D12: Glint and Glare Assessment

October 2023

AVIATION GLINT & GLARE ASSESSMENT

THE PROPOSED 150MW CARPE DIEM SOLAR PV FACILITY, MERAFONG CITY, GAUTENG, SOUTH AFRICA

PROJECT NAME	GLINT AND GLARE IMPACT ASSESSMENT OF THE PROPOSED CARPE DIEM SOLAR PV FACILITY
REPORT	ASSESSMENT REPORT
STAGE OF REPORT	VERSION 2
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I hereby declare that I do:

(a) have knowledge of and experience in conducting assessments, including knowledge of the Act, these regulations and guidelines that have relevance to the proposed activity;

(b) perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;

(c) comply with the Act, these regulations, guidelines, and other applicable laws.

I also declare that there is, to my knowledge, no information in my possession that reasonably has or may have the potential of influencing –

(i) any decision to be taken with respect to the application in terms of the Act and the regulations; or

(ii) the objectivity of this report, plan or document prepared in terms of the Act and these regulations.

Dr Brett Williams
Managing Director
Future Impact (Pty) Ltd

EXECUTIVE SUMMARY

Future Impact were appointed by Aviata Consulting to conduct a desktop review pertaining to glint and glare impacts on aviation receptors as a result of light reflecting off of solar PV panels. The proposed solar facility and its associated infrastructure is located near Carletonville, Gauteng, South Africa.

The assessment was conducted with the objective of determining how ‘glint’ and ‘glare’ will affect aviation receptors such as pilots on final approach to the airport. If the ‘glint’ and ‘glare’ effects are strong enough, it has the potential to cause temporary flash blindness in the receptors and hinder their abilities to conduct their operations. The glare is rated in three categories, namely as green, yellow, and red with red being the highest risk from an aviation perspective as a permanent after image could occur.

The Carletonville airstrip (ICAO: FACR) is a small-scale aerodrome primarily utilized by the Johannesburg Skydiving Club for conducting skydiving operations. The aerodrome features a single runway identified as Runway 13/31, positioned in an East-West configuration. Situated within the Johannesburg Area South-West FAJA ACC Airspace, the aerodrome lacks an Air Traffic Control Tower (ATCT), thus making the aircraft approach paths the sole focus of this glint and glare assessment. These 2-Mile approach paths are as follows:

- 2 Mile Approach Path to Runway 13 describes the aviation receptors when the aircraft is approaching the runway from the West.
- 2 Mile Approach Path to Runway 31 describes the aviation receptors when the aircraft is approaching the runway from the East.

Three Solar PV configurations were assessed for the proposed facility as the developers have not yet finalized the design specifications for the proposed project. This will aid the developers in making an informed decision, from an aviation glint and glare perspective, when confirming the final design parameters of the proposed Solar PV Facility.

The three configurations included a fixed tilt axis configuration, single axis tracking configuration, and a double axis tracking configuration. The modelling results showed that the pilots will not be exposed to glint or glare if a fixed tilt or single axis tracking configuration is implemented. If a double axis tracking configuration is implemented, a pilot approaching from the East (Approach path to Runway 31) will be exposed to a total of 20 minutes of yellow glare and 26.5 hours of green glare throughout the year.

In South Africa, there is limited literature and no regulatory framework with regards to the glint and glare effects from solar panels in relation to airspace use. In the absence of a regulatory requirement, the United States Federal Aviation Administration’s (FAA) Technical Guidance for Evaluating Selected Solar Technologies on Airports, effective as of 11 May 2021, was used as the main reference. The FAA guideline policy states that receptors along the 2-Mile approach path may be exposed to green and yellow glare but may not be exposed to red glare. Furthermore, the policy states that if an ATCT is present, it may not be exposed to any glare.

It is therefore recommended that the project receive authorisation from the Civil Aviation Authority from a glint and glare perspective.

Dr Brett Williams

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

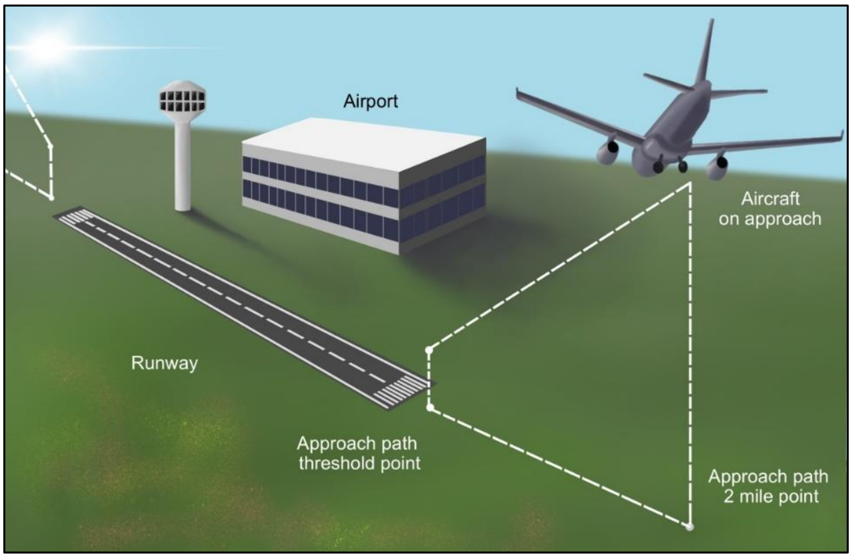

Figure 1: Flight Path

Flight Path Parameters are as follows:

Name: Descriptive alphanumeric label of receptor

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

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

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

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

Azimuthal viewing angle (°): The left and right field-of-view of the pilot during approach. A view angle of 180° implies the pilot can see glare emanating from behind the plane.

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

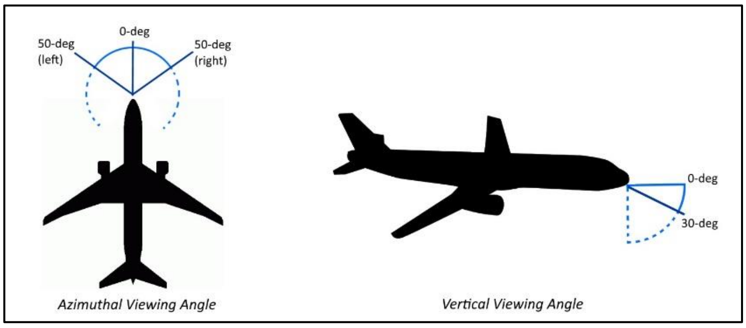

Figure 2: Viewing Angles.

Glint and Glare: Glint is typically defined as a momentary flash of bright light, often caused by a reflection off a moving source. A typical example of glint is a momentary solar reflection from a moving car. Glare is defined as a continuous source of bright light. Glare is generally associated with stationary objects, which, due to the slow relative movement of the sun, reflect sunlight for a longer duration. The difference between glint and glare is duration. Industry-standard glare analysis tools evaluate the occurrence of glare on a minute-by-minute basis; accordingly, they generally refer to solar hazards as 'glare'. Based on figure 3 (below), the ocular impact of solar glare is quantified into three categories:

→Green - low potential to cause after-image (flash blindness)

→Yellow - potential to cause temporary after-image.

→Red - potential to cause retinal burn (permanent eye damage)

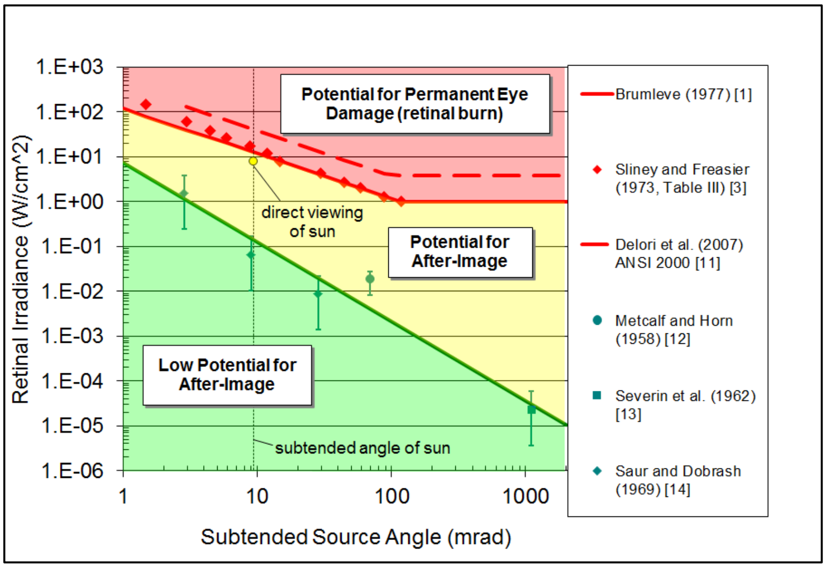

Figure 3: Glare Categories.

mrad: Milliradian, equal to one-thousandth of a radian. A radian is a unit of angular measure equal to the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle, approximately 57°17'44.6".

Peak DNI (W/m2 or Wh/m2): The maximum Direct Normal Irradiance at the given location at solar noon. DNI is the amount of solar radiation received in a collimated beam on a surface normal to the sun during a 60-minute period. On a clear sunny day at solar noon, a typical peak DNI is ~1,000 W/m2.

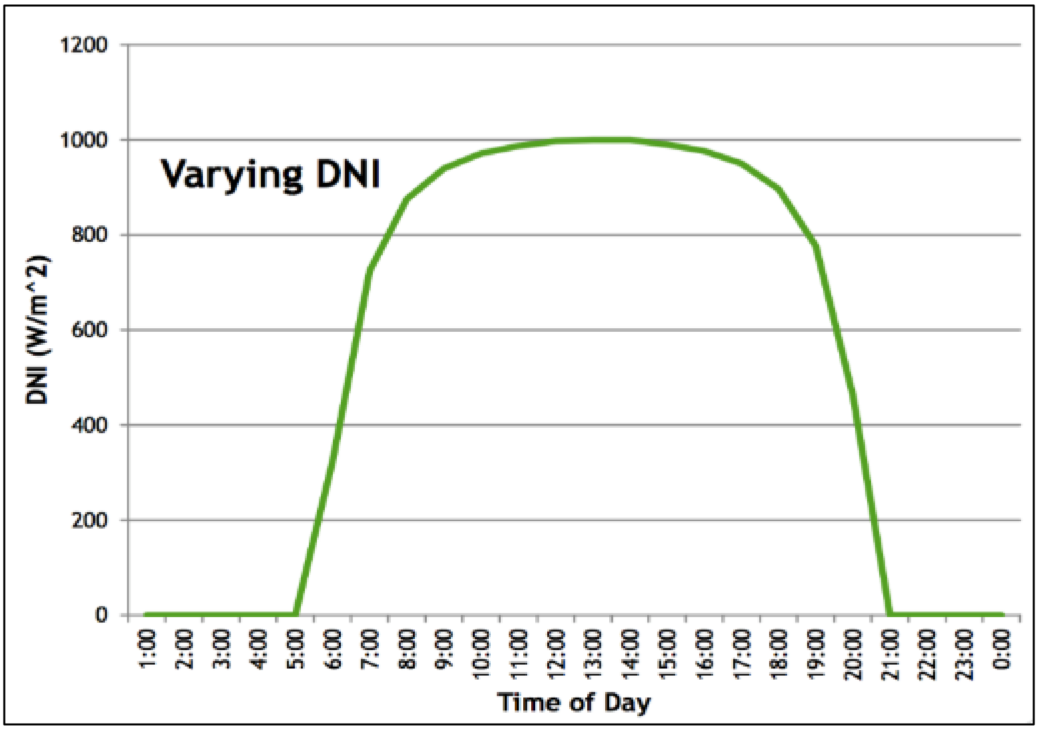

Figure 4: Peak Daily DNI

Slope error (mrad): Specifies the amount of scatter that occurs from the PV module. Mirror-like surfaces that produce specular reflections will have a slope error closer to zero, while rough surfaces that produce more scattered (diffuse) reflections have higher slope errors. Based on observed glare from different PV modules, an RMS slope error of ~10 mrad (which produces a total reflected beam spread of 0.13 rad or 7°) appears to be a reasonable value. Not used if correlate slope error to module surface type is checked. In this report, the worst-case scenario was assumed. Therefore, a light-textured PV panel with an anti-glare coating was selected for modelling. The properties of the selected panel are as follow: 9.16mrad average RMS slope error; 119.00mrad average beam spread; 3.17 standard deviation of slope error; and 38.00 standard deviation of beam error.

Module Reflectance Profiles (surface texture): Sandia National Laboratories developed five generic PV module material reflectance profiles by analysing over twenty PV module samples.

Figure 5 below illustrates the reflectance of each material profile as a function of incidence angle, where an angle of 0° implies the panels are directly facing the sun. For example, a high glancing angle near 90° for panels with 0° tilt (lying flat) occurs daily at sunrise and sunset.

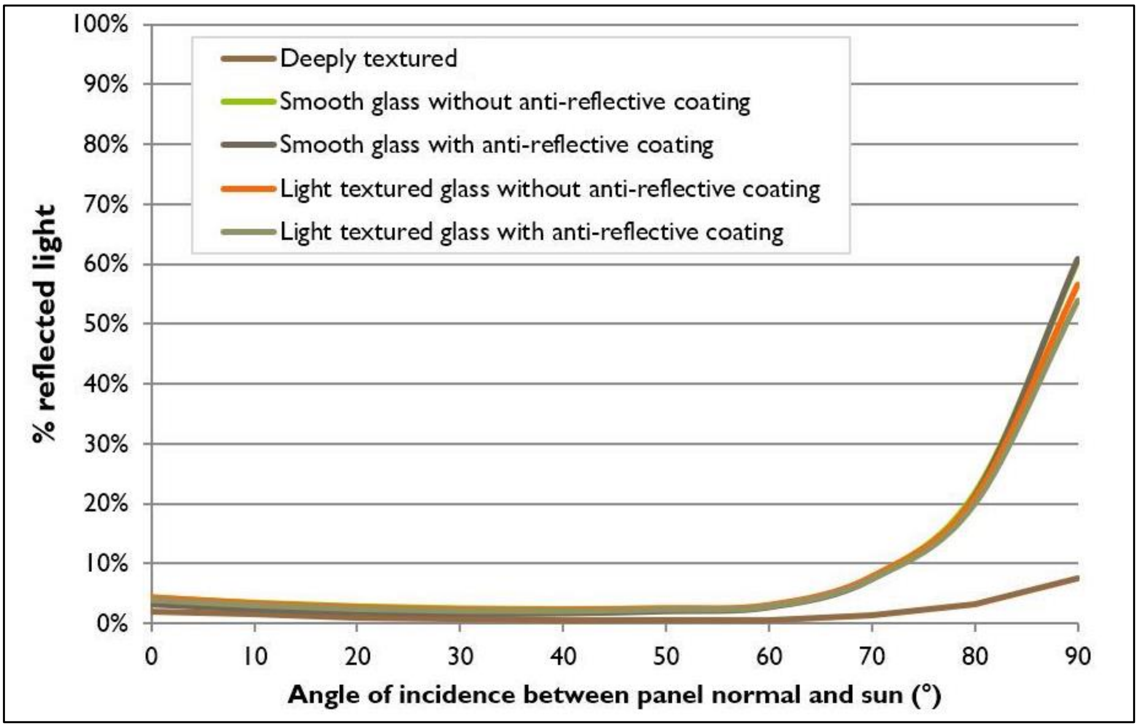

Figure 5: Module Reflectance Profiles

Anti-reflective coatings (ARC) and surface texturing can reduce panel reflectivity, but this reduction is typically less than 8% (Yellowhair, 2015). In addition, greater surface texturing can increase the size of the subtended source angle (i.e. glare spot). All panels modelled in this study are classified as smooth glass surfaces with anti-reflective coating.

ATCT: *Air Traffic Control Tower*
FAA: *Federal Aviation Authority*
FACR: *Airport Code for Carletonville Airport*
FoV: *Field of View*
FP: *Flight Path*
mRad: *milliradian*
OP: *Observation Point*
PV: *Photovoltaic*
RMS: *Root Mean Square*

1 INTRODUCTION

1.1 TERMS OF REFERENCE

This report aims to determine the effect that potential solar PV 'glint and glare' may have on various aviation receptors due to the proposed 150MW Carpe Diem Solar PV Facility in Carletonville, Gauteng, South Africa ("The proposed project"). The main receptors of concern are the aviation receptors (i.e., the pilots) at the Carletonville Airport (FACR). The proposed project is located approximately 5.7km to the south west of the centre of the Carletonville Airport runway 13/31. The airfield consists of one runway. The runway (FACR 13/31) is orientated east to west.

Other community receptors have not been modelled, such as the nearby suburbs and motor vehicles, as this report's focus is solely on the aviation receptors.

At certain angles, the sun may reflect light in a specular manner off the surface of the photovoltaic panels and affect the receptors vision, thereby causing an 'after-image' or 'temporary blindness' depending on the strength of the specular reflection. In South Africa, there is limited scientific literature and no regulatory standard with regards to the 'glint and glare' effects from solar panels in relation to airspace use. In the absence of a specific regulatory standard, the United States Federal Aviation Administration's (FAA) Technical Guidance for Evaluating Selected Solar Technologies on Airports, effective as of 11 May 2021, was used as the main reference. Within this guideline are numerous case studies of solar projects similar to this project. The FAA approved ForgeSolar software package was used to predict the effects of the glint and glare from the PV panels.

1.2 ASSUMPTIONS AND LIMITATIONS

The design specifications of the project were supplied by the client. A summary of assumptions and abstractions required by the ForgeSolar analysis methodology is provided below:

- The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, the software developers have validated the models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque USA, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
- Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects analyses of path receptors.
- Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including Air Traffic Control Towers (ATCT's). The ForgeSolar methodology relies on an analytical, qualitative approach to accurately determine the overall hazard (i.e., green vs. yellow) of expected glare on an annual basis.
- The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)

- The algorithm does not consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
- The variable direct normal irradiance (DNI) feature scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
- The ocular hazard predicted by the tool depends on several environmental, optical, and human factors, which can be uncertain. The developers provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results.
- The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round.
- Hazard zone boundaries shown in the Glare Hazard plot (based on Figure 3) are an approximation and visual aid. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
- Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
- Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
- Due to technical constraints of the software, the geometry of the original solar PV array layout (supplied by the client) was simplified to reduce the number of vertices. Areas where circular "no-go" buffers have been identified have been excluded to reduce the number of vertices of the polygons. Clusters of smaller PV arrays, separated by areas where it is not suitable to build these structures, have been aggregated to form one larger array. This simplification of geometries considers the worst-case scenario. Therefore, the impacts of solar PV arrays built on the intended areas will be the same or lower as the worst-case scenario.

2 LEGAL REQUIREMENTS

There are no legal requirements or guidelines that are applicable in South Africa. The US FAA guidelines were used as a reference.

3 PROJECT DESCRIPTION

The client is proposing the installation of a 150MW Solar PV Facility. The final design parameters have not yet been confirmed as three options are being considered, as described below:

1. **Fixed-tilt Solar PV structures** mounted 5m above the ground. These panels will be orientated at 90º towards the North (i.e. east to west) and tilted between 22º and 25º. Several simulations were run at various tilt angles within this range. The modelling results showed that the tilt angle of 22º resulted in the most exposure time to glint and glare on the aviation receptors and is therefore described in this report as this configuration represents a worst-case scenario.
2. **Single Axis Tracking System Solar PV Structures** mounted 5m above the ground. These panels will be orientated at 90º to the north (i.e. north to south) and will have a maximum tracking angle of 60º. The resting angle will be 30º.

3. **Double Axis Tracking System Solar PV Structures** mounted 5m above the ground. The double axis solar panel tracking system is designed to maximize solar energy generation by dynamically orienting solar panels towards the sun's position. This system utilizes both horizontal and vertical axes to achieve precise tracking.

The project will be located approximately 5.7km to the south west of the centre of the FACR Runway, as seen below in Figure 6 below.

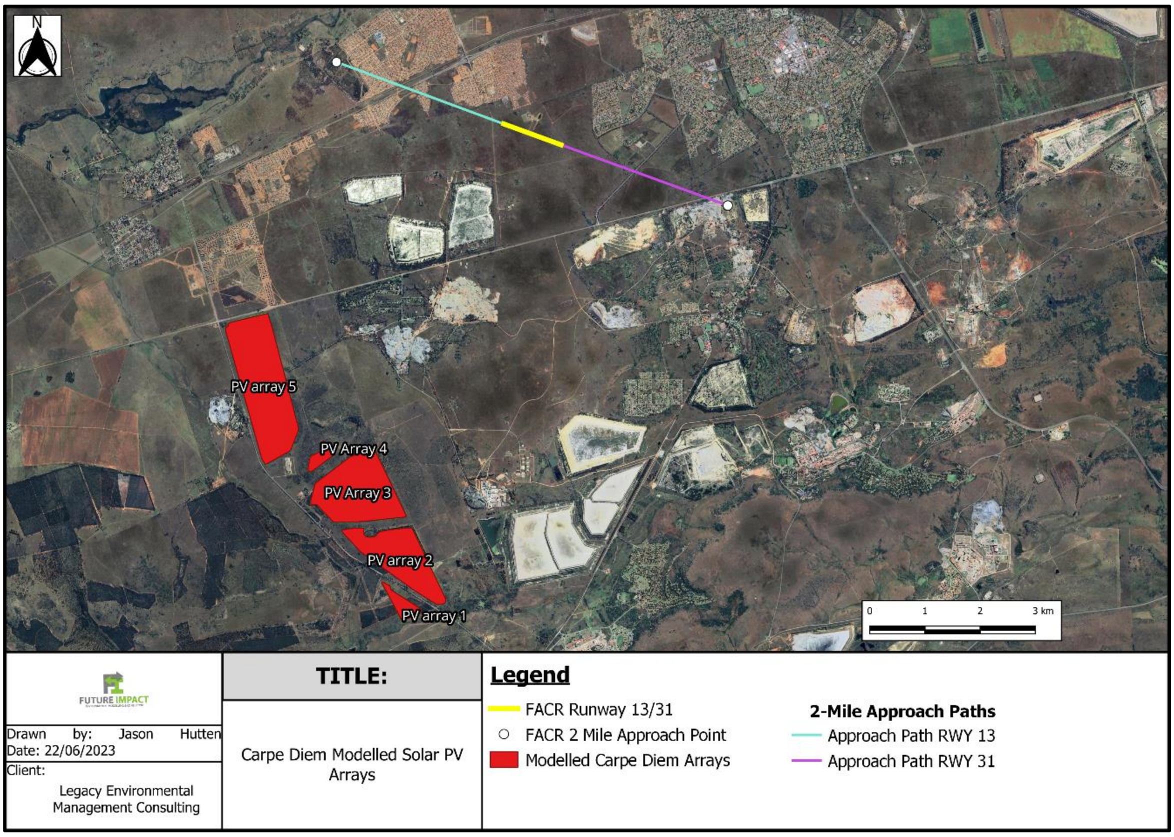

Figure 6: Regional Context

4 THE RECEIVING ENVIRONMENT

The proposed project may impact on aviation receptors located approximately 5.7km to the north east. The Carletonville Airport consists of one runway with two approach flight paths (FACR Runway 13 & FACR Runway 31). No Air Traffic Control Tower (ATCT) is present. The flight paths used in modelling are 2 miles long (statute miles is used in aviation studies as the flight navigational aids are referenced in miles. The software United States FAA distance parameters). Figure 6 above shows the two flight paths that were assessed. The small-scale airstrip is predominantly utilized by the Johannesburg Skydiving Club and no commercial airliners operate here.

5 RESULTS

The sections below show the results for each tracking system configuration. The analysis parameters and observer eye characteristics were as follows:

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

5.1 MODELLING RESULTS: FIXED TILT CONFIGURATION

The modelling results indicate that receptors will experience no glint and glare exposure throughout the year if a fixed tilt system, tilted at 22º and with a height of 5m is implemented. The orientation of panels is in this configuration is from east to west.

5.2 MODELLING RESULTS: SINGLE AXIS TRACKING CONFIGURATION

Utilizing a single axis tracking system with a maximum tracking angle of 60º, a height of 5m and a resting angle 30º will result in no glint and glare exposure throughout the year.

5.3 MODELLING RESULTS: DOUBLE AXIS TRACKING CONFIGURATION

If a double axis tracking system is used as the preferred configuration for the Carpe Diem Solar PV Facility, the receptor on the approach path to runway 31 (approaching from the east) may be exposed to 26.5 hours of green glare and 0.3 hours of yellow glare. Yellow glare has the potential to cause a temporary after-image to the receptors vision. Table 1 below shows the amount of glare that each receptor may be exposed to throughout the year if this configuration is utilized.

Table 1: Glint and Glare exposure time

Receiver Name	Green Glare (mins)	Green Glare (hours)	Yellow Glare (mins)	Yellow Glare (hours)	Red Glare (mins)
FACR Runway 13	0.0	0.0	0.0	0.0	0.0
FACR Runway 31	1 592	26.5	20	0.3	0.0
Total	**1 592**	**26.5**	**20**	**0.3**	**0.0**

PV array 4 and PV array 5 will expose the receptors to green glare for 2.7 hours and 26.5 hours respectively. Yellow glare exposure will be caused by PV array 5 exclusively (for 0.3 hours throughout the year). Figures 7-12 below provide further details of the glare exposure to receptors on the approach path to runway 31. The receptor for the approach path to runway 13 (approaching from the west), will not be exposed to any glare.

5.3.1 PV Array 4 Glint and Glare Profile (Double Axis Tracking System)

PV array 4 will cause green glare exposure during June and July in the morning hours when the sun is rising in the east. This exposure will occur from approximately 07h00 to 07h30. The maximum daily exposure will be approximately 10 minutes.

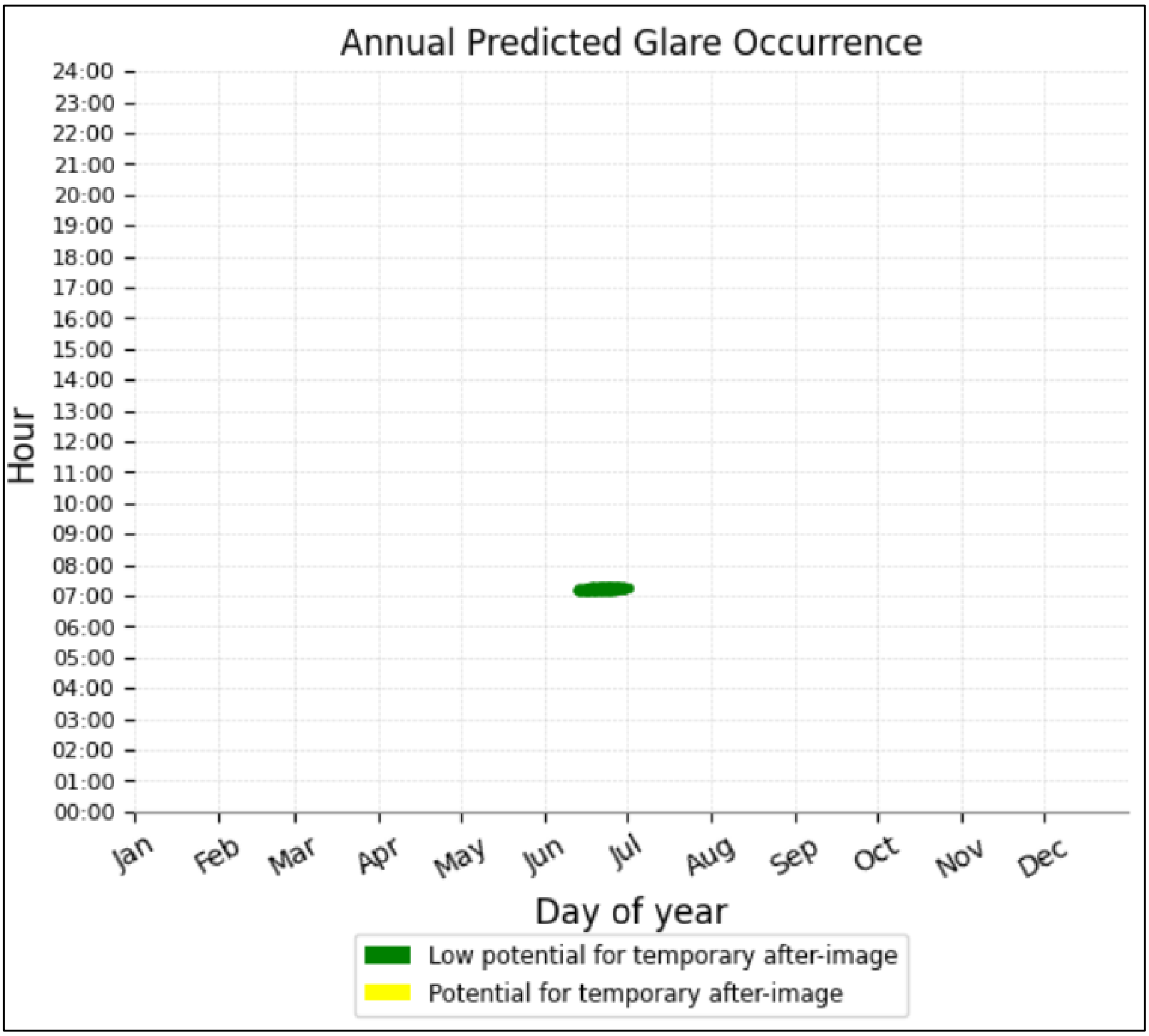

Figure 7: Annual Glare Exposure

The exposure will occur at the beginning of the pilot's approach path, as indicated below by the green dot.

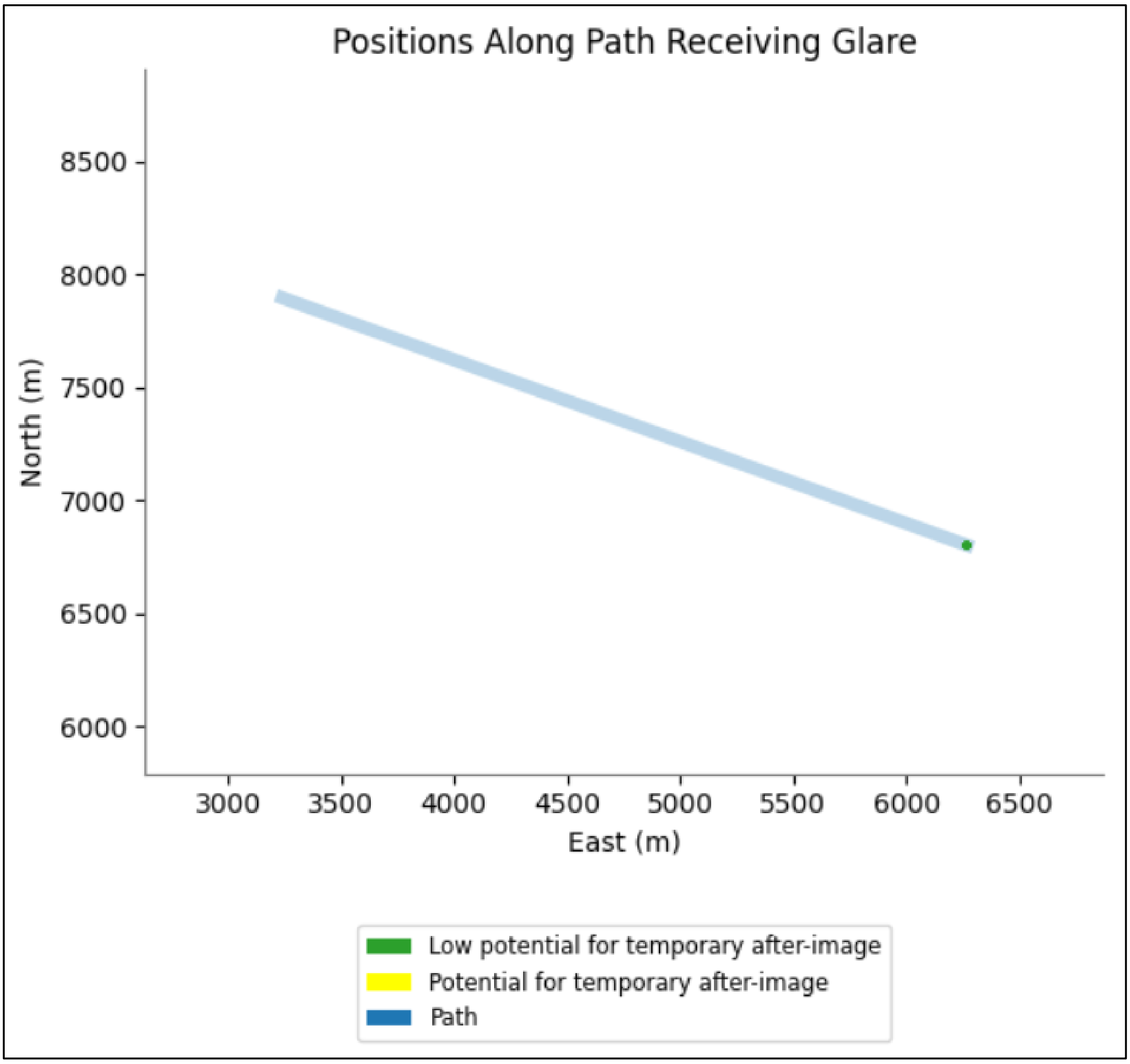

Figure 8: Position along approach path where glare will occur

The green glare will be a result of light reflecting off of the northern section of PV array 4, as seen in the PV array footprint below.

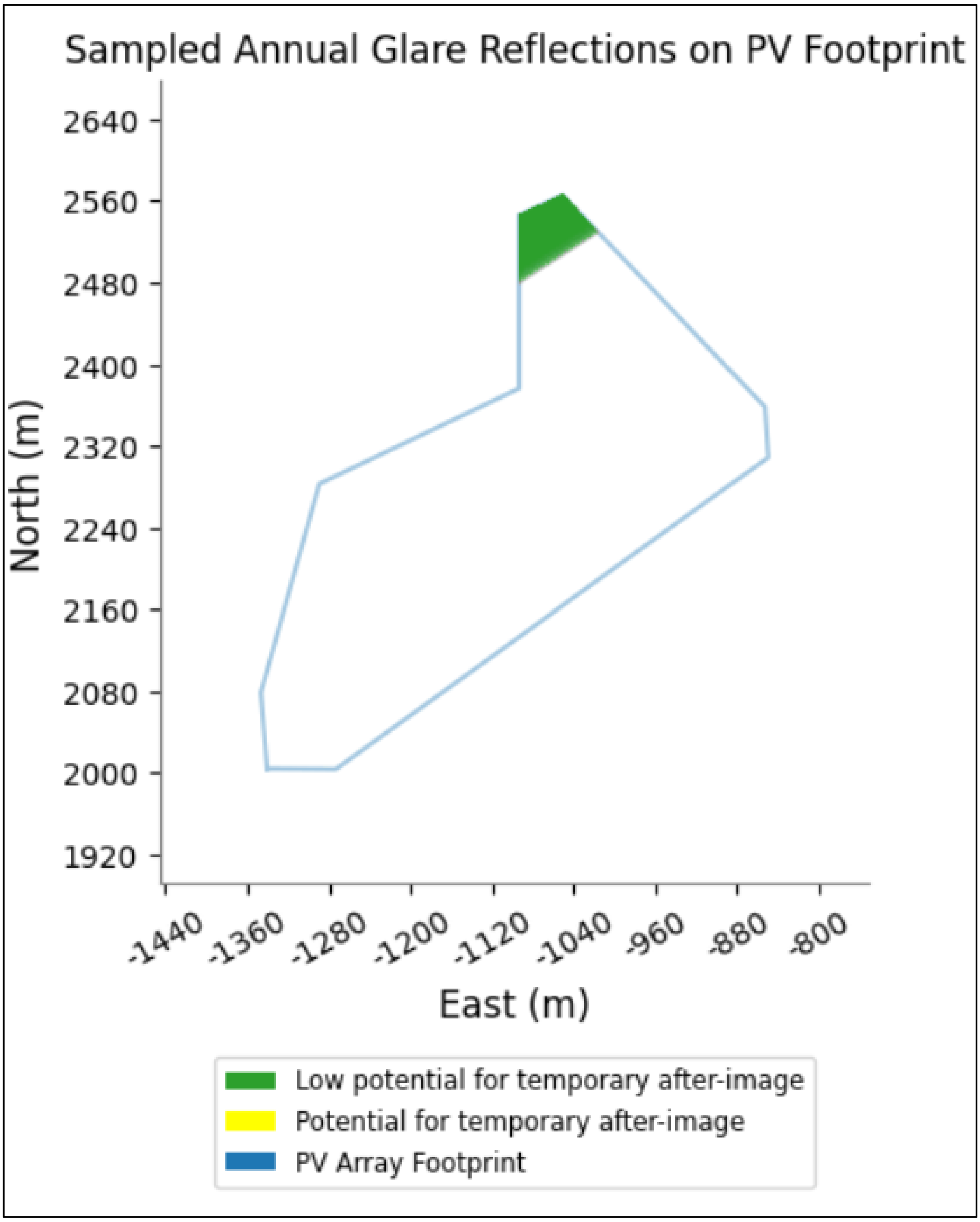

Figure 9: Areas of the PV array 4 footprint responsible for glare

5.3.2 PV Array 5 Glint and Glare Profile (Double Axis Tracking System)

PV array 5 will cause green and yellow glare exposure from April to September in the morning hours when the sun is rising in the east. This exposure will occur from approximately 06h30 to 07h30. The maximum daily exposure will be approximately 15 minutes.

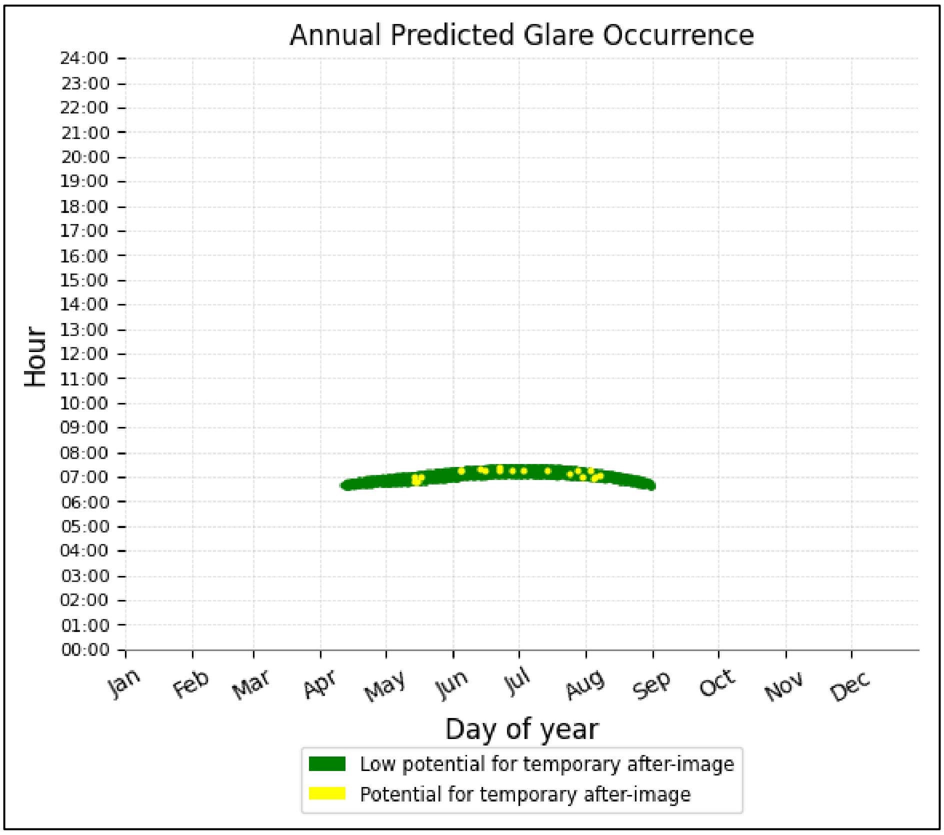

Figure 10: Annual Glare Exposure

The exposure will occur along the majority of the pilot's approach path, as indicated below.

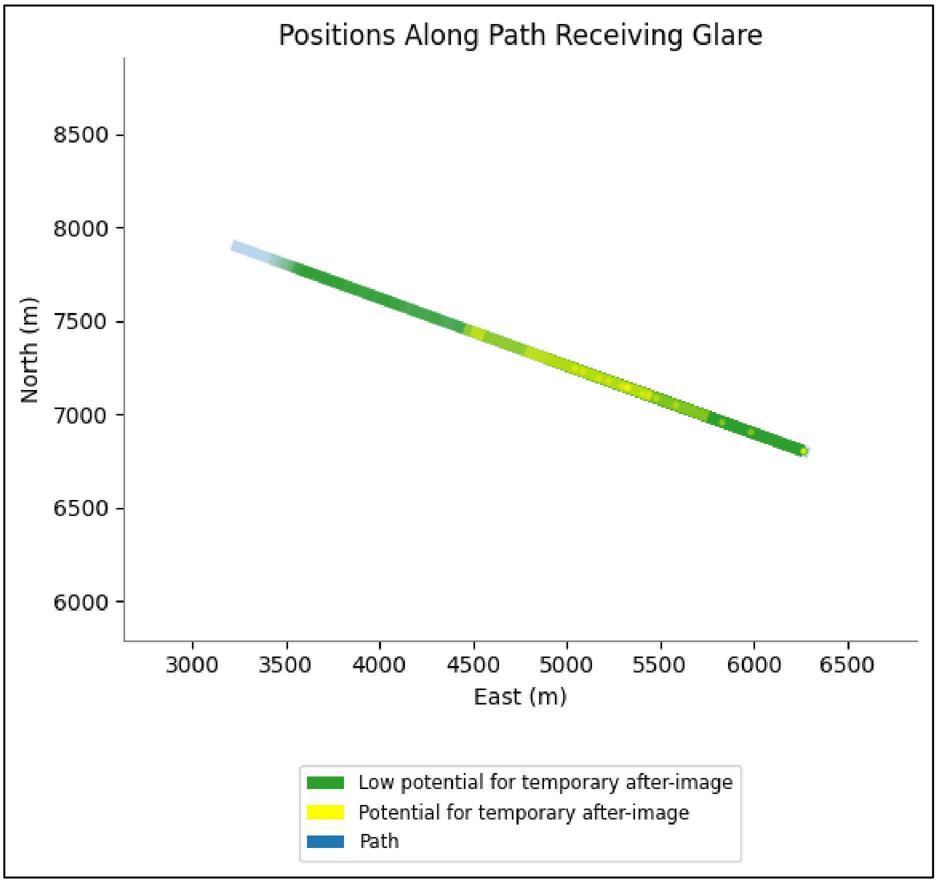

Figure 11: Position along approach path where glare will occur

The green glare will be a result of light reflecting off of the entire area of PV array 5, as seen in the PV array footprint below. Yellow glare will be experienced over most of the PV footprint area, however, the majority of the yellow glare will be produced by the southern section of the PV footprint.

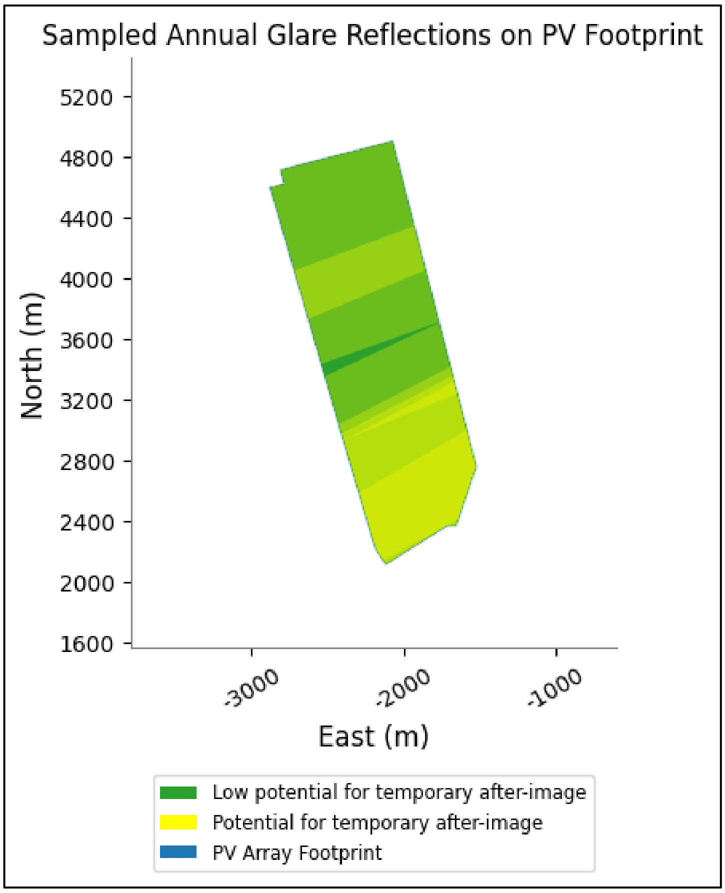

Figure 12: Areas of the PV array 5 footprint responsible for glare

6 CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to determine the impact that solar glint and glare would have on various aviation receptors. The FAA model considered the 2-mile receptors on the approach to the various runways. An Air Traffic Control Tower (ATCT) was not considered as none are present at the Carletonville Airport.

The modelling results indicate that the receptors will be exposed to no glint and glare if a fixed tilt system or single axis tracking system are used.

If a double axis tracking system is used, the aviation receptors on the approach path to runway 31 (approaching from the east of the Carletonville Airport) will be exposed to green and yellow glare.

According to the FAA Guidelines, the glint and glare impacts are acceptable due to the following reasons:

- The receptors on the approach paths are not exposed to red glare, which has the potential to cause a permanent after-image to the receptor.
- No ATCT is present (if an ATCT is present, it should not be exposed to any glare).

It is therefore recommended that the project receive authorisation from the Civil Aviation Authority from a glint and glare perspective.

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7 BIBLIOGRAPHY

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- Yellowhair, J. and C.K. Ho. "Assessment of Photovoltaic Surface Texturing on Transmittance Effects and Glint/Glare Impacts". ASME 2015 9th International Conference on Energy Sustainability collocated with the ASME 2015 Power Conference, the ASME 2015 13th International Conference on Fuel Cell Science, Engineering and Technology, and the ASME 2015 Nuclear Forum. 2015. American Society of Mechanical Engineers.