Appendix L: Glint and Glare Information

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Analyzing Glare Potential of Solar Photovoltaic Arrays

Light reflected from solar photovoltaic (PV) panels may cause glare. It is important to consider potential impacts from glare when siting a solar PV array at or near airfields.

Glint and Glare Basics

Glint is a momentary direct reflection of light, whereas glare is an indirect reflection of light that can be both larger and of longer duration. PV arrays typically do not cause glint, but glare can be a concern. Glare intensity from PV arrays is generally low compared to that of buildings or snow and ice because the panels are designed to absorb sunlight and have textured glass and/or antireflective coatings that reduce reflectivity.

In conjunction with the U.S. Department of Energy, the Federal Aviation Administration (FAA) has determined that glare from solar PV arrays could result in ocular impact to pilots and/or air traffic controllers; therefore, a glare analysis is required for all proposed PV system installations within FAA-controlled boundaries. The FAA requests that the Solar Glare Hazard Analysis Tool (SGHAT), developed by Sandia National Laboratories, be used to complete any such analysis. Additionally, the FAA has established the following acceptance criteria:

- No potential for glare to the air traffic control tower (ATCT) at cab elevation
- Only glare with a low potential for after-image during the last two miles of the standard, straight-in landing approach.

The Department of Defense (DoD) has issued guidance recommending the use of SGHAT for impact analysis of solar PV on DoD air operations. Unlike the FAA, however, it does not specify allowable risk thresholds (i.e., acceptance criteria).

Glare Analysis

SGHAT can be used to determine whether a proposed solar PV project would have the potential for ocular impact. The tool has the capability of determining the following conditions:

- No glare
- Glare with the low potential to cause an after image[1]
- Glare with the potential to cause an after image
- Glare with the potential to cause eye damage.[2]

To perform the analysis, SGHAT requires information about local flight operations and design parameters of the PV array (i.e., array elevation, geometry, orientation, and tilt). Flight operations are modeled using either observation points (OP) or flight-path traces. An OP assumes a 360° unobstructed view from a vantage point defined by a specified longitude, latitude, and altitude. Flight paths are a straight line of OPs that restrict the view angle and downward azimuth, therefore, glare occurring behind and/or below the aircraft is not considered in the output. The tool also assumes perfect, clear-day conditions (i.e., maximum solar irradiance and no atmospheric attenuation), no line-of-sight obstructions (i.e., buildings, trees), and no use of ocular aids to reduce irradiance to the retina (i.e., sunglasses, tinted visor).

1. An image that continues to appear in one's vision after the exposure to the original image has ceased

2. It is highly unlikely that a PV array could cause glare with the potential to cause eye damage since the panels are designed to absorb sunlight

Naval Air Station Meridian Case Study

Naval Air Station (NAS) Meridian is a military airport located 11 miles northeast of Meridian, Mississippi, and is one of the Navy's two jet strike pilot training facilities.

When a solar PV installation was proposed at NAS Meridian, NREL worked closely with air operations and air wing personnel to develop a new methodology for analyzing and visualizing complex flight patterns. Aviators and air traffic controllers provided detailed information about flight patterns, landing approaches, altitudes, cockpit visibility, and line-of-sight. Based on this input, it was determined that non-linear flight paths could be replicated by a series of OPs in lieu of analyzing segments of flight paths. Both OPs and the minimum and maximum prescribed altitudes could be used to mimic the flight pattern and landing approaches. This ensured that results were robust and conservative.

Proposed PV system design parameters, provided by the developer, were assessed to identify the potential impact PV arrays could have on the numerous flight patterns and landing approaches for each runway, as well as the ATCT. Preliminary SGHAT runs showed that in order to ensure a complete and defensible set of results, more OPs were needed to fill in gaps. Results also indicated that average altitude for each flight segment was adequate to ensure robust results. In all, about 300 SGHAT runs were completed, which provided a thorough understanding of potential impacts on flight operations from the proposed PV systems.

SGHAT results can be difficult to interpret by personnel unfamiliar with the tool. Therefore, NREL also developed a new way to display the information in an easy-to-understand format. The novel method plotted the outputs along the flight paths, showing pilots where they could expect to encounter glare from the solar PV array(s). This information permitted aviators and air operations personnel to provide constructive feedback regarding PV system placement and design, which enabled the project to move forward in the development cycle.

Department of the Navy (DoN) flight operations are not the same as those for commercial air traffic. Flight patterns are much more complex, including more overhead routes. Landing approaches are often non-linear and generally steeper (up to 10°). SGHAT is capable of varying the steepness of descent (or glide slope), but does not have the ability to analyze curved flight patterns and landing approaches. To address these limitations, NREL has developed a new methodology for analyzing and visualizing complex flight patterns. The new approach provides conservative, defensible results that can be used as an aid in determining the development pathway for a PV system at a military airport.

Useful References

1. Federal Aviation Administration (FAA). 2010. Technical Guidance for Evaluating Selected Solar Technologies at Airports. Federal Aviation Administration-Office of Airports, Washington, DC; FAA-ARP-TR-10-1:162 pp. https://www.faa.gov/airports/environmental/policy_guidance/media/airport-solar-guide-print.pdf.

2. Federal Aviation Administration (FAA). 2013. Interim Policy, FAA Review of Solar Energy System Projects in Federally Obligated Airports. Federal Register; Vol. 78, No. 205, pg. 63276-63279. https:/www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf.

3. U.S. Department of Defense (DoD). 2014. Procedures Memo #4: Glint/Glare Issues on or near Department of Defense Aviation Operations. Office of the Secretary of Defense (OSD), Washington, DC. http://www.acq.osd.mil/dodsc/library/Procedures_Memo_4_Glint%20Glare%20Issues%20on%20or%20near%20DoD%20Aviation%20Operations.pdf.

4. Ho, C.K., C.A. Sims, J. Yellowhair, and E. Bush. 2014. Solar Glare Hazard Analysis Tool (SGHAT) Technical reference Manual. Sandia National Laboratories, Albuquerque, NM: SAND2014-18360. https://share.sandia.gov/phlux.

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Prepared by the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy; NREL is operated by the Alliance for Sustainable Energy, LLC.

NREL/FS-6A10-67250 • www.navy.mil • November 2016

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GLINT & GLARE ASSESSMENT REPORT
ROOS SOLAR PV FARM
SOLAR PV FACILITY

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28th July 2023

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1. EXECUTIVE SUMMARY

This report assesses the impact of potential glare, originating from a proposed solar PV facility, located in Mpumalanga, South Africa. The impact of glare is assessed against ocular hazard protocols to determine whether such glare can be considered a nuisance or harmful to potential observers operating in, and around the solar PV facility. Several buildings and the natural environment surrounding the location of the proposed PV facility and several glare receptors, including route receptors such as nearby roads and railway lines, which lie within the viewshed of the proposed solar PV facility were considered in this assessment. Aviation receptors are excluded from this assessment due to none being in close proximity to the proposed solar PV facility.

Using sun-path algorithms for every minute of the year, it was calculated if, and when glare may theoretically occur at a particular receptor. If unacceptable levels of solar reflection (glare) were found to be geometrically possible at a particular location, further analysis was undertaken to ascertain whether the receptor geometry and intervening landforms would shield the receptor from solar reflection sufficiently.

The level of potential glare from solar PV panels is similar to that of water and much less than that of materials such as concrete and vegetation. Many common elements of the built environment, such as concrete, vegetation, roof sheeting and nearby water bodies, offer similar, if not higher levels of glare than that caused by solar PV systems.

For the purpose of glare assessments, the international glare development team at SANDIA Labs recommends the use of the Solar Glare Hazard Plot (Figure 4) to measure the ocular impact of a solar array. Receptors with theoretical potential for glare can fall into one of three different areas:

Green - "Low potential for after-image",
Yellow - "Potential for after-image" and
Red - "Potential for Permanent Eye Damage (retinal burn)".

Results Summary

The results of this assessment demonstrate that:

Using smooth glass solar PV modules without an anti-reflective coating will result in either no glare, or green glare received at the assessed receptors. Green glare is described as glare with a low potential to cause temporary after-image. The nature of this glare is typically diffuse without specular strength (able to form a core shadow), and is therefore not significant. This type of glare has a low intensity and is typical of many materials in the building environment. The proposed solar PV facility will not cause any significant impact from a glint and glare perspective.

2. INTRODUCTION

SOLINK, a specialist Renewable Energy Consultancy with extensive experience in the development and assessment of solar PV installations in Southern Africa, has been appointed by Juwi to conduct a glint and glare assessment for a ground mount solar PV facility on the premises of Roos Solar PV Farm. Our technical team has followed the development of glint and glare research from its origins in the field of concentrated solar power, reviewing the original publications developed by Sandia National Laboratories ("Sandia Labs"), to today, where the same principles are used to assess the effects of glint and glare resulting from solar PV facilities on air traffic and other sensitive activities in the built environment.

The analysis presented in this report makes use of a desktop-based simulation tool originally developed by Sandia Labs and adapted for use in solar PV installations. The analysis reviews the effects of solar PV induced glare by tracking the path of the sun over a 365-day period, at simulation resolution intervals of 1 minute. The impact of this glare is assessed at several receptors in the surroundings of the solar PV facility. If glare is found to be geometrically possible from a particular location, further analysis is then carried out. This analysis determines the significance of the glare that could potentially be experienced and also if, in reality, these effects are likely to be experienced by an observer at that location. In certain cases, where glare is found to be significant and a likely source of hazard or nuisance, mitigation factors are explored.

The rest of this report includes a description of the solar PV facility, a review of the established guidelines for assessing the ocular impact of sources of glare, and a contextual discussion of the reflective capabilities of solar PV modules when compared to other materials in the built environment. This is followed by the methodology of the glare assessment, and the results of the glare assessment. The report concludes with a summary of the assessment's key findings.

3. PROJECT DESCRIPTION

Roos Solar PV Farm is located in Mpumalanga, South Africa. The site area is located on open land with varying terrain, and is surrounded by a few building dwellings, adjacent roads, and a railway line.

Figure 1: Roos Solar PV Farm, Mpumalanga

The proposed solar PV facility is divided into four portions, namely Areas 1-4, which comprise the different phases of the solar PV project. The site configuration includes a 8m pitch distance in the design, with the system comprising a total of 39.6 MW rated power.

The outcome of this assessment will form part of the Environmental Impact Assessment report submitted to the Department of Forestry, Fisheries, and the Environment. As such, the findings of the report will demonstrate the effect of the proposed solar PV facility on the site surroundings from a glint and glare perspective. The intensity and duration of glare received at the identified receptors will be obtained from the simulations conducted, and will inform on the impact.

4. ASSESSMENT OBJECTIVES

The aim of this solar PV glint & glare assessment is to determine the number of occurrences and severity of unacceptable levels of glare which directly originate from the proposed solar PV facility. The assessment will comprise a desktop assessment which will include several glare simulations using the appropriate industry recognised software.

The scope of this assessment shall include:

- ➔ A review of the proposed solar PV facility and its parameters.
- ➔ Compilation of study area & base data including high risk zones for glare.
- ➔ Desktop review of the potential viewshed.
- ➔ Selection of key observer points (receptors) which represent areas of potential glare impact.
- ➔ Assessment of the potential glare using Forgesolar.
- ➔ Completing a desktop glare evaluation of the glare impact resulting from the proposed solar PV facility on the identified receptors, rating the glare potential as"no glare", "green", "yellow" or "red" in severity.
- ➔ Repeating the desktop glare evaluation to assess the effects of including an anti-reflective coating (ARC) on the surface of the solar panel and its effects on the potential glare severity, in the event where unacceptable levels of glare are achieved.

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5. ASSESSMENT BACKGROUND

5.1. Glint & Glare Overview

Glint and glare are phenomena caused when electromagnetic radiation in the form of visual light, is reflected off a material surface. This reflection can result in the potential to cause ocular hazard (hazard to the eye), nuisances or unwanted visual impacts. The concepts of glint and glare have been officially defined by the United States Federal Aviation Administration (FAA) in their "Technical Guidance for Evaluating Selected Solar Technologies on Airports":

Glint is a momentary flash of bright light.
Glare is a continuous source of bright light.

Glint and glare are also commonly referred to as 'solar reflection'. To determine the impact that solar reflection could potentially have on the built environment and its surroundings, it is necessary to carry out a glint and glare assessment for the proposed solar PV farm.

5.2. Risks and Hazards of Glint & Glare in the Built Environment

The primary concern following short term exposure to bright light is the impact of such light on the health of the eye retina. The impact of solar reflectance on the health of the eye is determined by an ocular assessment which considers two variables: retinal irradiance and the subtended angle (size) of the glare source (Figure 2). The retinal irradiance is a measure of the total power entering the pupil and the retinal image area.The subtended source angle provides an indication of the intensity of the glare source.

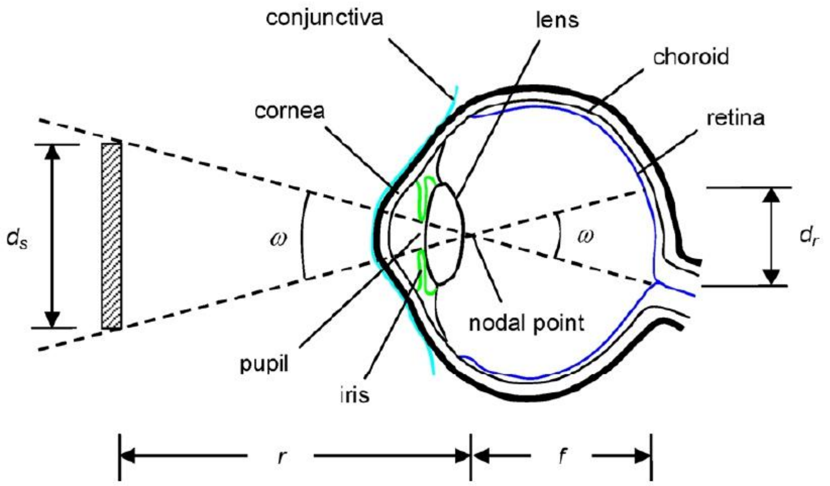

Figure 2: Image projected onto the retina of the eye [1]

Figure 3 summarizes the potential impact of different retinal irradiances as a function of subtended source angle for short-term exposures. Three regions are shown: (1) potential for permanent eye damage (retinal burn), (2) potential for temporary after-image (flash blindness), and (3) low potential for temporary after-image. If the retinal irradiance is sufficiently large for a given subtended source angle, permanent eye damage from retinal burn may occur. The three classifications of glare are often abbreviated to green, yellow, and red glare, corresponding to the different regions of the after-image depicted in Figure 3.

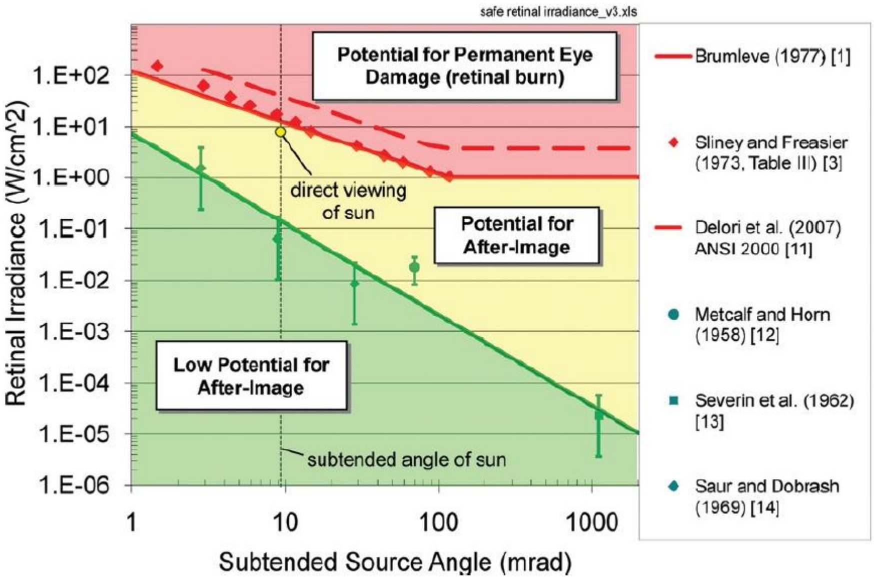

Figure 3: Solar Glare Hazard Plot [1]

5.3. Solar PV Module Reflectivity

All surface and material types have different reflectivity properties. This results in varying degrees of sunlight reflection. Solar PV modules, by their nature, are designed to absorb as much sunlight as possible, thus converting the sun's energy to electricity. As a result, the amount of light reflected off these installations is typically less than most other materials in the built environment. Figure 4 illustrates that the reflectance of solar PV panels is of a similar nature to water. Typical values for the reflectance levels of solar PV panels are far less than that of materials such as snow, concrete and even vegetation. However, like water, the effects of solar reflectance resulting from solar PV modules are dependent on the angle of incidence between the light source and the panel's surface.

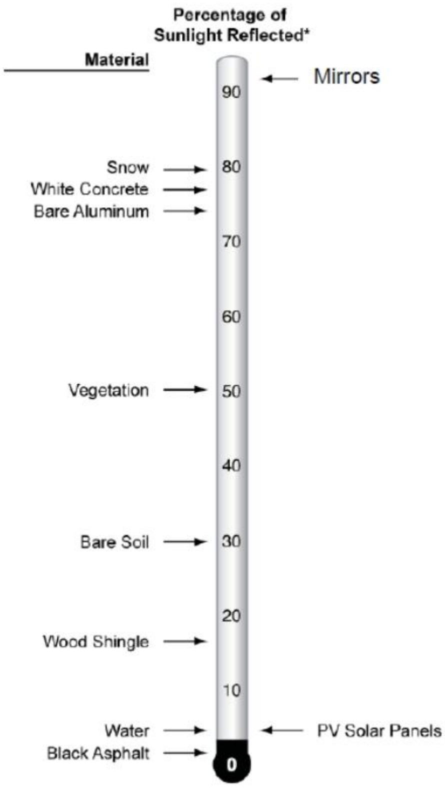

Figure 4: Reflective properties of different substances [2]

At high angles of incidence, such as in the early morning or late afternoons, the proportion of reflected sunlight for modules installed at low angles of inclination tends to be greater than during midday. However, sunlight intensity is usually also reduced at these times, further limiting the effects of solar reflectance.

There are two types of reflection which can occur on a surface; specular and diffuse. Specular reflection is a direct reflection which produces a concentrated type of light. It occurs when light reflects off a smooth or polished surface like glass or still water. Diffuse reflection, on the other hand, produces a less focused type of light. Diffuse reflection occurs as a result of light reflecting off a rough surface such as vegetation, concrete or choppy water. Figure 5 helps to illustrate the difference between these two types of reflection. The main type of reflectance from solar PV panels is specular due to the texture of the outer layer of glass on the panel surface. However, in reality, like all surfaces, there will be a combination of both specular and diffuse reflection.

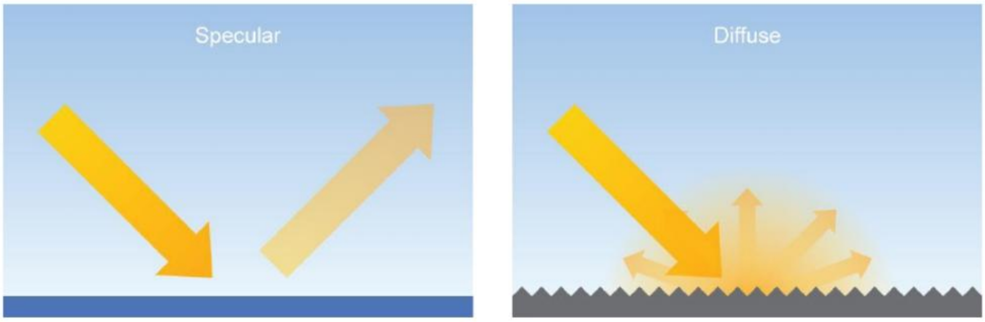

Figure 5: Different types of Solar Reflection [2]

As discussed earlier, the level of potential glare from solar PV panels is similar to that of water and much less than that of materials such as concrete and vegetation. Many common elements and materials in the built environment, such as concrete, roof sheeting, and open bodies of water, offer similar, if not higher levels of glare than that caused by solar PV systems.

6. ASSESSMENT METHODOLOGY

6.1. Solar PV Array Layout and Orientation

The proposed solar PV facility will comprise a single-axis tracker system which allows for each solar array to track the sun's path for optimal solar production. The system has a north-south axis, where the solar arrays track the east-west direction and has a rotation angle of -60° to +60°. The ground coverage ratio has been specified as 68%. The pitch distance (or row-to-row spacing) for the proposed system is 8 m to mitigate near shading effects which has a significant impact on the solar yield. Due to a considerable space present between each solar PV array, the effects of glare are anticipated to be low.

6.2. Observer Point (Receptor) and Route Selection

The glare severity resulting from a solar PV facility is a function of the size of the facility and its proximity to the point of observation. For this assessment, receptor selection was based on the identified points from a viewshed analysis of the solar system's glare projection (Figures 6 - 9).

Figure 6: Solar PV viewshed - Area 1

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Figure 7: Solar PV viewshed - Area 2

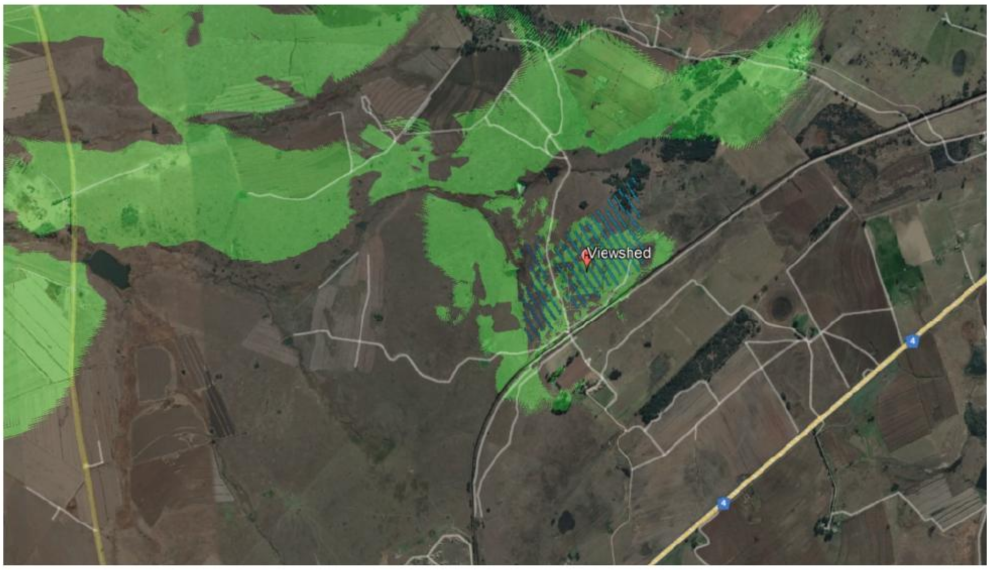

Figure 8: Solar PV viewshed - Area 3

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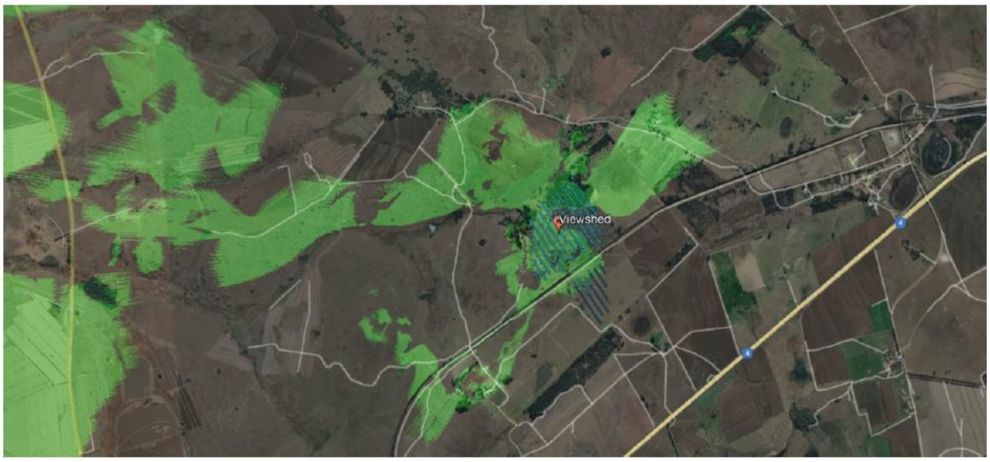

Figure 9: Solar PV viewshed - Area 4

A total of 22 observer points ("OP") at varying elevation, as well as 3 route receptors were selected around the site (Figure 10) for the simulation, listed below.

1. Afgri Wonderfontein Silo (OP 1 - 2)
2. BKB Grain Storage (OP 3)
3. Residential homes A - west of PV Area 1 (OP 4 - 14)
4. Residential homes B - South-east of PV Area 1 (OP 15 - 16)
5. Cattle Farming (OP 17)
6. National Road - N4 (Route)
7. North-South Main Road (Route)
8. Railway line (Route)
9. Farm housing units (x4) - north of PV Areas 4 and 5 (OP 18 - 22)

Figure 10: Roos Solar PV Farm identified glare receptors

6.3. Forgesolar Software Glare Simulations

The glint & glare analysis was conducted using the Solar Glare Hazard Analysis Tool (SGHAT) originally developed by SANDIA National Laboratories and licensed to Forge Solar. The analysis tool makes use of the coordinates and elevation of the solar PV arrays relative to those of the receptors to determine glare origination. The area of the arrays and the sun's position and path are then used in a set of vector calculations to determine the receptors susceptible to glare and the glare impact. The user is required to input details relating to the pitch and orientation of the PV arrays, the solar panel classification and reflectance and the ocular parameters for the simulation.

If glare is found, the simulation determines the retinal irradiance and subtended source angle (size/distance) of the glare which inform on the potential ocular hazards. The results are used to specify when glare will occur throughout the year, with color codes corresponding to the potential severity of the ocular hazard. The simulation models consider combining vertically aligned solar PV arrays (Figure 11). In this way the impact from glare modeled on a conservative basis where additional area and the effect from a larger PV arrays is simulated.

Figure 11: Typical solar PV array configuration - combined arrays

Where PV arrays are in close proximity to receptors, single tracker units are assessed (Figure 12).

Figure 12: Typical solar PV array configuration - single arrays

6.4 Assumptions and Limitations

The simulation year for the assessment was assumed to be 2023, and the assessment did not consider:

- ➔ Varying Weather conditions (simulation is based on 365 days of sunny weather).
- ➔ Intervening landforms or obstructions (such as: vegetation, parapet walls etc) between the panels and receptors.
- ➔ The software package used in this assessment allows for a maximum of twenty solar PV modules per model

7. RESULTS AND DISCUSSION

The model configuration summary and results of the assessment are presented in Tables 1 and 2. These results should be assessed against the locations of the observer points relative to the proposed PV facility. In Table 2, the results represent the total glare received by each receptor from the solar PV arrays considered in this assessment. For more detailed insight into the report modeling, please refer to Appendix A (Forgesolar Glare Simulation Reports). It must be noted that during the initial stages of this assessment, an additional area was excluded from the evaluation and hence the report appendices for "Areas 1 - 4" are labeled as "Areas 2 - 5".

Table 1: Model configuration summary

Description	Area 1	Area 2	Area 3	Area 4
Number of simulation models per area	9	7	18	8
Total number of simulation models	43			

Table 2: Model results summary

Model Configuration	Model Sub-configuration Label	Analysis Result
"Area 1"	Area 2-1	*No Glare*
	Area 2-2	*Green Glare*
	Area 2-3	*Green Glare*
	Area 2-4	*No Glare*
	Area 2-5	*No Glare*
	Area 2-6	*No Glare*
	Area 2-7	*Green Glare*
	Area 2-8	*Green Glare*
	Area 2-9	*Green Glare*
"Area 2"	Area 3-1	*Green Glare*
	Area 3-2	*Green Glare*
	Area 3-3	*Green Glare*

	Area 3-4	*Green Glare*
	Area 3-5	*Green Glare*
	Area 3-6	*Green Glare*
	Area 3-7	*Green Glare*
"Area 3"	Area 4-1	*Green Glare*
	Area 4-2	*Green Glare*
	Area 4-3	*Green Glare*
	Area 4-4	*Green Glare*
	Area 4-5	*Green Glare*
	Area 4-6	*Green Glare*
"Area 4"	Area 5-1	*Green Glare*
	Area 5-2	*Green Glare*
	Area 5-3	*Green Glare*
	Area 5-4	*Green Glare*
	Area 5-5	*Green Glare*
	Area 5-6	*No Glare*

From the above information presented, the glare received at nearby surroundings does not produce any harmful impact. In some cases, no glare was predicted annually, and in other cases green glare was observed - i.e., glare with a "low potential for after-image". The nature of this glare is typically diffuse without specular strength (able to form a core shadow), and is therefore not significant. This type of glare is typical of many materials within the built environment. Solar PV panels reflect as little as two percent of incoming sunlight, about the same as water and less than most soils.

None of the simulation models produced yellow or red glare - i.e. glare of an intensity which could result in the "potential for temporary after-image" on the observer retina (retinal bleaching).

For more detailed information on the particulars of potential glare experienced at each receptor, please refer to the appendices of this report. The appendices contain glare impact matrices that show the contribution of each solar PV array to the glare received at each receptor, and Forge Solar simulation results with graphs for any solar PV array showing the potential for glare, the date and time of potential glare, the potential duration of the glare, and the hazard plot indicating the magnitude of the potential glare. Please note that all references to time herein refer to South African Standard Time (SAST) which equates to UTC/GMT +2 hours, and some array positions have been somewhat displaced in the compilation of the simulation results by the simulator.

8. IMPACT STATEMENT

The impact from the proposed Roos PV solar farm from a glint and glare perspective, was assessed using Forgesolar glare hazard analysis. The below table classifies glare types, their impact and potential mitigation required in the event negative impacts are observed.

Glare Classification	Glare Intensity	Glare Impact	Mitigation Required
No Glare	None	None	Not required
Green Glare	Low	Low potential for after-image	Not required
Yellow Glare	Medium	Potential for after-image	Anti-reflective coating, Light textured glass, Deeply textured Glass
Red Glare	High	Potential for Permanent Eye Damage (retinal burn)	Not applicable to solar PV technology

As seen from the results of this assessment in section 7, the potential impacts from the proposed solar PV facility from glint and glare are either none, or have a low impact (Green Glare). Green glare has a low intensity level and is similar to many materials such as concrete, steel sheeting and other building materials that have minimal visual impact. No negative impacts were observed from the site analysis.

Due to low glare intensity observed during the analysis of the site, no negative impacts were identified and therefore no mitigation measures are required for the proposed solar PV modules. Using smooth glass solar PV modules without protective coatings will be suitable and not cause any harmful visual impact on surroundings. Please refer to Appendix B for the impact statement on the site assessment.

9. CONCLUSIONS AND RECOMMENDATIONS

Using smooth glass solar PV modules without an anti-reflective coating will result in either no glare, or green glare received at the assessed receptors. Green glare will not cause any harmful effect on nearby observers due to its low intensity and has a low potential for temporary after-image. As such, the proposed solar PV facility will not cause any significant, or harmful impact on nearby surroundings from a glint and glare perspective. SOLINK supports the findings of this report, as supplementary to the intended renewable energy project's Environmental Impact Assessment applications.

It must be noted that although the intended solar PV project does not trigger any requirements for an aviation-related glint and glare assessment according to South African Civil Aviation Authority regulations, it would be advisable to contact Air Traffic Navigation Services (ATNS) to confirm in writing that Obstacle Registration with ATNS is not required due to their requirements (for glint and glare assessments, and obstacle registration) not being triggered:

- *The solar PV facility is not within 3 km of any aerodrome, airstrip, or helipad.*
- *The solar PV facility does not lie within the extended 8 km, 9 degree diverted runway viewshed.*

SOURCES

[1]: C. K. Ho, Methodology to Assess Potential Glint and Glare Hazards From Concentrating Solar Power Plants: Analytical Models and Experimental Validation, Albuquerque, NM, 2015

[2]: H Miller, S.B. Barret, Technical Guidance for Evaluating Selected Solar Technologies on Airports, Washington, DC, 2018