GLINT AND GLARE ANALYSIS
EERO
SOLAR POWER PARK

For NORDIC GENERATION

19.08.2024

Administration

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3	19.08.2024	Updated to change from 35° to 30° panel tilt angle

EXECUTIVE SUMMARY

Report Purpose

Welado Oy has been commissioned to evaluate the potential impact of light reflection and glare resulting from a proposed solar photovoltaic (PV) installation in Kajaani, Finland. This evaluation specifically addresses the potential effects on a 2km segment of road, extending from Iisalmentie 713 to Iisalmentie 995. The solar farm is planned to be situated within 15 meters of these boundaries

Findings

Potential solar reflections from the proposed development are to be expected while traveling along the Iisalmentie road from both directions.

Assessment Results – Aviation Receptors

No assessment has been undertaken for the aviation sector

Assessment Results – Dwellings

No assessment has been undertaken for the surrounding houses

Assessment Results – Road: Iisalmentie

The analysis indicates that solar reflections from the proposed solar development could affect road users traveling in both directions on Iisalmentie road, from early March through to early October.

Overall Conclusion

The assessment indicates that the proposed development could potentially cause solar reflections for travelers heading both north and south on Iisalmentie. While the glare is not expected to cause damage, it could potentially distract motorists. Therefore, measures should be implemented to mitigate this glare and prevent it from distracting drivers

Recommendation

In light of the glare radiating from the solar power plant, we propose the installation of two (2) fences along Iisalmentie road. The first fence, referred to as the Southern fence, should stand at a minimum height of 2m and span approximately 320m in length. The second fence, referred to as the Northern fence, should stand at a minimum height of 3m and span approximately 430m in length.

We suggest that the fences be constructed from wood due to its cost-effectiveness. However, alternative materials such as concrete or metal may be used, provided they are coated with a non-reflective (matte) paint. The color of the paint should either be approved by the municipality or be in non-offensive hues that blend with the surrounding forest, such as dark green.

CONTENTS

OVERVIEW

Nordic Generation Oy is in the process of planning a solar power plant with a maximum capacity of 98.35MWp in the region of Kajaani, Finland. The proposed project site spans a maximum area of 178 hectares and is situated entirely within the boundaries of three (3) properties (205-408-10-21, 205-408-10-23, 205-108-21-3).

The project site is positioned approximately 24 kilometers southwest of Kajaani's city center. The entirety of the project area currently comprises farmland. Additionally, there are several patches of forest land within the area, characterized by sparse, young mixed woodland.

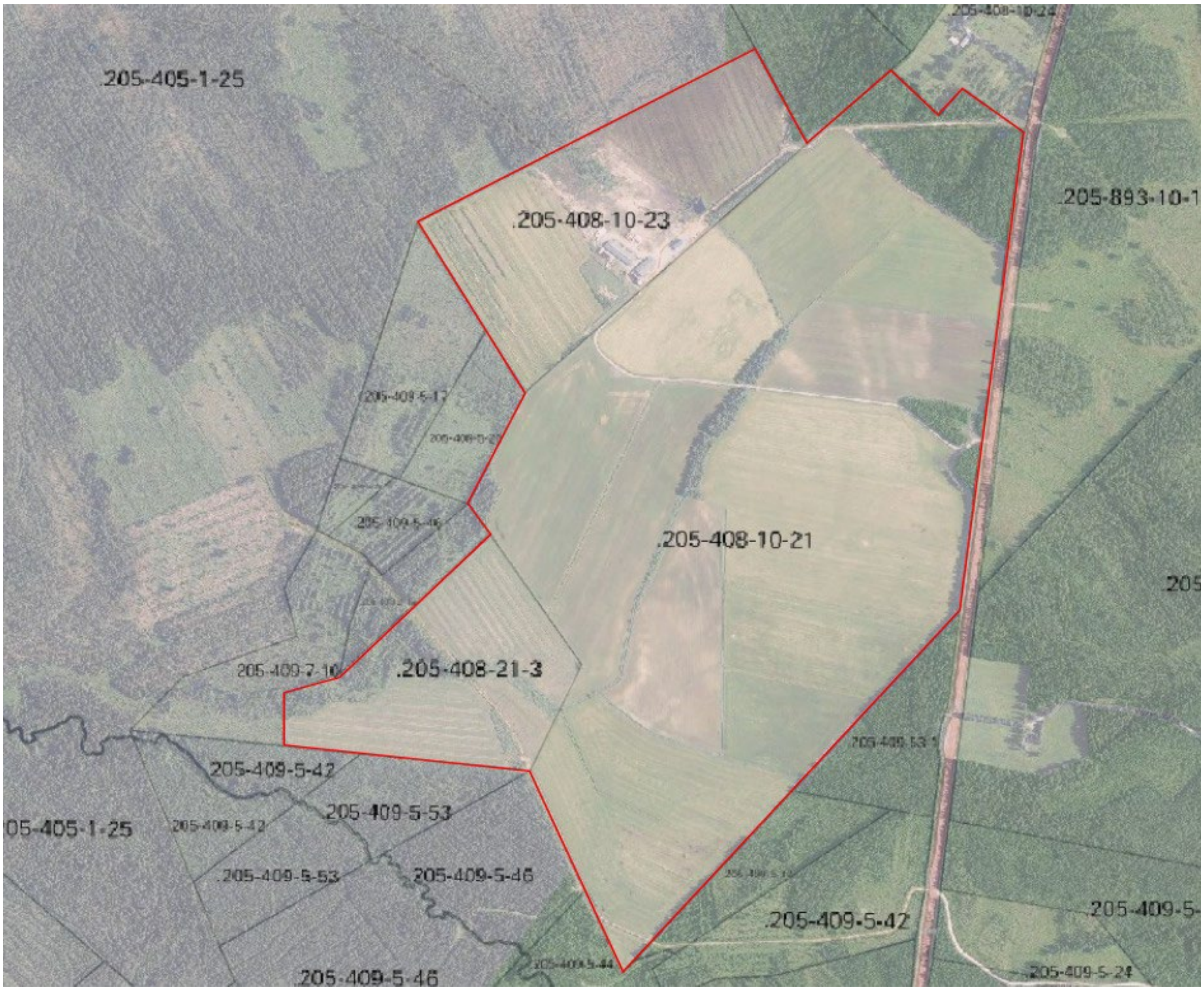


Figure 1 – Dwelling & route receptors

Project Scope

Welado Oy has been commissioned to conduct an investigation into the potential solar glint and glare effects of the proposed 98.35MW solar power plant under development in the Kajaani region. This investigation has been initiated in response to concerns raised by the Kajaani municipality, specifically pertaining to the Iisalmentie road and the potential impact on motorists.

The Kajaani municipality has requested that this investigation determine the extent of solar glare that could be generated from the proposed solar power plant and provide a risk assessment based on the findings. It should be noted that the Finnish Transport and Communications Agency retains the authority to prohibit, limit, or impose conditions on the operation of the solar farm based on the results of this investigation.

In particular. The analysis contains the following:

- Details of the solar development.
- Explanation of glint and glare.
- Overview of relevant guidance.
- Overview of relevant studies.
- Identification of aviation concerns and receptors.
- Assessment methodology.
- Glint and glare assessment for:
    - Roads,
- Results discussion.

Glint and Glare Definition

The definition of glint and glare can vary however, the definition used by Welado Oy is as follows:

- Glint – a momentary flash of bright light typically received by moving receptors or from moving reflectors.
- Glare – a continuous source of bright light typically received by static receptors or from large reflective surfaces.

PROPOSED DEVELOPMENT LOCATION AND DETAILS

Proposed Development – Location

The location of the proposed development is shown in the aerial image1 of Figure 1 below (panel arrays shown by blue outline).

Figure 2 – Location of proposed development

Proposed Development – Layout

The arrangement of the solar panels has been provided by Nordic Generations Oy. Their details are as follows:

Panel tilt: 30 degrees,
Panel orientation: 180 degrees (south facing),
Height of the panel above ground: 1m at the front.

GLINT AND GLARE ASSESSMENT METHODOLOGY

Guidance and Studies

Appendix A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels and glass are possible.
- The measured intensity of a reflection from solar panels can vary from 2% to 30% depending on the angle of incidence.
- Published guidance shows that the intensity of solar reflections from solar panels are equal to or less than those from water and similar to those from glass. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

Background

Details of the Sun's movements and solar reflections are presented in Appendix C.

Methodology

The evaluation approach draws from guidelines, research, past stakeholder interactions, and the hands-on experience of Welado. Details about the methodologies employed by both Welado and Sandia National Laboratories are provided.

Welado's Methodology

The glint and glare assessment methodology has been derived from the information provided to Welado through consultation with stakeholders and by reviewing the available guidance. The methodology for the glint and glare assessment is as follows:

- Identify receptors in the area surrounding the proposed development.
- Consider direct solar reflections from the proposed development towards the identified receptors by undertaking geometric calculations.
- Consider the visibility of the reflectors from the receptor's location. If the reflectors are not visible from the receptor, then no reflection can occur.
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur.
- Consider the solar reflection intensity, if appropriate.
- Consider both the solar reflection from the proposed development and the location of the direct sunlight with respect to the receptor's position.
- Determine whether a significant detrimental impact is expected in line with Appendix D.

In Welado's model, the area of the reflector and the pertinent receptor locations are determined. This leads to a diagram indicating the possibility of a reflection, its duration, and the panels capable of generating a solar reflection towards the receptor. If a solar reflection is detected for a receptor on an aviation approach path, intensity computations are performed following the methodology of Sandia National Laboratories (which will be elaborated in the next section).

SolarForge Methodology

Sandia National Laboratories developed the Solar Glare Hazard Analysis Tool (SGHAT) which is no longer available.

Solarforge and their modelling software GlareGauge, utilizes the Solar Glare Hazard Analysis Tool technology developed by Sandia National Laboratories, stands out for its comprehensive use of SGHAT algorithms. These algorithms allow for the analysis of entire flight paths and individual receptor points. A notable aspect of GlareGauge and ForgeSolar is the involvement of Cianan Sims, the co-inventor of SGHAT, who frequently provides technical support to users.

GlareGauge offers several unique benefits not found in other glare tools, including the soon-to-be-retired SGHAT site from Sandia. These benefits encompass the ability to analyze entire flight paths for more comprehensive results, the capability to model potential glare generators like glass buildings and billboards beyond PV arrays, and the feature to save and load site configurations and results from any computer, eliminating the need to re-run analyses. Furthermore, GlareGauge uses new and improved glare-check algorithms for repeatable, rigorous results and features an enhanced interface for easier creation and organization of analyses.

ForgeSolar is used globally by industry, academia, and military to evaluate PV glare. ForgeSolar satisfies FAA, EU, and other regulatory requirements including ocular impact and luminance.

Overview

This assessment has been carefully carried out, concentrating on the potential implications for the Iisalmentie road. It's important to note that there is no officially established guidance concerning the maximum distance for evaluating glint and glare. In theory, there are no boundaries to the distance at which potential reflections can transpire.

However, the influence of a solar reflection diminishes as the distance expands. This can be attributed to the fact that as the distance augments, the reflective area constitutes a smaller fraction of an observer's visual field. For observers based on the ground, the probability of the terrain and vegetation obstructing the view escalates with the increase in distance. This is a crucial factor to consider in our analysis.

Roads

The analysis has considered through-roads that:

- Are within, or close to one kilometre of the proposed development; and
- Have a potential view of the panels.

Route Receptors

Name: Iisalmentie road

- Path type: Two-way
- Observer view angle: 180.0°
- Coordinate Start: 64.050784, 27.452060
- Coordinate Finish: 64.032224, 27.446610

Figure 3 – Dwelling & route receptors

Vegetation Obstacles

The road way passes dense forest land before and after the proposed solar powered plant and is assumed that this forest will stay in situate. It has been considered that the forest will not be removed in the near future and have considered this to be an obstacle during the evaluation process.

Obstacles 1

Name: Tree Line 1

Top height: 5.0 m– actual height may differ onsite

Location: 64°02'58.8"N 27°27'05.5"E

Figure 4 – Tree Line 1

Obstacles 2

Name: Tree Line 2

Top height: 5.0 m – actual height may differ onsite

Location: 64°02'26.8"N 27°26'44.3"E

Figure 5 – Tree Line 2

Obstacles 3

Name: Tree Line 2

Top height: 5.0 m– actual height may differ onsite

Location: 64°02'42.2"N 27°26'59.8"E

Figure 6 – Tree Line 3

General Site and Project Information

Model input information	
Time Zone	UTC+02:00
Minimum Sun Altitude	0.0 deg
Direct Normal Irradiation (DNI)	peaks at 1,000.0 W/m
Ocular transmission coefficient	0.5
Pupil diameter	0.002m
Eye focal length	0.017m
Sun subtended angle	9.3 mrad

Table 1 – Model information

PV Array location

Model input information	
Axis tracking	Fixed (No rotation)
Tilt	30.0°
Orientation	180° (South facing panels)
*Rated panel power (estimated)	665.0 watts
Panel material	Smooth glass with Anti-Reflective (AR) coating
Reflectivity	Vary with sun
Slope error	Correlate with material

Table 2 – Array information

*Rated power may change during the development or construction phase; however, it does not impact the results within this report

GLINT AND GLARE ASSESSMENT RESULTS

Overview

The subsequent section provides a summary of the solar reflection modelling for the receptors identified. The model has been employed to ascertain the possibility of reflections.
When solar reflections are anticipated, intensity computations are performed following the methodology of Sandia National Laboratories. In instances where glare is predicted, the intensity model estimates the expected intensity of a reflection in relation to the potential occurrence of an after-image or something more severe.

The model's designation, along with the corresponding colour coding, is displayed in Table 3 below. This model has utilised industry standard solar panels with an anti-reflection coating (ARC) being applied.

Coding Used	Intensity Key
Low potential	Potential for After-Image Zone Low Potential for After-Image Zone Permanent Retinal Damage Zone Hazard from Source Data Hazard Due to Viewing Unfiltered Sun
Potential	
Potential for permanent eye damage	

Table 3 – Glare intensity designation

Glint and Glare Impact Significance

The impact of glint and glare can differ based on the receptor. This section provides a broad understanding of the criteria for significance in relation to solar reflection.

The subsequent table offers a suggested interpretation of 'impact significance' in terms of glint and glare, along with the necessary mitigation measures for each category.

Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.

Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels.	No mitigation required.
Potential	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation.
Potential for permanent eye damage	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact.	Mitigation will be required if the proposed development is to proceed.

Table 4 – Impact significance

Summary of Results

The tables in the following subsections summarise the months and times during which a solar reflection could be experienced by a receptor.

This does not mean that reflections would occur continuously between the times shown.

The range of times at which reflections are geometrically possible is generally greater than the length of time for any particular day. This is because the times of day at which reflections could start and stop vary throughout the days/months.

The results of the analysis are presented in the following sections. Appendix B presents the results charts.

Geometric Calculation Results Overview

The results of the geometric calculation are presented in Table 4 on the following page.

Receptor	Predicted reflection times (GMT)			Comment
	AM	PM	Glare Type	
Iisalmentie Route	None.	Yes	Potential	potential of after image with a low retinal irradiance

Table 5 - Geometric Calculation Results

Geometric Assessment Results and Discussion

Iisalmentie Route

The photovoltaic array is projected to generate the following types of glare for this receptor:

- Approximately 197 minutes (3.3hrs) of "green" glare, which carries a low potential for inducing temporary after-images.
- Roughly 7,980 minutes (133.0hrs) of "yellow" glare, which has the potential to cause temporary after-images.

Our study suggests a potential for after-images occurring daily between 17:00 – 18:45 from early March through early October, with an estimated duration of approximately 40 minutes each evening.

Distinct glare per month

PV	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pv-array-1 (green)	0	0	17	25	35	31	38	26	24	1	0	0
pv-array-1 (yellow)	0	0	690	1206	1270	1255	1277	1255	1020	7	0	0

Figure 7 – Monthly figures

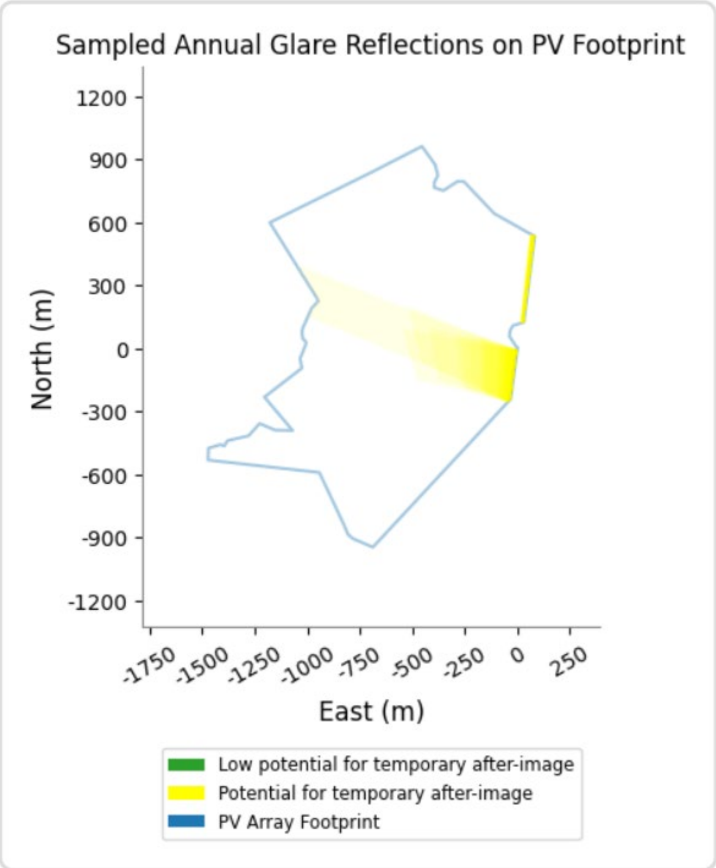
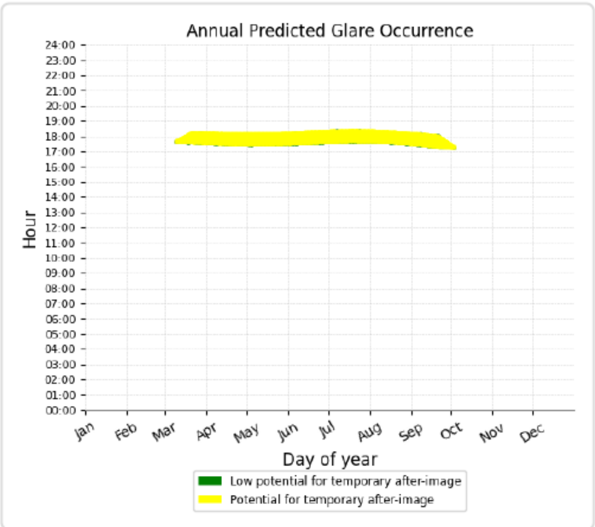
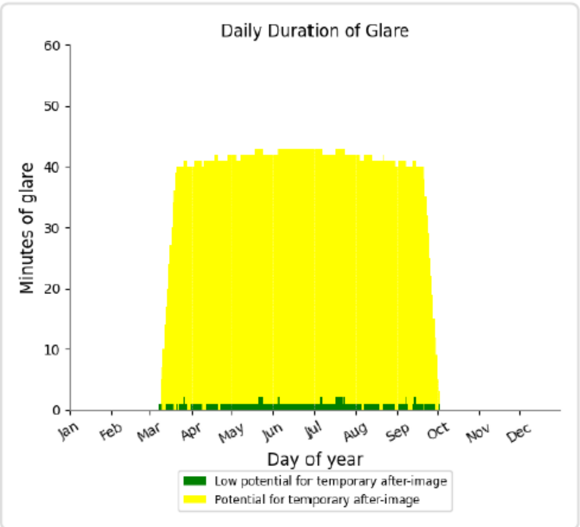
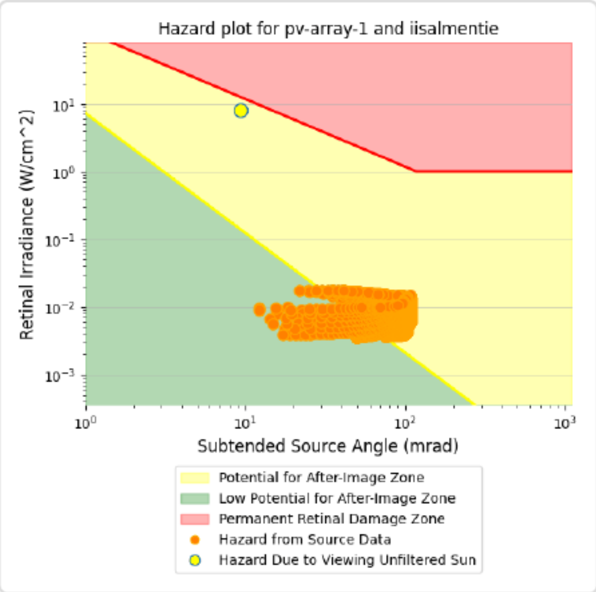


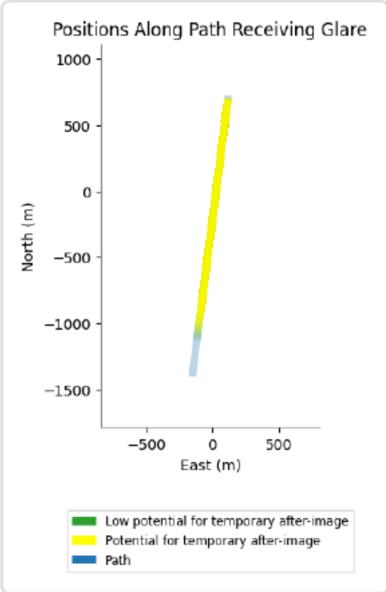
Figure 8 – Glare from solar power plant

Figure 9 –Satellite image of the solar power plant









Recommendation

Considering the glare produced by the solar power plant, we recommend the erection of two (2) barriers along Iisalmentie road. The first barrier, known as the Southern barrier, should have a minimum height of 2m and an approximate length of 320m.

The second barrier, known as the Northern barrier, should have a minimum height of 3m and an approximate length of 430m. We advise that these barriers be built from wood due to its economic advantage. However, other materials like concrete or metal could be considered, given they are treated with a non-reflective (matte) paint. The paint color should be either sanctioned by the municipality or chosen to be in unobtrusive shades that harmonize with the neighboring forest, such as dark green

Geometric Calculation Results Overview with Fences Installed

The results of the geometric calculation are presented in Table 4 on the page 15.

Receptor	Predicted reflection times (GMT)			Comment
	AM	PM	Glare Type	
Iisalmentie Route	None.	Yes	Potential	potential of after image with a low retinal irradiance

Table 6 - Geometric Calculation Results

Geometric Assessment Results and Discussion

Iisalmentie Route

The photovoltaic array is projected to generate the following types of glare for this receptor:

- Approximately 425 minutes (7.1 hrs) of "green" glare, which carries a low potential for inducing temporary after-images.
- Roughly 716 minutes (11.9hrs) of "yellow" glare, which has the potential to cause temporary after-images.

Our study suggests a potential for after-images occurring daily between 17:30 – 18:30 from early March through late September, with an estimated duration of less than 10 minutes each evening.

Distinct glare per month

PV	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pv-array-1 (green)	0	0	16	27	90	120	116	32	24	0	0	0
pv-array-1 (yellow)	0	0	58	112	111	120	112	114	89	0	0	0

Figure 10 – Monthly figures

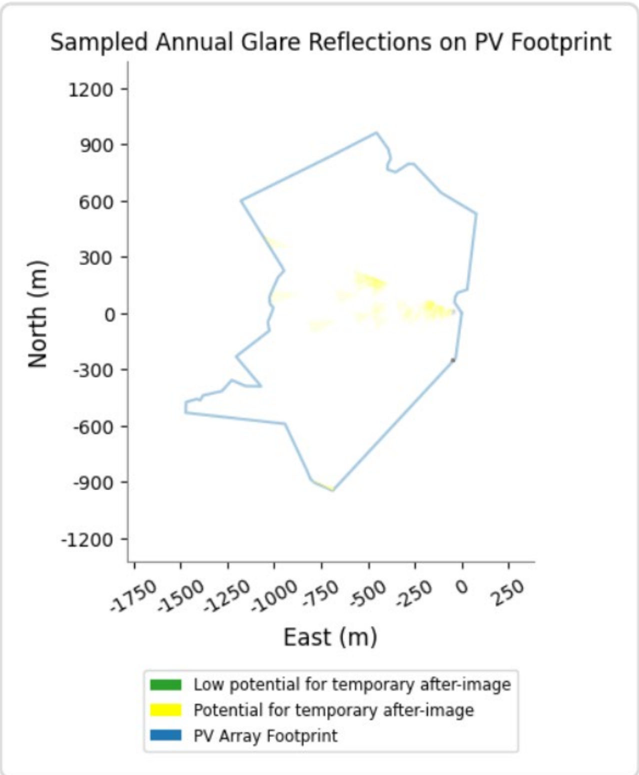
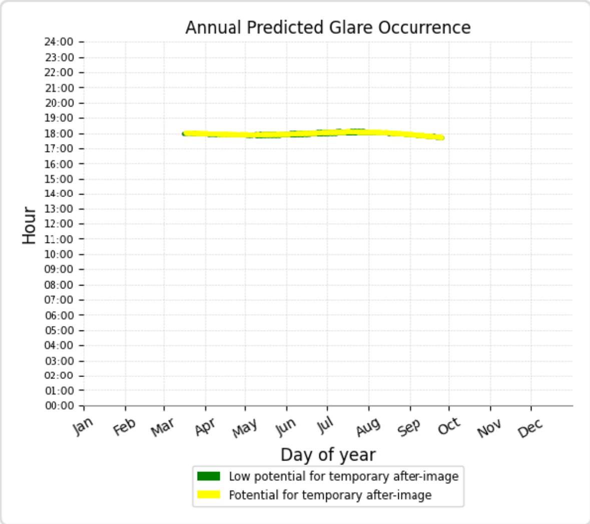
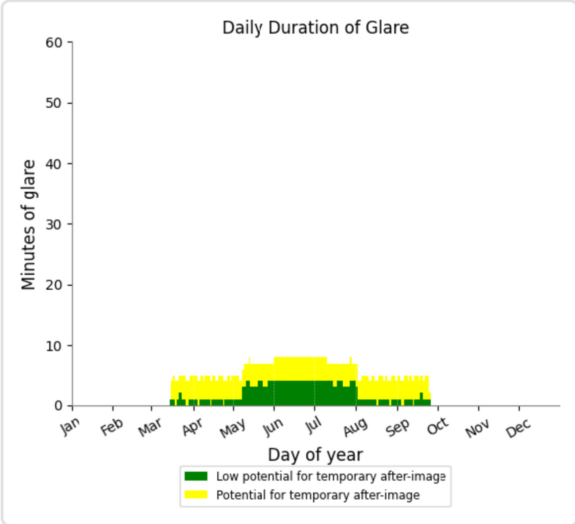
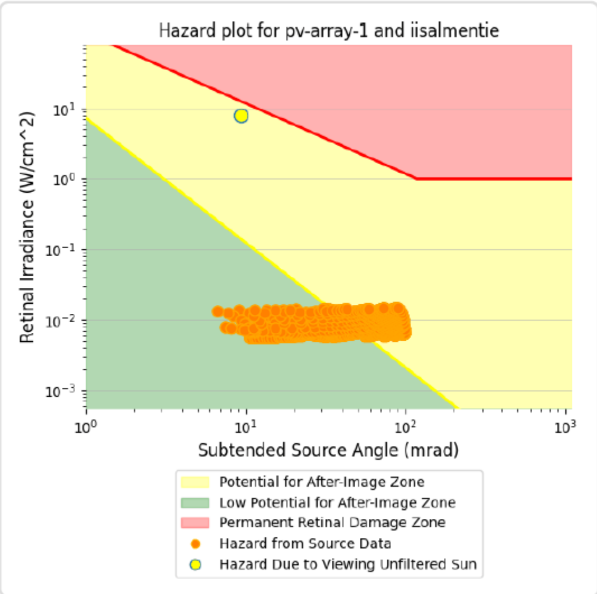


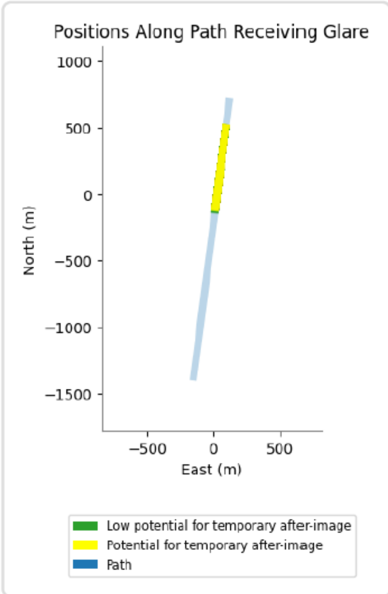
Figure 11 – Glare from solar power plant

Figure 12 –Satellite image of the solar power plant


Annual Predicted Glare Occurrence
Hour
Day of year
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Low potential for temporary after-image
Potential for temporary after-image


Daily Duration of Glare
Minutes of glare
Day of year
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Low potential for temporary after-image
Potential for temporary after-image


Hazard plot for pv-array-1 and iisalmentie
Retinal Irradiance (W/cm^2)
Subtended Source Angle (mrad)
Potential for After-Image Zone
Low Potential for After-Image Zone
Permanent Retinal Damage Zone
Hazard from Source Data
Hazard Due to Viewing Unfiltered Sun


Positions Along Path Receiving Glare
North (m)
East (m)
Low potential for temporary after-image
Potential for temporary after-image
Path

Location of Fence

Figure 13 – Fence location overview

Name: Fence 1
Upper edge height: 2.0 m

Vertex	Latitude deg	Longitude deg	Ground elevation m
1	64.044511	27.449904	171.92
2	64.042202	27.449142	170.00

Figure 14 – Fence location - South

Name: Fence 2 North
Upper edge height: 3.0 m

Vertex	Latitude deg	Longitude deg	Ground elevation m
1	64.049356	27.451461	177.37
2	64.045512	27.450299	173.00

Figure 15 – Fence location - North

TYPES OF FENCES TO BE CONSIDERED

Given the need for two (2) barrier fences - the Southern barrier, standing at a height of 2m and spanning approximately 320m in length, and the Northern barrier, with a minimum height of 3m and a length of approximately 430m - we propose the following fence types.

Furthermore, while the planting of trees may be contemplated in the future, their slow growth rate necessitates the installation of a fence in the interim. We recommend that trees be planted in front of the fence to serve as a natural camouflage.

Figure 16 – Fence solution 1

Figure 17 – Fence solution 2

Figure 18 – Fence solution 3

OVERALL CONCLUSIONS

The proposed solar power plant is expected to generate glare annually during the evenings between the months of March and October. The construction of a fence will have a significant impact on the glare towards the motorists travelling on Iisalmentie road by the following:

- Approximate **increase** of 228 minutes (3.8 hrs) of "green" glare, which carries a low potential for inducing temporary after-images.
- Approximate **reduction** of 7,264 minutes (121hrs) of "yellow" glare, which has the potential to cause temporary after-images.

We do recommend that trees are planted in front of the fence to camouflage the fence and proposed solar power plant, however this is not a requirement to reduce the glare.

APPENDIX A: GENERAL INFORMATION

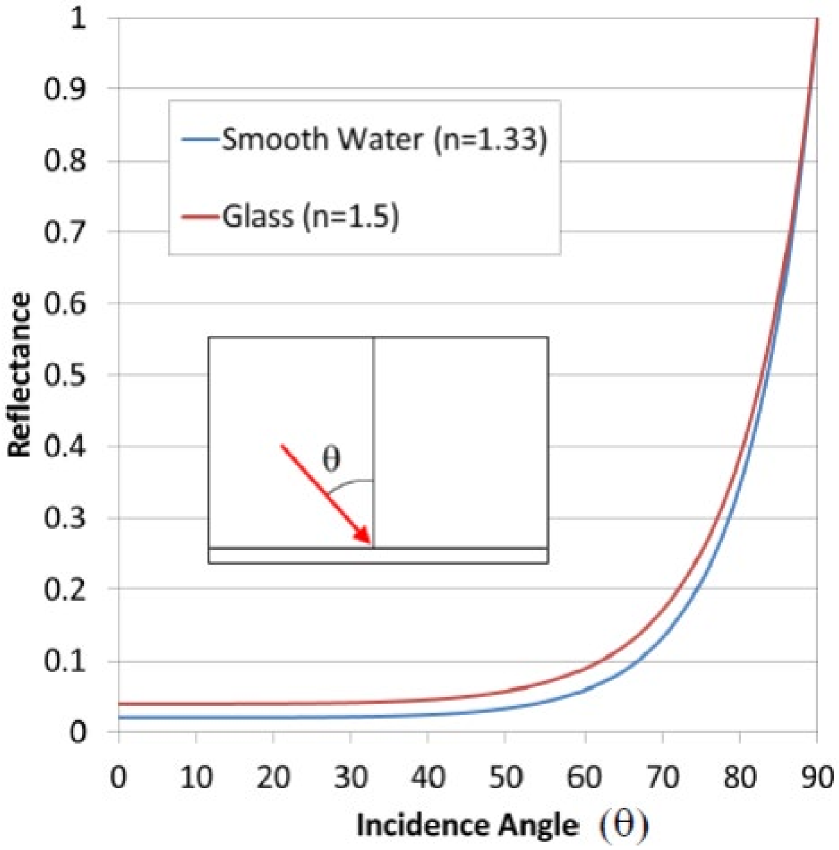
Glint and Glare Basics

Studies have been undertaken assessing the type and intensity of solar reflections from various surfaces including solar panels and glass.

The guidelines presented are related to aviation safety. The results are applicable for the purpose of this analysis.

Glint is a momentary flash of bright light, while glare is a continuous source of excessive brightness relative to ambient lighting (Federal Aviation Administration [FAA], 2018). This can occur when light reflected off a surface (reflector) is viewed by a person (receptor). Typically, glint may be experienced in instances when either the receptor or the reflector is moving; while glare may occur when the reflector and receptor are completely or close to stationary, or from large reflective surfaces.

For a transparent material (e.g. glass, water) the quantity of light reflected depends on the surface itself (i.e. material and texture), and the angle at which the light intercepts it (angle of incidence). A higher angle of incidence will result in a higher proportion of light being reflected.

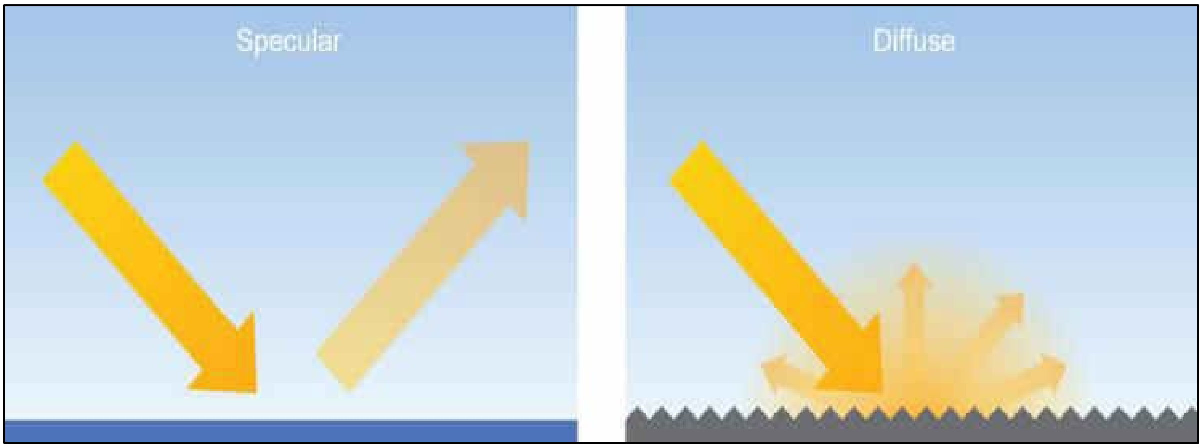


Appendix Image 1 – Water comparison to glass

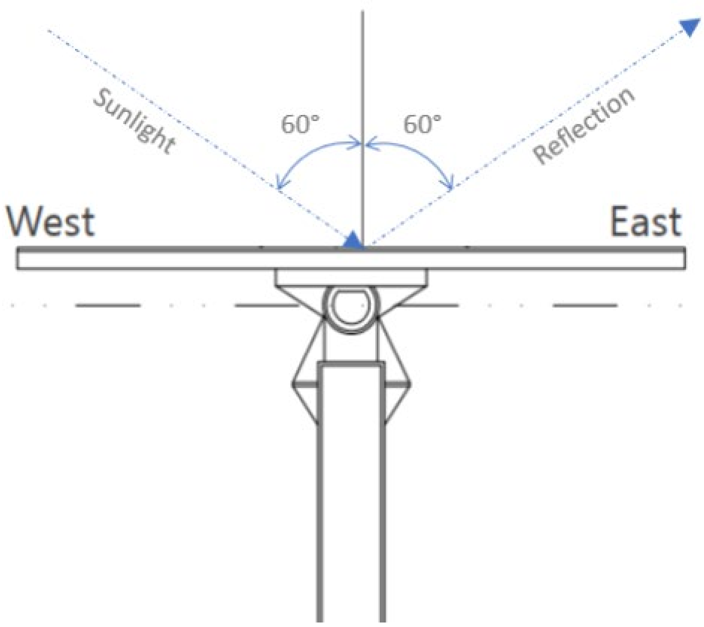
Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance25, illustrates the difference between the two types of reflections. Because solar panels are flat and have a smooth surface most of the light reflected is specular, which means that incident light from a specific direction is reradiated in a specific direction.

The small percentage of light reflected from PV modules varies depending on the angle of incidence. A larger angle of incidence will result in a higher percentage of reflected light.



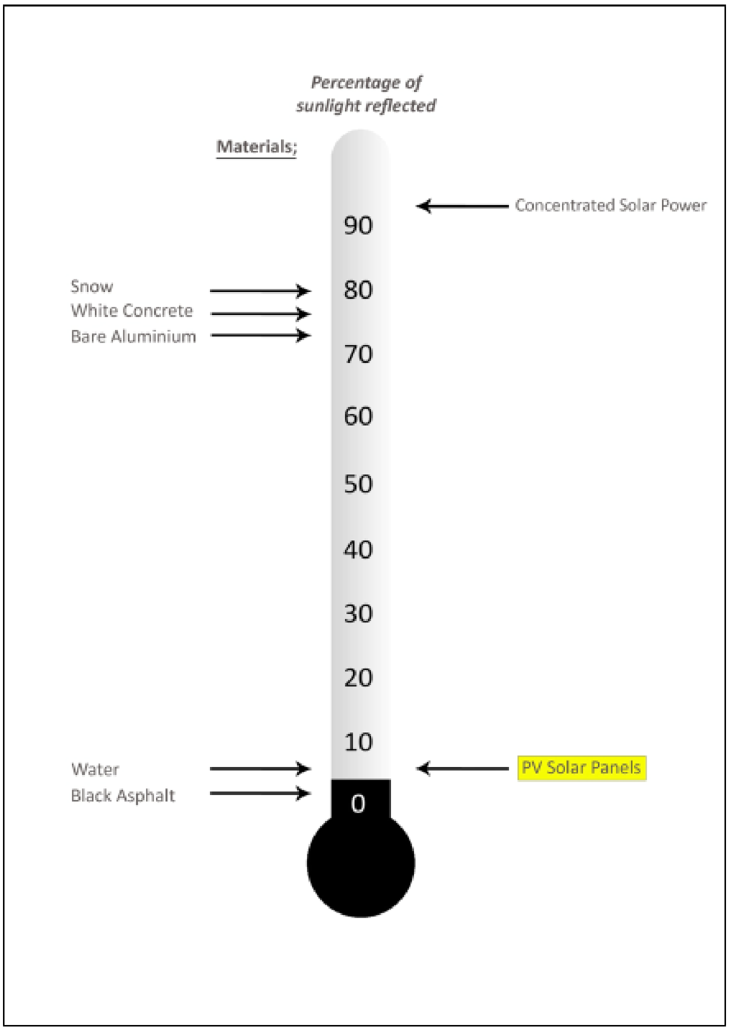
Appendix Image 2 – Flat glass vs diffused glass



Appendix Image 3 – example of reflection

Glare from Solar PV

Solar photovoltaic (PV) cells are designed to absorb as much light as possible to maximise efficiency (generally around 98% of the light received). To limit reflection, solar cells are constructed from dark, light-absorbing material and are treated with an anti-reflective coating. PV modules generate less glare than many other surfaces.



Appendix Image 4 – comparison of reflection

FAA Guidance – “Technical Guidance for Evaluating Selected Solar Technologies on Airports”

The 2010 FAA Guidance included a diagram which illustrates the relative reflectance of solar panels compared to other surfaces. The figure shows the relative reflectance of solar panels compared to other surfaces. Surfaces in this figure produce reflections which are specular and diffuse. A diffuse reflection will reflect the incoming light and scatter it in many directions. A table of reflectivity values, sourced from the figure within the FAA guidance, is presented below.

Surface	Approximate Percentage of Light Reflected
Snow	80
White Concrete	77
Bare Aluminum	74
Vegetation	50
Bare Soil	30
Wood Shingle	17
Water	5
Solar Panels	5
Black Asphalt	2

Appendix Table 1 – percentage of light reflected from objects

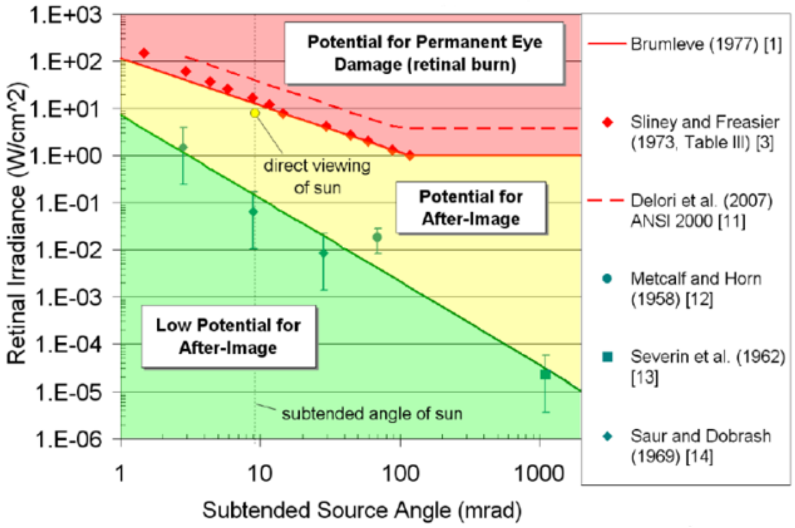
Impacts from Glint & Glare

Potential visual impacts from glint and glare include distraction and temporary after-image; at its worst, it can cause retinal burn. The ocular hazard caused by glint or glare is a function of:

- The intensity of the glare upon the eye (retinal irradiance)
- The subtended angle of the glare source (i.e. the extent to which the glare occupies

the receptor's field of vision; dependent on size and distance of the reflector). The severity of the ocular hazard can be divided into three levels, as shown in Figure 2:

- 'Green' glare: Low potential for temporary after-image
- 'Yellow' glare: Potential for temporary after-image
- 'Red' glare: Retinal burn, not expected for PV



Appendix Image 5 – Potential for after-image and eye damage

Overview of Sun Movements and Relative Reflections

The location of the Sun in the sky can be precisely defined by its azimuth and elevation. The azimuth is a direction based on true north (horizontal angle, i.e., from left to right), while the elevation represents the Sun's angle relative to the horizon (vertical angle, i.e., up and down).

The Sun's position can be accurately determined for a specific location using the following data:

- Time
- Date
- Latitude
- Longitude

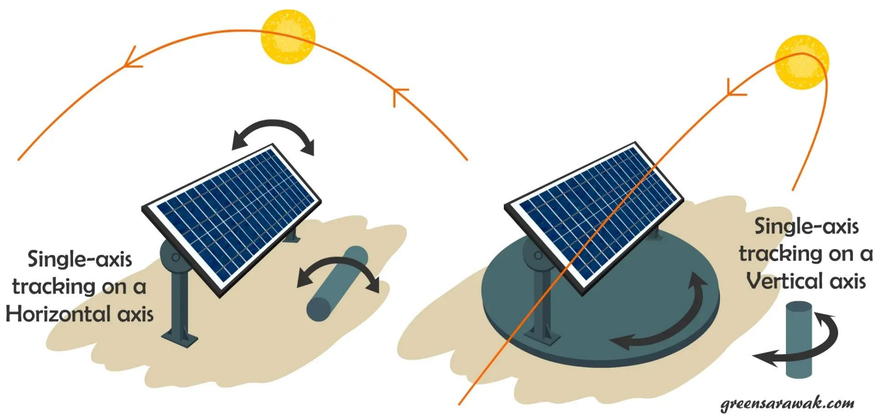
The interplay of the Sun's azimuth angle and vertical elevation influences the direction and angle of sunlight.

Types of tracking systems

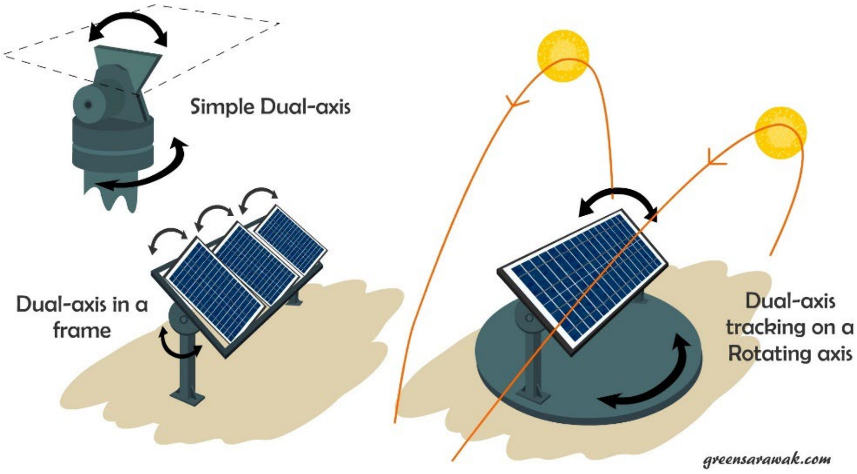
The two predominant types of PV mounting structures are fixed-tilt and single-axis tracking. Fixed-tilt arrays remain stationary, while single-axis tracking arrays rotate the module's receiving surface from east to west throughout the day, following the sun's movement across the sky.

In a fixed-tilt PV array, the angle of incidence fluctuates as the sun moves across the sky, given that the modules are stationary. This angle is smallest around noon when the sun is directly overhead and largest in the early morning and late afternoon when the sun is close to the horizon. Consequently, there is a higher potential for glare during these times.

For a single-axis tracking system, the angle of incidence varies less as the module's reflective surface rotates on a horizontal axis to track the sun. As a result, single-axis tracking arrays produce less glare than fixed-tilt arrays. The tracking adjusts throughout the year to align with the seasonal changes in the sun's trajectory.



Appendix Image 6 – Example of sun tracking



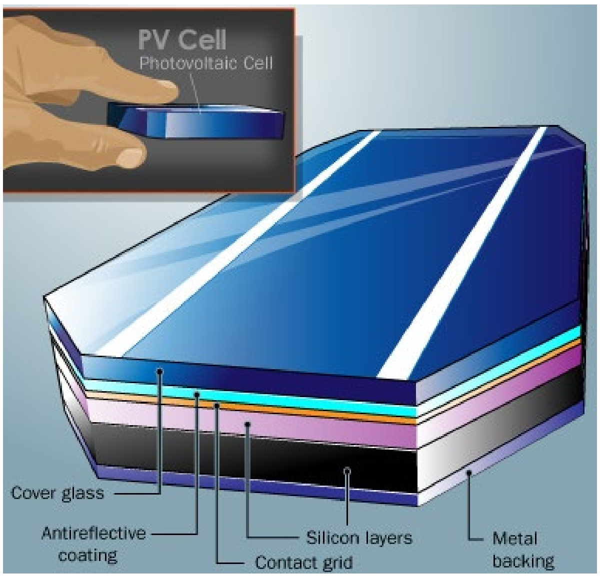
Appendix Image 7 – Example of sun tracking

Solar Panel Construction

Solar cells are often coated with an anti-reflective layer to enhance their light absorption. Without this coating, over 30% of light would be reflected off the bare silicon solar cells. Materials like silicon nitride or titanium oxide are typically used for this thin anti-reflective coating. If the coating is omitted, the cells appear dark grey. By adjusting the coating's thickness, the solar cell's colour can be altered. This type of coating is not exclusive to solar cells and can also be found on other devices like camera lenses.

In addition to solar cells, the glass surface (superstrate) of solar panels can also be treated with an anti-reflective coating. This improves light transmittance, thereby boosting the photovoltaic module's overall efficiency.

The coating also reduces glare from the glass, which can help the panels blend into their surroundings and makes them safer for installation near airports to prevent blinding pilots.



Appendix Image 8 – Solar panel composition

APPENDIX B - SOLAR FORGE MODEL

The following pages are extracted from the Solarforge model.

FORGESOLAR GLARE ANALYSIS

Project: **Lassinniitty Eero**

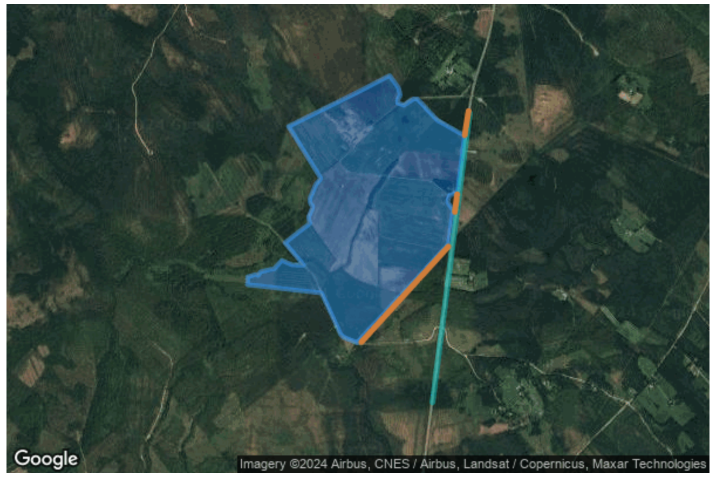
Proposed 98.35MW PV solar power plant located at Iisalmentie 819, 87800 Kajaani Reviewing the solar glare to passing motorists.

Site configuration: **Eero - No Fence**

Client: Nordic Generations

Created 24 Jul, 2024
Updated 14 Aug, 2024
Time-step 1 minute
Timezone offset UTC2
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 10 MW to 100 MW
Site ID 124964.21418

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



Summary of Results

Glare with potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	30.0	180.0	197	3.3	7,980	133.0	1,307,000.0

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

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	197	3.3	7,980	133.0

Component Data

PV Arrays

Name: PV array 1
Axis tracking: Fixed (no rotation)
Tilt: 30.0°
Orientation: 180.0°
Rated power: 665.0 kW
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	64.044534	27.449631	171.77	1.00	172.77
2	64.042360	27.448966	170.00	1.00	171.00
3	64.036038	27.435558	152.19	1.00	153.19
4	64.036405	27.433606	151.77	1.00	152.77
5	64.036583	27.433134	151.42	1.00	152.42
6	64.037006	27.432726	151.66	1.00	152.66
7	64.039228	27.430346	152.89	1.00	153.89
8	64.039762	27.419502	150.00	1.00	151.00
9	64.040269	27.419545	150.00	1.00	151.00
10	64.040420	27.420704	150.00	1.00	151.00
11	64.040363	27.421090	150.00	1.00	151.00
12	64.040589	27.421390	150.00	1.00	151.00
13	64.040795	27.423450	150.42	1.00	151.42
14	64.040983	27.423837	150.92	1.00	151.92
15	64.041321	27.424523	151.79	1.00	152.79
16	64.041040	27.426025	152.05	1.00	153.05
17	64.041021	27.427742	153.77	1.00	154.77
18	64.042448	27.424995	152.58	1.00	153.58
19	64.043688	27.428643	156.38	1.00	157.38
20	64.043970	27.428514	156.79	1.00	157.79
21	64.044120	27.428471	157.01	1.00	158.01
22	64.044241	27.428610	157.18	1.00	158.18
23	64.044692	27.429018	157.84	1.00	158.84
24	64.044795	27.429061	158.00	1.00	159.00
25	64.044945	27.428739	158.22	1.00	159.22
26	64.045077	27.428675	158.41	1.00	159.41
27	64.045255	27.428653	158.67	1.00	159.67
28	64.045405	27.428739	158.89	1.00	159.89
29	64.046232	27.429576	160.08	1.00	161.08
30	64.046551	27.430241	160.55	1.00	161.55
31	64.046731	27.430027	160.81	1.00	161.81
32	64.049905	27.425520	162.82	1.00	163.82
33	64.052057	27.435455	167.45	1.00	168.45
34	64.053157	27.440338	169.16	1.00	170.16
35	64.052368	27.441625	170.00	1.00	171.00
36	64.051918	27.441883	169.37	1.00	170.37
37	64.051617	27.441539	168.93	1.00	169.93
38	64.051392	27.441539	168.60	1.00	169.60
39	64.051266	27.442425	168.95	1.00	169.95
40	64.051660	27.443798	170.92	1.00	171.92
41	64.051660	27.444399	171.79	1.00	172.79
42	64.050289	27.447360	173.22	1.00	174.22
43	64.049313	27.451308	177.00	1.00	178.00
44	64.045648	27.450257	173.00	1.00	174.00
45	64.045497	27.449185	171.77	1.00	172.77
46	64.045291	27.448927	171.40	1.00	172.40
47	64.045047	27.448841	171.27	1.00	172.27

Route Receptors

Name: Iisalmentie Route E63
Path type: Two-way
Observer view angle: 180.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	64.050784	27.452060	180.70	1.25	181.95
2	64.032224	27.446610	158.02	1.25	159.27

Obstruction Components

Name: Tree Line 1
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.049336	27.451338	177.14
2	64.050890	27.451896	180.83

Name: Tree Line 2
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.045554	27.450231	173.00
2	64.044427	27.449877	171.88

Name: Tree line 3
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.036094	27.436207	153.19
2	64.042209	27.448937	170.00

Glare Analysis Results

Summary of Results Glare with potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	30.0	180.0	197	3.3	7,980	133.0	1,307,000.0

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

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	197	3.3	7,980	133.0

PV: PV array 1 potential temporary after-image

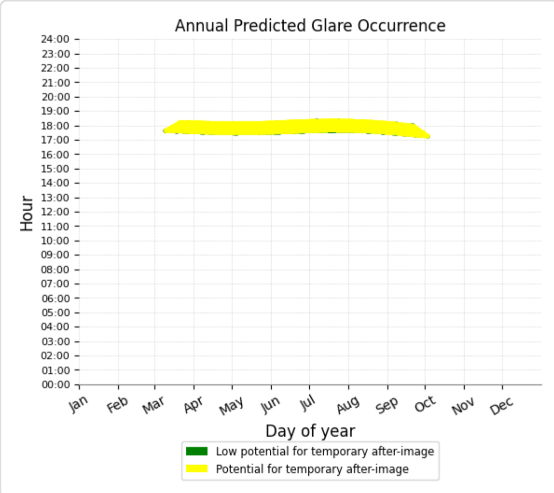
Receptor results ordered by category of glare

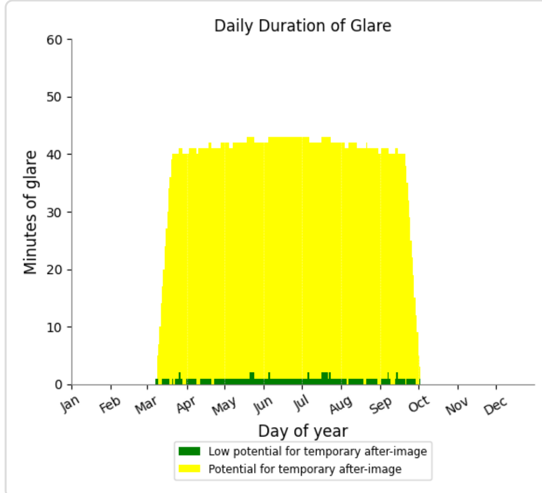
Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	197	3.3	7,980	133.0

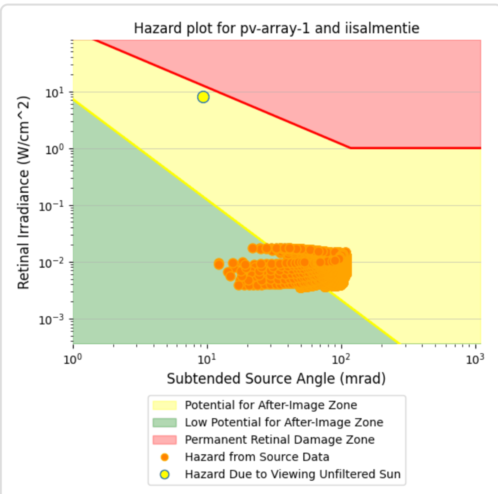
PV array 1 and Route: Iisalmentie Route E63

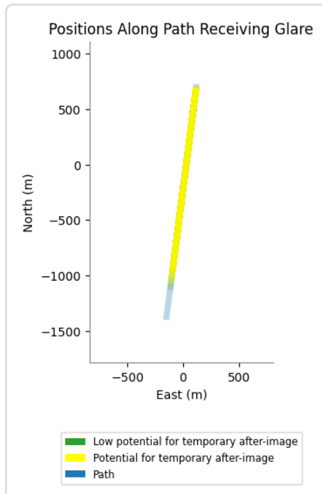
Yellow glare: 7,980 min.

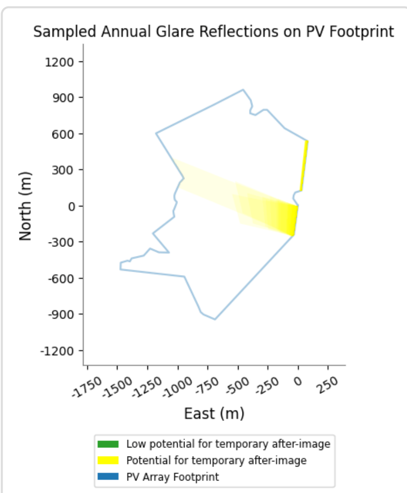
Green glare: 197 min.











Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
Several V1 calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare. This primarily affects V1 analyses of path receptors.
Random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including ATCTs. Note that the SGHAT/ForgeSolar methodology has always relied on an analytical, qualitative approach to accurately determine the overall hazard (i.e. green vs. yellow) of expected glare on an annual basis.
The analysis does not automatically consider obstacles (either man-made or natural) between the observation points and the prescribed solar installation that may obstruct observed glare, such as trees, hills, buildings, etc.
The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
The variable direct normal irradiance (DNI) feature (if selected) scales the user-prescribed peak DNI using a typical clear-day irradiance profile. This profile has a lower DNI in the mornings and evenings and a maximum at solar noon. The scaling uses a clear-day irradiance profile based on a normalized time relative to sunrise, solar noon, and sunset, which are prescribed by a sun-position algorithm and the latitude and longitude obtained from Google maps. The actual DNI on any given day can be affected by cloud cover, atmospheric attenuation, and other environmental factors.
The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.
The system output calculation is a DNI-based approximation that assumes clear, sunny skies year-round. It should not be used in place of more rigorous modeling methods.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Refer to the Help page at **www.forgesolar.com/help/** for assumptions and limitations not listed here.

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

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

FORGESOLAR GLARE ANALYSIS

Project: **Lassinniitty Eero**

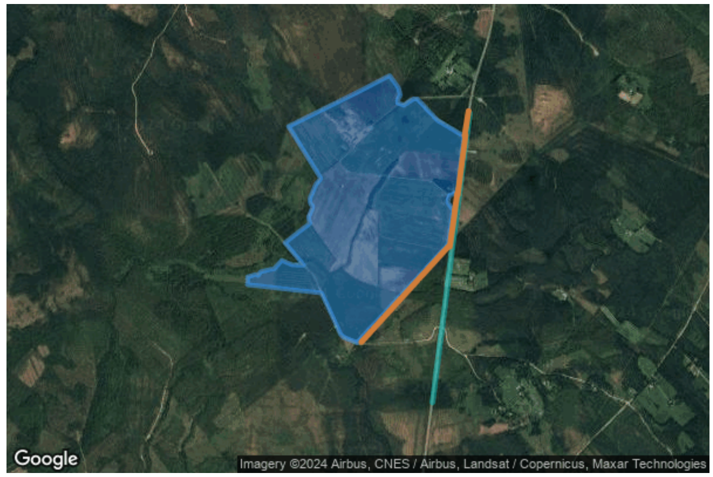
Proposed 98.35MW PV solar power plant located at Iisalmentie 819, 87800 Kajaani Reviewing the solar glare to passing motorists.

Site configuration: **Eero - Fence 2**

Client: Nordic Generations

Created 24 Jul, 2024
Updated 13 Aug, 2024
Time-step 1 minute
Timezone offset UTC2
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 10 MW to 100 MW
Site ID 124994.21418

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



Summary of Results

Glare with potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
PV array 1	30.0	180.0	425	7.1	716	11.9	1,307,000.0

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

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	425	7.1	716	11.9

Component Data

PV Arrays

Name: PV array 1
Axis tracking: Fixed (no rotation)
Tilt: 30.0°
Orientation: 180.0°
Rated power: 665.0 kW
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	64.044534	27.449631	171.77	1.00	172.77
2	64.042360	27.448966	170.00	1.00	171.00
3	64.036038	27.435558	152.19	1.00	153.19
4	64.036405	27.433606	151.77	1.00	152.77
5	64.036583	27.433134	151.42	1.00	152.42
6	64.037006	27.432726	151.66	1.00	152.66
7	64.039228	27.430346	152.89	1.00	153.89
8	64.039762	27.419502	150.00	1.00	151.00
9	64.040269	27.419545	150.00	1.00	151.00
10	64.040420	27.420704	150.00	1.00	151.00
11	64.040363	27.421090	150.00	1.00	151.00
12	64.040589	27.421390	150.00	1.00	151.00
13	64.040795	27.423450	150.42	1.00	151.42
14	64.040983	27.423837	150.92	1.00	151.92
15	64.041321	27.424523	151.79	1.00	152.79
16	64.041040	27.426025	152.05	1.00	153.05
17	64.041021	27.427742	153.77	1.00	154.77
18	64.042448	27.424995	152.58	1.00	153.58
19	64.043688	27.428643	156.38	1.00	157.38
20	64.043970	27.428514	156.79	1.00	157.79
21	64.044120	27.428471	157.01	1.00	158.01
22	64.044241	27.428610	157.18	1.00	158.18
23	64.044692	27.429018	157.84	1.00	158.84
24	64.044795	27.429061	158.00	1.00	159.00
25	64.044945	27.428739	158.22	1.00	159.22
26	64.045077	27.428675	158.41	1.00	159.41
27	64.045255	27.428653	158.67	1.00	159.67
28	64.045405	27.428739	158.89	1.00	159.89
29	64.046232	27.429576	160.08	1.00	161.08
30	64.046551	27.430241	160.55	1.00	161.55
31	64.046731	27.430027	160.81	1.00	161.81
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34	64.053157	27.440338	169.16	1.00	170.16
35	64.052368	27.441625	170.00	1.00	171.00
36	64.051918	27.441883	169.37	1.00	170.37
37	64.051617	27.441539	168.93	1.00	169.93
38	64.051392	27.441539	168.60	1.00	169.60
39	64.051266	27.442425	168.95	1.00	169.95
40	64.051660	27.443798	170.92	1.00	171.92
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45	64.045497	27.449185	171.77	1.00	172.77
46	64.045291	27.448927	171.40	1.00	172.40
47	64.045047	27.448841	171.27	1.00	172.27

Route Receptors

Name: Iisalmentie Route E63
Path type: Two-way
Observer view angle: 180.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	64.050784	27.452060	180.70	1.25	181.95
2	64.032224	27.446610	158.02	1.25	159.27

Obstruction Components

Name: Fence 1
Top height: 2.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.044511	27.449904	171.92
2	64.042202	27.449142	170.00

Name: Fence 2 North
Top height: 3.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.049356	27.451461	177.37
2	64.045512	27.450299	173.00

Name: Tree Line 1
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.049296	27.451318	176.99
2	64.050890	27.451896	180.83

Name: Tree Line 2
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.045607	27.450244	173.00
2	64.044504	27.449875	171.90

Name: Tree line 3
Top height: 5.0 m

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)
1	64.036094	27.436207	153.19
2	64.042209	27.448937	170.00

Glare Analysis Results

Summary of Results Glare with potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
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Total glare received by each receptor; may include duplicate times of glare from multiple reflective surfaces.

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	425	7.1	716	11.9

PV: PV array 1 potential temporary after-image

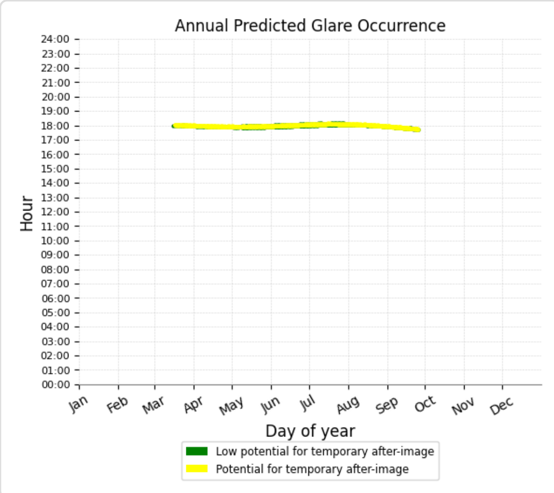
Receptor results ordered by category of glare

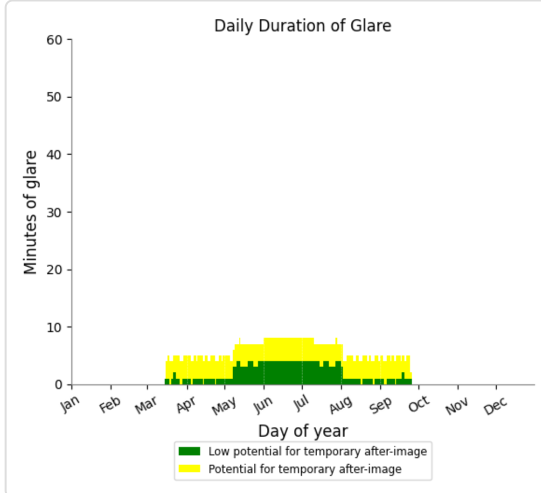
Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Iisalmentie Route E63	425	7.1	716	11.9

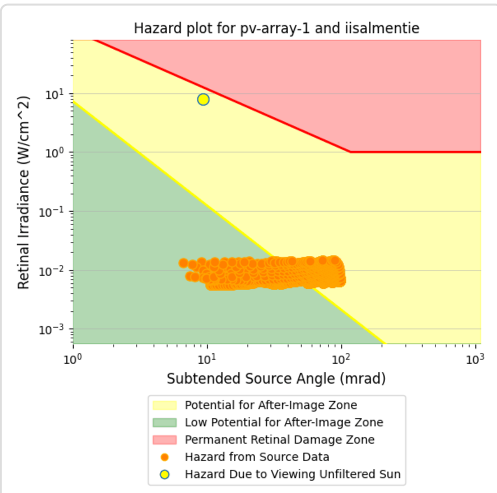
PV array 1 and Route: Iisalmentie Route E63

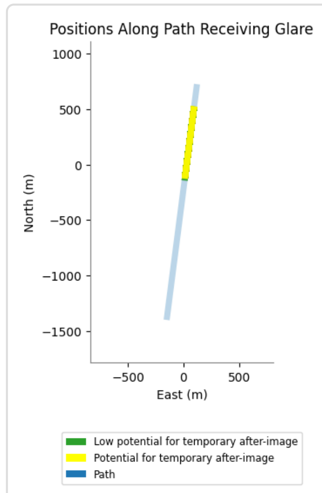
Yellow glare: 716 min.

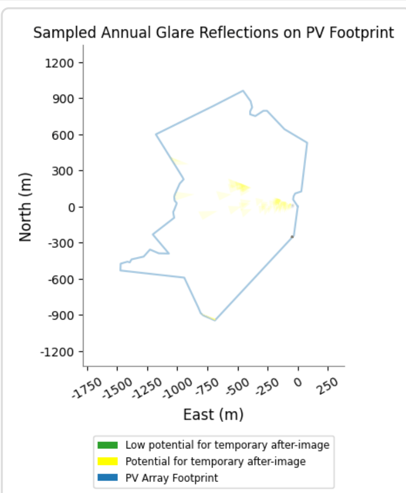
Green glare: 425 min.











Assumptions

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"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
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The algorithm does not rigorously represent the detailed geometry of a system; detailed features such as gaps between modules, variable height of the PV array, and support structures may impact actual glare results. However, we have validated our models against several systems, including a PV array causing glare to the air-traffic control tower at Manchester-Boston Regional Airport and several sites in Albuquerque, and the tool accurately predicted the occurrence and intensity of glare at different times and days of the year.
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The ocular hazard predicted by the tool depends on a number of environmental, optical, and human factors, which can be uncertain. We provide input fields and typical ranges of values for these factors so that the user can vary these parameters to see if they have an impact on the results. The speed of SGHAT allows expedited sensitivity and parametric analyses.
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Refer to the Help page at **www.forgesolar.com/help/** for assumptions and limitations not listed here.

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

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