, panels move back to their start point, ie 60° facing east, in time for sunrise the next day.
SIM-3 SGHAT "Equivalent" Bifacial Underside Panel Mode" FIXED – Tilted 15degE Roughened Panel Surface Refer Figure 19-C Section 7.4	This is a hypothetical scenario aimed at simulating potential reflections from the underside panels of the facility. In this mode, all panels fixed all day long in a tilted position, 15° from the vertical facing east. In this position, the upper reflecting surface of the panels is able to produce reflections towards the east similar to the way that the underside surface of the bifacial panels would produce reflections when the topside is facing westwards (by the same angle). It is important to note however, that the intensity of the reflections simulated in this scenario would be 10-100 times lower than the actual reflections given the diffuse nature of the characteristics of the underside of the panels – refer Section 2.2. Accordingly, to account for the diffuse nature of the reflections from the bifacial panel underside surface, the panels in this scenario are modelled as being "roughened" so they generate diffuse-like reflections. Finally, the duration of reflections generated in this simulation mode over-estimates the actual duration of any potential underside reflections as panels are always in some form of tracking mode during actual operations.
SIM-4 FIXED Tilt 5degW Refer Figure 19-D Section 7.5	This is a hypothetical scenario whereby all panels throughout the entire facility are left fixed with a tilt angle of 5° west.
SIM-5 FIXED Tilt 20degE Refer Figure 19-E Section 7.6	This is a hypothetical scenario whereby all panels throughout the entire facility are left fixed with a tilt angle of 20° east. It is similar to SIM-3 (slightly different tilt angle), however the panels are assumed to have normal smooth (ie specular) solar glazing.

Figure 19 Glare Analysis Simulation Modes

7.2 Results SIM-1

Overall Summary (SGHAT)

A summary of the SIM-1 SGHAT results is shown in Table 4 showing the number of minutes/day that solar panel reflections are potentially visible AT ANY RECEIVER during the "worst-case" month within any relevant SGHAT "colour zone" – refer Figure 8.

The SGHAT analysis suggests that reflections from somewhere within the facility may be visible to receivers surrounding the site at some point in the year.

Table 4 SGHAT Analysis Results – SIM-1

Bomen SF Panel Array Segment ID	SGHAT Panel Array Name	"SIM-1" Minutes/Day that Reflections are Visible at ANY Receiver
1	PV Array 10	0 - 15 min
2	PV Array 11	0 - 12 min
3	PV Array 2	0 - 14 min
4	PV Array 3	0 - 16 min
5	PV Array 4	0 - 15 min
6	PV Array 5	0 - 16 min
7	PV Array 6	0 - 6 min
8	PV Array 7	0 - 11 min
9	PV Array 8	0 - 8 min
10	PV Array 9	0 - 16 min

Detailed SGHAT Array Segment versus Receiver Results

Table 5 provides greater detail regarding the specific panel arrays of Bomen SF where reflections are visible at specific receivers. The SGHAT output suggests that:

- Reflections will not be visible at any time of the year from any of the panels within the facility for Receivers 8, 9, 10, 11, 57, 114, 132 and 134. These receivers are all located to the south to southeast of the facility.
- The remaining receivers are able to perceive reflections at different times of the year from different areas of the facility (depending upon time of the year).

Table 5 SGHAT Analysis Detailed Results – SIM-1

Receptor	No of Minutes per Annum that Reflections from Bomen SF are Visible from the following Bomen SF Panel Arrays									
	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	ID9	ID10
R57										
R60	567	593					5	281	130	130
R64	10									31
R69	1240	782						831	48	493
R133			46	810	662					
R76	363	429	1117	1270	866	1564	225	398	168	169
R132										
R19			588	550	775	1369	290			
R08										
R18	45	718	598	580	833	917				
R09										
R11										
R10										
R114										
R131			793	712	1193	969				
R20			562	1213	1671	414				
R128			738	981	1691	796				
R129			927	769	1412	928				
R134										
R127	623	1034					2	911	91	291
R130			1120	580	879	1375				
R140	385	373	519	535	527	647	278	562	254	204

Representative Results

Figure 20 shows three representative reflection conditions occurring at different times of the year:

Receiver R76 (Op6) / Panel Array ID3

- Reflections are visible around the equinox periods between around 6:00pm and 6:30pm
- During this period, reflections are visible for up to 12 minutes each day

Receiver R129 (Op18) / Panel Array ID5

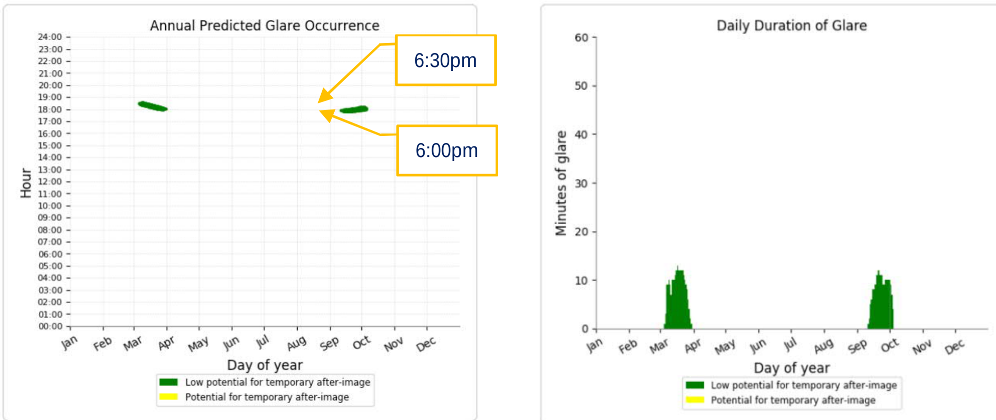
- Reflections are visible around the winter solstice between around 5:00pm and 6:00pm
- During this period, reflections are visible between 5 to 13 minutes each day

Receiver R699 (Op4) / Panel Array ID8

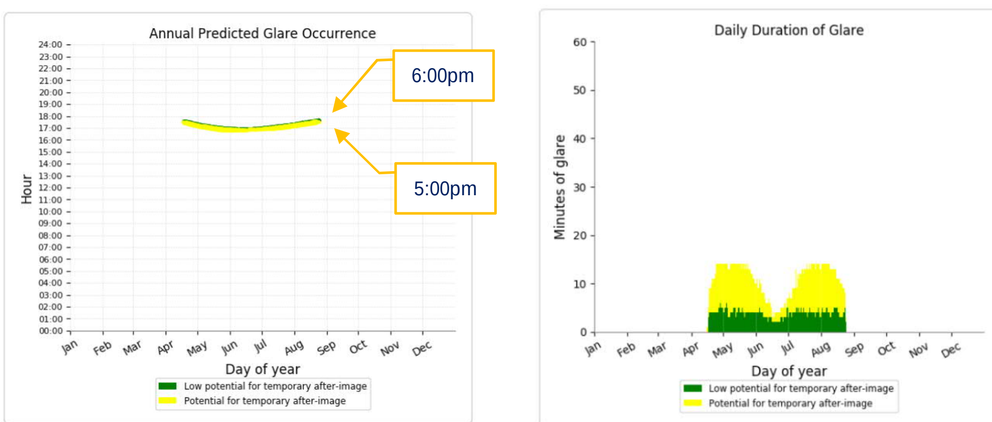
- Reflections are visible around the summer solstice between around 7:00pm and 7:30pm
- During this period, reflections are visible for up to 15 minutes each day

Figure 20 Selected SGHAT Results: Standard Operational Back-Tracking Mode

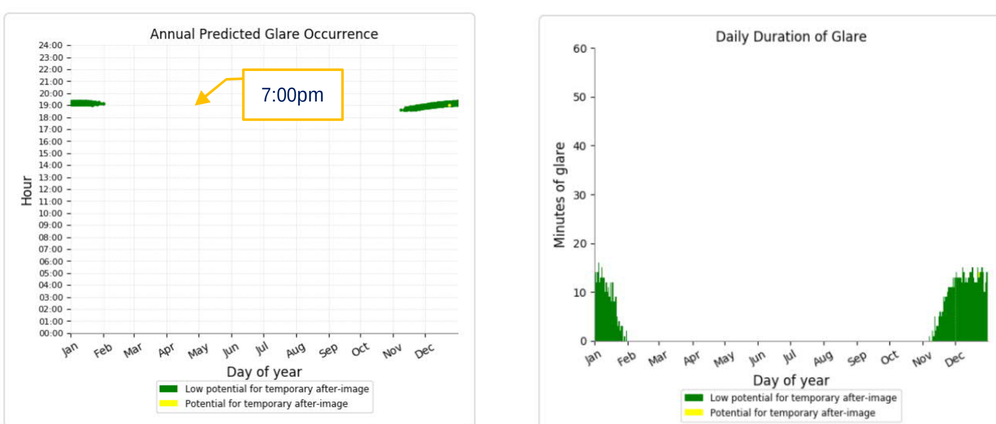
Receiver R76 (Op6) / Panel Array ID3



Receiver R129 (Op18) / Panel Array ID5



Receiver R69 (Op4) / Panel Array ID8



SIM-1 Overall Trends

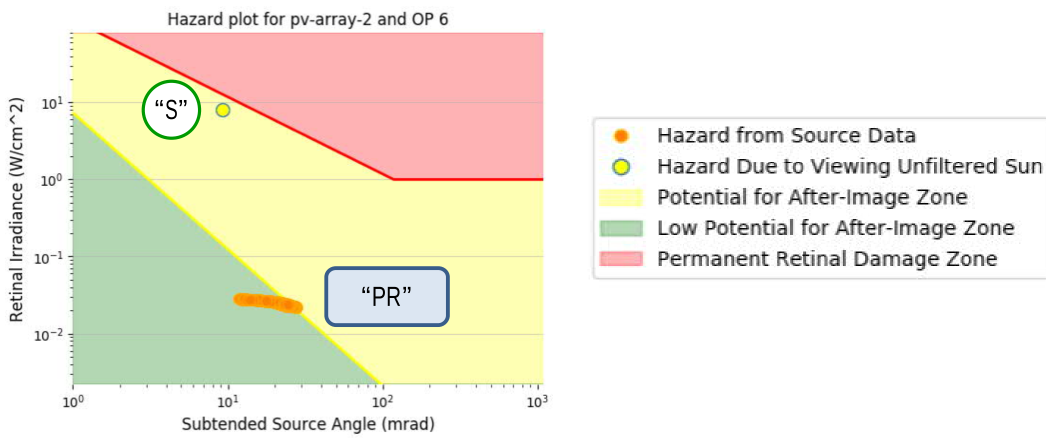
What is apparent in the SIM-1 scenario is that ALL of the visible reflection conditions occur in the late afternoon period, AFTER the panels have reached the maximum 60° westward tilt position and back-tracked instantaneously to a horizontal position, ie reflections only become visible when the panels are in a horizontal position late in the afternoon – refer typical times in Figure 20 (ranging from 5:00pm to 5:30pm in winter to 7:00pm to 7:30pm in summer).

It will be appreciated that, in this circumstance,
all receivers able to perceive reflections would ALSO be looking in the same direction
as the incoming direct solar rays of the sun (causing the reflections).

Common practice in relation to daytime glare studies
for Motorist Disability and Pedestrian Discomfort Glare is that
the above condition does not constitute an actual glare condition,
given that an observer would take action to avoid looking directly
at the incoming solar rays (ie the sun),
thereby avoiding any potential glare from the associated reflections.

To further emphasize the above, Figure 21 is the SIM-1 Ocular Plot for the R76(Op6) / Panel ID3.
It shows that the retinal irradiance associated with gazing at the sun ("S")
is over 100 times more intense than gazing at the concurrent panel reflections ("PR").

Figure 21 Representative SGHAT Ocular Plot: SIM-1, R76 (Op6) / Panel Array ID3



7.3 SIM-2 "Normal Tracking"

The results of the SIM-1 scenario (refer Section 7.2) suggest reflections only become visible in the late afternoon period AFTER the panels have reached their maximum 60° tilt westward position and instantaneously back-tracked to a horizontal resting position (where they remain till sunset).

To test this assumption, a scenario, SIM-2, was run with ±60° Tilt, but NO back-tracking, ie "normal tracking".

A summary of the results is shown in Table 6.

The SGHAT SIM-2 analysis confirms that no reflections from the facility would be visible at any of the surrounding receivers assessed, at any time of the year.

Table 6 SGHAT Analysis Results – SIM-2

Bomen SF Panel Array Segment ID	SGHAT Panel Array Name	"SIM-2" Minutes/Day that Reflections are Visible at ANY Receiver
1	PV Array 10	0 min
2	PV Array 11	0 min
3	PV Array 2	0 min
4	PV Array 3	0 min
5	PV Array 4	0 min
6	PV Array 5	0 min
7	PV Array 6	0 min
8	PV Array 7	0 min
9	PV Array 8	0 min
10	PV Array 9	0 min

7.4 "Equivalent" Bifacial Underside Panel Reflection Mode

No known software is available which can model the reflections emanating from the underside of bifacial solar panels. Accordingly, an "equivalent" simulation scenario was developed to model this condition.

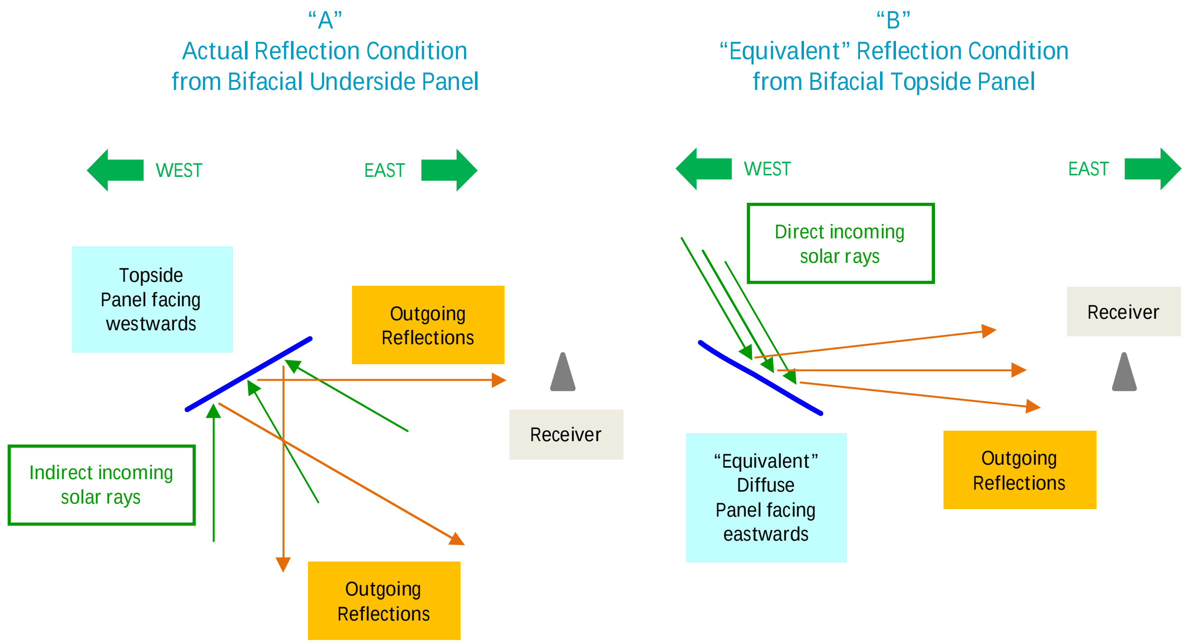
The background to this "equivalent" scenario is shown in Figure 22.

- Figure 22-A shows potential reflections emanating from the underside of a bifacial panel which is facing westwards. A small portion of these reflections has the potential to be directed towards an east-side receiver. Because of the indirect (scattered) nature of both the incoming solar rays and outgoing reflections, the reflection condition can be described as being "double-diffuse" in nature.
- Figure 22-B shows an equivalent scenario involving a panel facing eastwards (at the same angle). The surface of the panel is "roughened" so that outgoing reflections are scattered, ie "diffuse". Note however, that in this equivalent scenario, the incoming solar rays are parallel, not scattered.
- While both of the scenarios shown in Figure 22 result in reflections able to be perceived by an east-side receiver, the intensity of the reflections simulated in the "equivalent" scenario would be 10-100 times lower, given the "double-diffuse" nature of the panel underside reflections – refer bifacial panel discussion found in Section 2.2 (p.14).

The "equivalent" scenario developed from the above was the SIM-3 FIXED TILT, 15°East scenario. As described above, this seeks to model the potential reflections seen by receivers located towards the east of Bomen SF emanating from the underside of panels during the afternoon period when panels are facing west.

Note also that the "equivalent" simulation SIM-3 scenario (Figure 22-B) is FIXED all day long, whereas any potential actual reflections from the underside of the Bomen SF panels would be changing constantly as the tilt angle of the panels moves with the afternoon sun.

Figure 22 Bifacial Underside Panel Reflection Simulation Equivalent Scenario



Overall Summary (SGHAT)

A summary of the results is shown in Table 7 showing the number of minutes/day that solar panel reflections are potentially visible AT ANY RECEIVER within any relevant SGHAT "colour zone" – refer Figure 8.

The SGHAT analysis suggests that reflections from somewhere within the facility may be visible to receivers surrounding the site at some point in the year.

Note: In relation to the number of minutes/day shown in Table 7, they do not however represent the actual time underside panel reflections may be visible as this "equivalent" scenario has all panels within the facility remaining FIXED all day long, whereas underside panel reflections would vary with the actual "normal tracking" and "back-tracking" action of the panels during the afternoon. The actual times would therefore be a very small fraction of the numbers shown in Table 7.

Table 7 SGHAT Analysis Results – SIM-3

Bomen SF Panel Array Segment ID	SGHAT Panel Array Name	"SIM-3" Minutes/Day that Reflections are Visible at ANY Receiver [1]
1	PV Array 10	0 - 13 min
2	PV Array 11	0 - 20 min
3	PV Array 2	0 - 19 min
4	PV Array 3	0 - 28 min
5	PV Array 4	0 - 20 min
6	PV Array 5	0 - 19 min
7	PV Array 6	0 – 12 min
8	PV Array 7	0 - 10 min
9	PV Array 8	0 - 8 min
10	PV Array 9	0 - 5 min

Note 1 Actual times that reflections from underside panels may be potentially visible will be a fraction of the numbers shown above as panels in SIM-3 are left FIXED all day long at 15°East, whereas they are moving all day long – refer detailed discussion in this section.

Representative Result

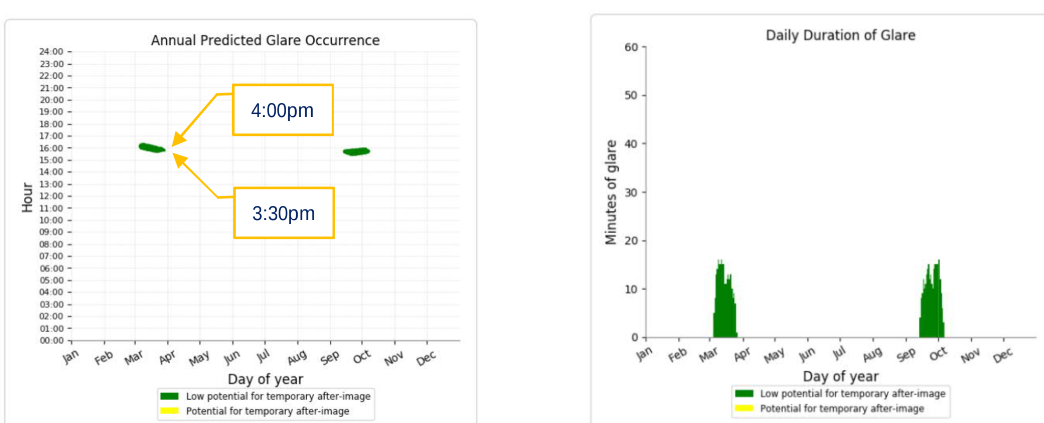
Figure 23 shows a representative reflection condition for SIM-3.

Receiver R140 (Op22) / Panel Array ID2

- Reflections are visible around the equinox periods between around 3:30pm and 4:00pm;
- Model reflections are visible for up to 15 minutes each day – actual reflections would be significantly less (refer discussion above);
- The retinal irradiance of these reflections (refer SGHAT Ocular Plot next page) is over a 1,000 times less intense than gazing directly at the sun.

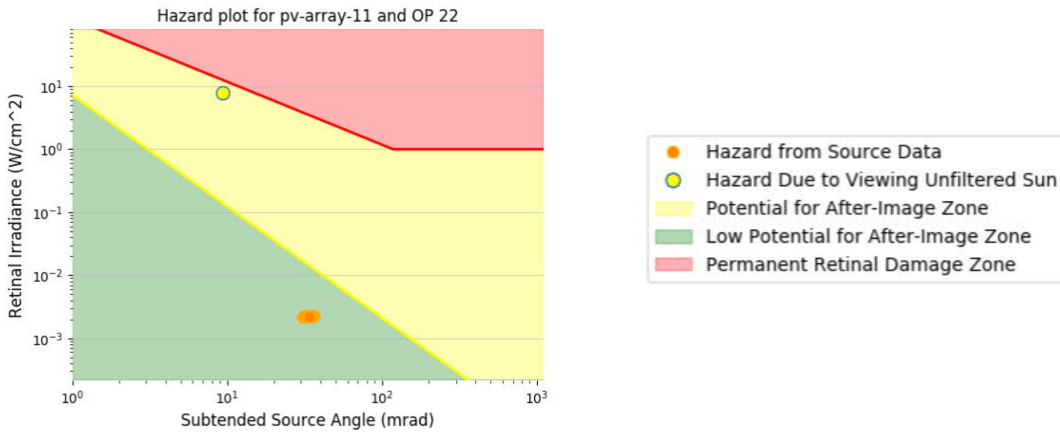
Figure 23 Selected SGHAT SIM-3 Result

Receiver R140 (Op22) / Panel Array ID2



(Fig.23 cont'd)

Ocular Plot for Receiver R140 (Op22) / Panel Array ID2



7.5 Theoretical Scenario – SIM-4: FIXED TILT 5°West

In this theoretical scenario, all panels within the facility remain at a fixed tilt of 5° westwards (all day long).

A summary of the results is shown in Table 8.

The SGHAT analysis shows that no reflections from the facility would be visible at any of the surrounding receivers assessed, at any time of the year.

Table 8 SGHAT Analysis Results – SIM-4: FIXED TILT 5°WEST

Bomen SF Panel Array Segment ID	SGHAT Panel Array Name	"SIM-4" Minutes/Day that Reflections are Visible at ANY Receiver
1	PV Array 10	0 min
2	PV Array 11	0 min
3	PV Array 2	0 min
4	PV Array 3	0 min
5	PV Array 4	0 min
6	PV Array 5	0 min
7	PV Array 6	0 min
8	PV Array 7	0 min
9	PV Array 8	0 min
10	PV Array 9	0 min

7.6 Theoretical Scenario – SIM-5: FIXED Tilt 20°East

It is understood that, during the construction phase of the project, prior to the time when tracking of panels commenced on site, there were periods when panels were left stowed in fixed positions that included low tilt positions facing eastwards.

The SIM-5 scenario simulates one such possible occurrence with panels left in a fixed tilt position of 20°East all day long.

A summary of the results is shown in Table 9.

Table 9 SGHAT Analysis Results – SIM-5: FIXED TILT 20°EAST

Bomen SF Panel Array Segment ID	SGHAT Panel Array Name	"SIM-4" Minutes/Day that Reflections are Visible at ANY Receiver
1	PV Array 10	0 - 16 min
2	PV Array 11	0 - 20 min
3	PV Array 2	0 - 17 min
4	PV Array 3	0 - 28 min
5	PV Array 4	0 - 20 min
6	PV Array 5	0 - 18 min
7	PV Array 6	0 – 11 min
8	PV Array 7	0 - 13 min
9	PV Array 8	0 - 7 min
10	PV Array 9	0 - 5 min

Representative Result

Figure 24 shows a representative reflection condition for SIM-5.

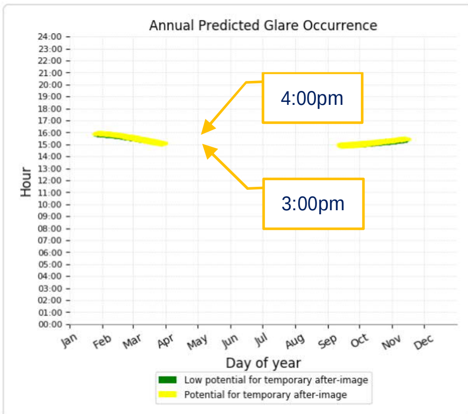
Receiver R19 (Op8) / Panel Array ID6

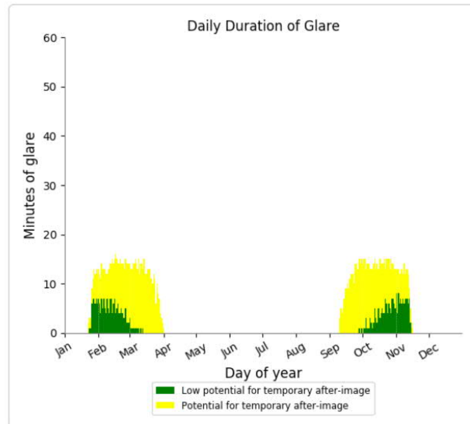
- Reflections would be visible from late January to late March from around 3:00pm to just after 4:00pm;
- SIM-5 reflections would be visible for up to 14 minutes each day;
- Retinal irradiance of these reflections (refer Ocular Plot next page) fall within both the "GREEN" and "YELLOW" zones suggesting that reflections would be noticeable.

SGHAT results at other receivers indicated that SIM-5 reflections would have been visible from early in the year (January) up until the time that tracking of panels commenced at the site.

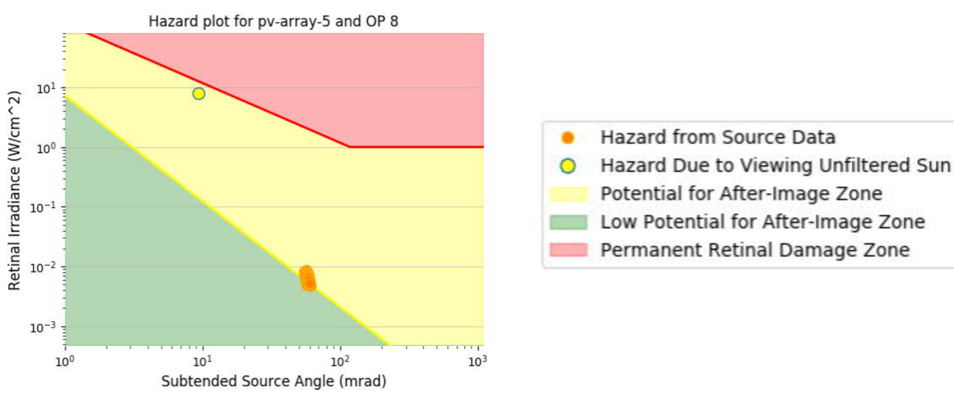
Figure 24 Selected SGHAT SIM-5 Result

Receiver R19 (Op8) / Panel Array ID6





Ocular Plot for Receiver R19 (Op8) / Panel Array ID6



7.7 TI Values Results and Comparison to SGHAT Output

Care must be taken when comparing SGHAT software output to TI Value Computations.

- The output of the SGHAT software is expressed in terms of irradiance (W/m^2) perceived by an observer along with the subtended angle of the incoming reflected rays (ie angular extent of view).
- Accordingly, SGHAT output cannot be directly compared to the Threshold Increment (TI) value which represents a ratio of luminance values, from an object (eg reflection) compared to the general background.

Moreover, the SGHAT software, when applied as in the present study to ground level receivers, makes a worst-case assumption that the receiver will be looking directly at the source of solar panel reflection, no matter what the relative elevations.

TI Value computations on the other hand depend on the angle difference between line of sight of the observer and the incoming reflection.

According to the relevant AS/NZS standards:

- In the case of Motorist Disability Glare, a driver's line of sight should be assumed to be parallel with the centreline of the roadway and directed 1° downwards relative to the plane of the road surface.
- In the case of Pedestrian Discomfort Glare, the pedestrian's eye height should be assumed to be 1.7 m above local ground level; the line of sight is parallel with the direction of pedestrian motion (ie along a footpath, across a pedestrian crossing, etc) and directed 1° downwards relative to the plane of the ground.

It can be seen in both of the above cases (Motorist Disability and Pedestrian Discomfort) the relationship between the activities of a Motorist (driving) and a Pedestrians (at a pedestrian crossing) does not directly correlate with the "nuisance" that would be perceived by a residential receiver located many hundreds of metres (possibly kilometres) from a reflection source.

Incoming Solar Rays and Outgoing Reflections in the same line of sight.

TI Values in the relevant Australian Standards (AS/NZS 1158 & AS/NZS 4282) were originally developed to assess the glare impact of luminaires at night-time. In this circumstance, the ratio approach involved in the TI Value computation (refer Section 4.3) appears logical, ie evaluating the luminance perceived by a nearby light source (luminaire) against the general background lighting level.

During the daytime, such an approach is also useful, although care must be taken to allow for the presence of direct solar impact, ie incoming solar rays, a situation which does not arise at night-time.

TI Values (as well as SGHAT Ocular Impact levels) are often high during the daytime when the angle of incidence of an incoming solar ray is high, ie the incoming solar rays and outgoing reflected ray are very close to the plane of the reflecting surface (note: by definition, the angle of incidence is equal to zero for a ray which is perpendicular to the reflecting surface).

In such instances, an observer would be looking at both incoming solar rays and outgoing reflections in essentially the same line of sight – see for example left side image in Figure 25.

- Common practice in relation to daytime glare studies for Motorist Disability and Pedestrian Discomfort Glare is that this does not constitute an actual glare condition, given that an observer would take action to avoid looking directly at incoming solar rays, thereby avoiding glare from the accompanying reflections at the same time.
- This is similar to Europe where glare situations (including for the assessment of solar facilities) are ignored when the angle difference between incoming solar rays and the reflected rays they generate, is less than around 10° – see right side image in Figure 25.

Figure 25 Examples of High Incidence Reflection Conditions

The TI Value calculations carried out for the various SGHAT simulation scenarios are summarised in Table 10.

Table 10 TI Value Computations

Simulation Name	Description
SIM-1 Section 7.2	• TI Values vary amongst receivers ranging from 0 (minimal reflection magnitude) to TI Values below TI=10 assuming an observer would be looking directly at the incoming reflections • ALL TI Values recorded occur at high incidence angles very late in the afternoon when the solar panels are in their "back-tracked" horizontal position • Under the above scenario, while reflections would be visible, the indicated TI Values do not constitute a "glare" condition, given that observers would be looking at both incoming solar rays and the outgoing reflections in essentially the same line of sight. • NIL GLARE (although reflection visible)
SIM-2 Section 7.3	• NO TI Values Recorded → NIL GLARE
SIM-3 Section 7.4	• TI Values vary amongst receivers ranging from 0 (minimal reflection magnitude) to TI Values below TI=1, taking into account the "double-diffuse" nature of the bifacial underside panel reflections – refer Section 2.2 • Negligible TI Values → NIL GLARE
SIM-4 Section 7.5	• NO TI Values Recorded → NIL GLARE
SIM-5 Section 7.6	• TI Values vary amongst receivers ranging from 0 (minimal reflection magnitude) to TI Values up to TI=10 assuming an observer would be looking directly at the incoming reflections • In some cases, the angle difference between incoming solar rays and their accompanying reflections is greater than 10°. In this case, the recommended criterion for Pedestrian Discomfort Glare (normally applied to pedestrian crossing situations) may be exceeded for an observer looking directly at the incoming reflections • This condition might be occurring for up to around 10-20 minutes per day

Comment on TI Value Results

The results of the TI Value calculations for the SIM-1 to SIM-4 scenarios suggest that, while reflections may indeed be visible under certain circumstances, eg panels in a horizontal position close to sunset, they would not constitute a “glare” condition according to the criteria normally applied to Motorist Disability and Pedestrian Discomfort Glare.

It will be recalled that the SIM-5 scenario modelled a situation which may have existed on occasion at Bomen SF during construction and prior to panel tracking commencing, when panels were left in a fixed tilt position facing east. The results of the TI Value calculations for the SIM-5 scenario suggest the recommended TI Value criterion for Pedestrian Discomfort Glare may have been exceeded during this period.

It is also noted that, since the commencement of normal panel operations, the possibility of the above SIM-5 scenario has significantly reduced.

8 SUMMARY AND CONCLUSIONS

SLR Consulting Australia Pty Ltd (SLR) has carried out a Reflective Glare Assessment of Bomen Solar Farm (SF), located several kms to the northeast of Bomen, NSW - refer Figure 1.

- Bomen SF comprises a 100 MWac solar facility;
- The facility incorporates Jinko Swan Bifacial HC 72m 380-390W photovoltaic (PV) panels, measuring approximately 2.0 m by 1.0 m;
- The panels are mounted (portrait-style) on single-axis ±60° tracking structures which are aligned in a north-south direction and spaced 4.8 m apart.

Section 2 describes the footprint and envelope of Bomen SF.

The following potential glare conditions have been considered:

- Daytime Reflective glare (and glint) arising from the solar PV panels within the facility

The ensuing analysis involved the following:

- 22 surrounding receivers were assessed – these are located to the northeast clockwise around to the south of the facility;
- Bomen SF was broken up into 10 panel array segments in order to capture the elevation variations (from RL200m to RL245m) present within the facility.

In terms of potential glare calculation methodologies, the following have been considered:

- SOLAR GLARE HAZARD ANALYSIS TOOL (SGHAT) Reflective Glare – normally applied to Aviation Glint & Glare studies; and
- THRESHOLD INCREMENT (TI) Reflective Glare – normally applied to Motorist “Disability” Glare and Pedestrian “Discomfort” Glare (the latter relevant to pedestrian crossing situations).

The present study has found the following:

- It is noted that there are no Australian guidelines covering reflective glare in relation to “Residence Nuisance” glare, as opposed to guidelines covering Aviation Glint and Glare, Motorist Disability Glare and Pedestrian Discomfort Glare. These latter guidelines have been used to characterise the level of glare being experienced by surrounding residential receivers.
- Under current “back-tracking” operational conditions, labelled as the SIM-1 scenario, reflections from Bomen SF may be visible to receivers located to the east of the facility during late afternoon periods at different months of the year, depending upon relative position of the receiver. Note that the present analysis does not take into account any shielding of reflections from intervening vegetation, trees, etc, including those found within the facility itself.
- The SIM-1 analysis suggests that reflections become visible only once the panels have “back-tracked” to their horizontal rest position after the sun has passed a solar zenith angle of 60° to the west.
- This was confirmed by running a “±60° Tilt / No Back-Tracking” scenario (SIM-2) which confirmed the absence of visible reflections at all surrounding receivers assessed in the study.

- A theoretical "Equivalent Bifacial Underside Panel" mode (SIM-3) was run aimed at simulating the diffuse reflections that may occur from the underside of west-facing panels towards the east. The outcome of this simulation suggests that such reflections may potentially be visible, but at negligible lux levels.
- Simulations involving panels being tilted towards the west (with even a small 5° tilt angle, ie almost horizontal) resulted in no reflections being created towards the east (all-year-round).
- The results of the TI Value calculations for the SIM-1 to SIM-4 scenarios suggest that, while reflections may indeed be visible to east side receivers under certain circumstances, eg panels in a horizontal position close to sunset, they would not constitute a "glare" condition according to the criteria normally applied to Motorist Disability and Pedestrian Discomfort Glare.
- A final "SIM-5" scenario was modelled, representing a situation which may have existed on occasion at Bomen SF during construction and prior to panel tracking commencing, when panels were left in a fixed tilt position facing east. The results of the TI Value calculations for the SIM-5 scenario suggest the recommended TI Value criterion for Pedestrian Discomfort Glare may have been exceeded during this period. It is noted that, since the commencement of normal tracker operations, the SIM-5 scenario is highly unlikely to occur again.

ASIA PACIFIC OFFICES

BRISBANE
Level 2, 15 Astor Terrace
Spring Hill QLD 4000
Australia
T: +61 7 3858 4800
F: +61 7 3858 4801

CANBERRA
GPO 410
Canberra ACT 2600
Australia
T: +61 2 6287 0800
F: +61 2 9427 8200

DARWIN
5 Foelsche Street
Darwin NT 0800
Australia
T: +61 8 8998 0100
F: +61 2 9427 8200

GOLD COAST
Ground Floor, 194 Varsity Parade
Varsity Lakes QLD 4227
Australia
M: +61 438 763 516

MACKAY
21 River Street
Mackay QLD 4740
Australia
T: +61 7 3181 3300

MELBOURNE
Suite 2, 2 Domville Avenue
Hawthorn VIC 3122
Australia
T: +61 3 9249 9400
F: +61 3 9249 9499

NEWCASTLE
10 Kings Road
New Lambton NSW 2305
Australia
T: +61 2 4037 3200
F: +61 2 4037 3201

PERTH
Ground Floor, 503 Murray Street
Perth WA 6000
Australia
T: +61 8 9422 5900
F: +61 8 9422 5901

ROCKHAMPTON
rockhampton@slrconsulting.com
M: +61 407 810 417

SYDNEY
2 Lincoln Street
Lane Cove NSW 2066
Australia
T: +61 2 9427 8100
F: +61 2 9427 8200

TAMWORTH
PO Box 11034
Toowoomba NSW 2340
Australia
M: +61 408 474 248
F: +61 2 9427 8200

TOWNSVILLE
Level 1, 514 Sturt Street
Townsville QLD 4810
Australia
T: +61 7 4722 8000
F: +61 7 4722 8001

AUCKLAND
68 Beach Road
Auckland 1010
New Zealand
T: +64 27 441 7849

NELSON
5 Duncan Street
Port Nelson 7010
New Zealand
T: +64 274 898 628

NEW PLYMOUTH
Level 2, 10 Devon Street East
New Plymouth 4310
New Zealand
T: +64 0800 757 695