GLARE STUDY ANALYSIS

TPE IL KN415, LLC (SOLAR FARM)

12/08/2023

Introduction:

A glare study was performed by TPE Development, LLC ("TPE") using ForgeSolar software to assess the possible effects of reflectivity created by the proposed solar project located near Gilberts, Kane County, IL (the "Project"). This report interprets and explains the inputs, assumptions, and results of the study.

ForgeSolar software incorporates GlareGauge, the leading solar glare analysis tool which meets Federal Aviation Administration ("FAA") standards and is used globally for glare analysis. It is based on the Solar Glare Hazard Analysis Tool licensed from Sandia National Laboratories. The tool assesses the possible effects of reflectivity, both glint and glare, from a proposed solar photovoltaic installation. The tool can take topography into account; however, the tool is not able to take existing vegetation (trees, shrubs, etc) or structures (fences, buildings, etc.) into account. If there is a tree line or fence obstructing visibility of the array, the tool may incorrectly report glare for which the user must adjust based on site specific vegetation or structures.

A model of the Project was input into the software along with several user defined observation points or paths ("Receptors"). The software calculates the sun's position relative to the Project for every minute of the year. Results are charted displaying annual glare duration and potential ocular impact type and duration for each Receptor.

Sun reflection is most noticeable when the sun is low on the horizon and sunlight reflects off the panels at a very low angle along the horizon where it can be seen by an observer standing next to the solar farm, driving along a road, or a neighboring dwelling. The assessment will capture all the possible reflection coming from the solar farm.

Reflectivity Summary:

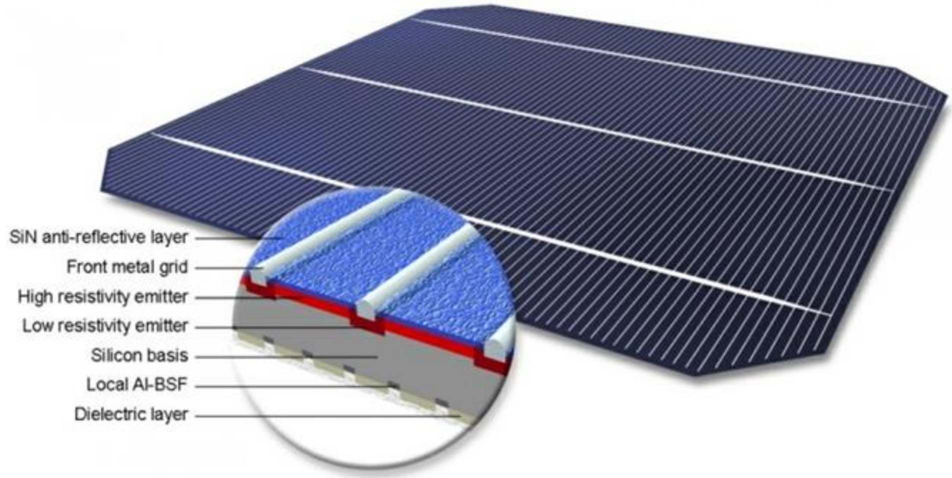
The term 'reflectivity' is used in this report to refer to both reflection types (i.e. glint and glare). The definition of glint and glare can vary; however, the definitions used in this report is aligned with the FAA and are detailed below:

- Glint: A momentary flash of bright light typically received by moving receptors or from moving reflectors. Example: a momentary solar reflection from a moving car.
- Glare: A continuous source of bright light typically received by static Receptors or from large reflective surfaces. Glare is generally associated with stationary objects, which, due to the slow relative movement of the sun, reflect sunlight for a longer duration.

The primary difference between glint and glare is duration. The Forge Solar GlareGauge tool captures both types of reflection on the surrounding roads and dwellings.

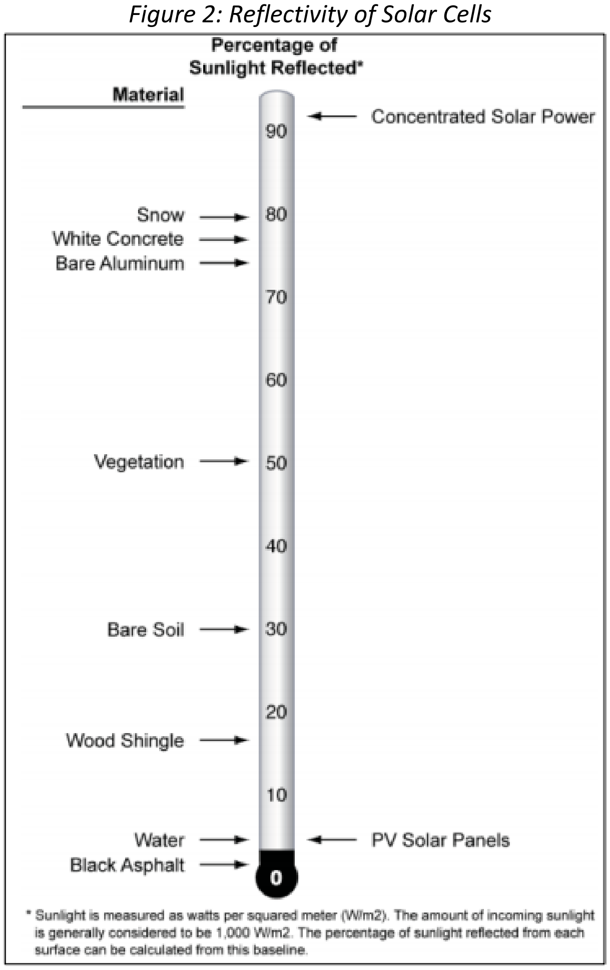
To limit reflection and maximize conversion to electricity, solar PV panels are constructed of dark silicon wafers/cells with light-absorbing materials and the glass is covered with an anti-reflective coating (ARC) as shown in Figure 1 below. These design features limit sunlight reflectance and maximize sunlight absorption.

Figure 1: Deconstructed Solar Panel



To calculate diffuse and specular reflectance of solar modules, TUV Rheinland (NRTL) performed a test using the ISO 9050 (External Light Reflectance) standards and the results are shown in Figure 2 below. The reflectivity of a typical mono-crystalline photovoltaic solar panel is approximately 5.7%, which is well below the other control samples included in the test.

Figure 2: Reflectivity of Solar Cells



ForgeSolar GlareGauge Analysis:

Inputs and Modeling Assumptions:

As input to the software, Route Receptors were created along roadways in vicinity of the site. Height was measured at 5’ above ground to emulate passengers in cars. Further, Observation Receptors were modeled at specific dwellings located around the perimeter of the solar array. Heights were modeled at 5’ above ground to emulate residents on the 1st floor of dwellings.

The model assumes the sun is shining 100% of the time it is above the horizon (during daylight hours). That is, it does not account for cloudy or overcast conditions when the sun is not shining, therefore the results presented would be the maximum expected glint and glare during any single year. The model assumes a coordinated universal time, meaning a standard time for the appropriate time zone is used.

Existing topography is taken into account in the simulation based on LIDAR (“Light Detection and Ranging”) data. Existing and planned vegetation are not considered in the simulation. The model assumed zero vegetation that may screen the Project, so this must be considered when interpreting the study results. A direct line of sight between the Project and the designated Route Receptors and Observation Receptors is required to produce any discernible glint/glare, so if there is existing or proposed vegetation between the receptor and the project, any glint/glare would be eliminated.

Solar panels will be mounted on single axis trackers with a southern azimuth and the panels will track the sun to capture as much sunlight as possible. Therefore, glare is typically not experienced during normal operational hours since any reflection would be back toward the location of the sun. Potential glare is most noticeable when the sun is low on the horizon, early in the morning or late in the afternoon, when sunlight reflects off the panels in a horizontal position (stow mode) at the opposite low angle along the horizon to the east or the west. To reduce glare in the east and west directions during these low sun periods, a 5-degree tracker resting angle was implemented during these times which avoids the main source of glare for solar projects.

Results:

Based on the project specific location, sun position throughout the year, and the above inputs/assumptions, no potential for glint or glare was identified in the analysis at any of the Route Receptors or neighboring Observation Receptors. While excluded from the analysis, existing and planned vegetation will further shield the view of the project from nearby properties and roadways.

No additional mitigation measures are recommended since no glint or glare is anticipated based on the ForgeSolar GlareGauge results.

If additional information is needed, contact Bob Malek, TPE Development, LLC at bmalek@tpoint-e.com.

FORGESOLAR GLARE ANALYSIS

Project: **ILKN415**
Site configuration: **ILKN415**

Created 16 Sep, 2023
Updated 16 Sep, 2023
Time-step 1 minute
Timezone offset UTC-6
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 1 MW to 5 MW
Site ID 100558.17532

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

Summary of Results No glare predicted

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

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
Route 1	0	0.0	0	0.0
Route 2	0	0.0	0	0.0
Route 3	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0

Component Data

PV Arrays

Name: PV array 1
Axis tracking: Single-axis rotation
Backtracking: Shade-slope
Tracking axis orientation: 180.0°
Max tracking angle: 60.0°
Resting angle: 5.0°
Ground Coverage Ratio: 0.33
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	42.141661	-88.364597	902.00	5.00	907.00
2	42.141682	-88.368891	894.38	5.00	899.38
3	42.145878	-88.368908	899.23	5.00	904.23
4	42.145880	-88.368268	902.72	5.00	907.72
5	42.144976	-88.368245	901.93	5.00	906.93
6	42.144978	-88.368070	902.98	5.00	907.98
7	42.144702	-88.368077	902.40	5.00	907.40
8	42.144704	-88.367644	904.70	5.00	909.70
9	42.144428	-88.367641	903.58	5.00	908.58
10	42.144437	-88.366536	908.04	5.00	913.04
11	42.144712	-88.366534	908.30	5.00	913.30
12	42.144705	-88.365638	907.05	5.00	912.05
13	42.144429	-88.365631	907.28	5.00	912.28
14	42.144425	-88.364937	907.70	5.00	912.70
15	42.144072	-88.364932	907.03	5.00	912.03
16	42.144072	-88.364587	905.98	5.00	910.98

Route Receptors

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	42.148794	-88.375967	903.14	5.00	908.14
2	42.147828	-88.372314	903.40	5.00	908.40
3	42.147184	-88.369943	899.99	5.00	904.99
4	42.146873	-88.369133	903.16	5.00	908.16
5	42.146486	-88.368385	906.05	5.00	911.05
6	42.145676	-88.367022	908.06	5.00	913.06
7	42.145002	-88.365681	907.63	5.00	912.63
8	42.144443	-88.364211	905.00	5.00	910.00
9	42.142823	-88.359658	903.97	5.00	908.97
10	42.141907	-88.357108	904.29	5.00	909.29
11	42.141026	-88.354445	902.32	5.00	907.32

Name: Route 2
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	42.147058	-88.369412	902.36	5.00	907.36
2	42.151625	-88.369418	906.02	5.00	911.02

Name: Route 3
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	42.148203	-88.374114	901.42	5.00	906.42
2	42.144233	-88.374077	895.99	5.00	900.99
3	42.137244	-88.374096	892.04	5.00	897.04
4	42.136394	-88.374108	891.13	5.00	896.13

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	42.145257	-88.367494	907.93	10.00
OP 2	2	42.141807	-88.357358	900.61	10.00
OP 3	3	42.140428	-88.357438	901.31	10.00
OP 4	4	42.142756	-88.357136	905.32	10.00
OP 5	5	42.140466	-88.373041	890.48	10.00
OP 6	6	42.143355	-88.373409	897.54	10.00
OP 7	7	42.144384	-88.373098	900.70	10.00
OP 8	8	42.147422	-88.372184	897.86	10.00
OP 9	9	42.148617	-88.369204	906.44	10.00
OP 10	10	42.147033	-88.363980	908.68	10.00

Glare Analysis Results

Summary of Results No glare predicted

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

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
Route 1	0	0.0	0	0.0
Route 2	0	0.0	0	0.0
Route 3	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0

PV: PV array 1 no glare found

Receptor results ordered by category of glare

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Route 1	0	0.0	0	0.0
Route 2	0	0.0	0	0.0
Route 3	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0

PV array 1 and Route: Route 1

No glare found

PV array 1 and Route: Route 2

No glare found

PV array 1 and Route: Route 3

No glare found

PV array 1 and OP 1

No glare found

PV array 1 and OP 2

No glare found

PV array 1 and OP 3

No glare found

PV array 1 and OP 4

No glare found

PV array 1 and OP 5

No glare found

PV array 1 and OP 6

No glare found

PV array 1 and OP 7

No glare found

PV array 1 and OP 8

No glare found

PV array 1 and OP 9

No glare found

PV array 1 and OP 10

No glare found

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