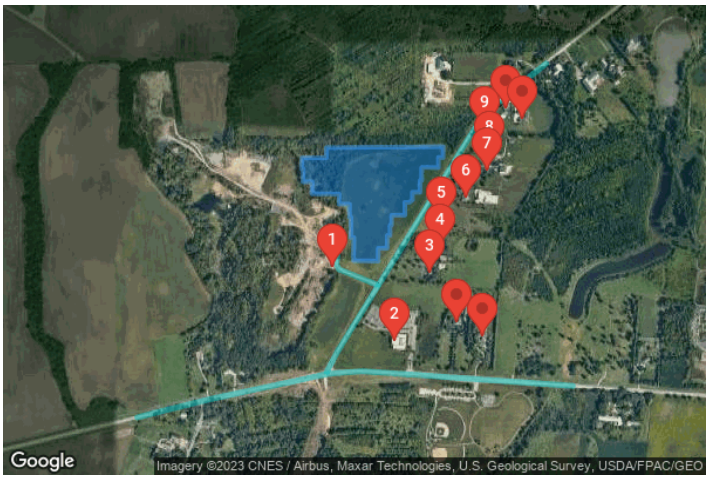
APPENDIX L – GLARE STUDY

FORGESOLAR GLARE ANALYSIS

Project: **ILKN216**
Site configuration: **ILKN216**

Created 06 Sep, 2023
Updated 06 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 99558.17367

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.

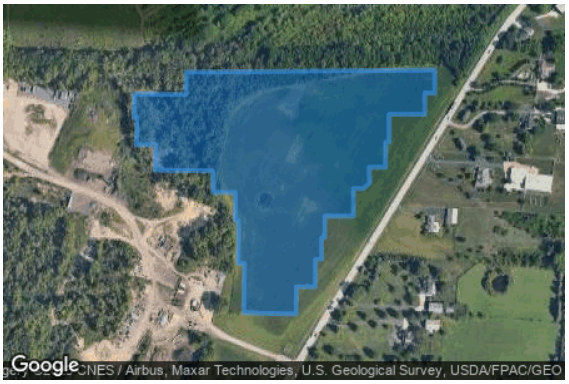
Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
Route 1	0	0.0	0	0.0
Route 2	0	0.0	0	0.0
Route 3	0	0.0	0	0.0
OP 1	0	0.0	0	0.0
OP 2	0	0.0	0	0.0
OP 3	0	0.0	0	0.0
OP 4	0	0.0	0	0.0
OP 5	0	0.0	0	0.0
OP 6	0	0.0	0	0.0
OP 7	0	0.0	0	0.0
OP 8	0	0.0	0	0.0
OP 9	0	0.0	0	0.0
OP 10	0	0.0	0	0.0
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
OP 13	0	0.0	0	0.0

Component Data

PV Arrays

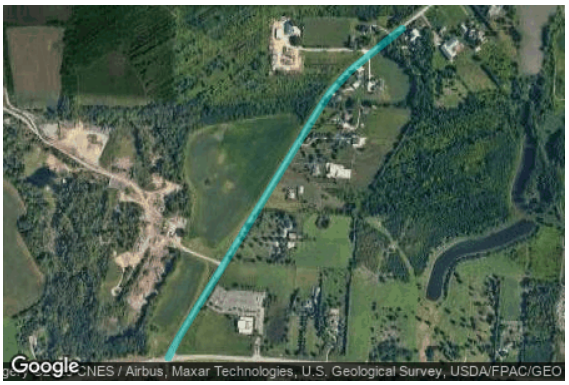
Name: PV array 1
Axis tracking: Single-axis rotation
Backtracking: Shade-slope
Tracking axis orientation: 180.0°
Max tracking angle: 60.0°
Resting angle: 5.0°
Ground Coverage Ratio: 0.5
Rated power: -
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
Slope error: correlate with material



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	41.850048	-88.399918	738.97	5.00	743.97
2	41.850064	-88.400819	751.93	5.00	756.93
3	41.850693	-88.400806	756.55	5.00	761.55
4	41.850692	-88.400915	759.95	5.00	764.95
5	41.851245	-88.400910	760.37	5.00	765.37
6	41.851245	-88.400964	761.52	5.00	766.52
7	41.851597	-88.400963	764.04	5.00	769.04
8	41.851600	-88.401349	771.85	5.00	776.85
9	41.851874	-88.401349	766.73	5.00	771.73
10	41.851884	-88.402346	778.81	5.00	783.81
11	41.852207	-88.402333	777.77	5.00	782.77
12	41.852206	-88.402665	778.80	5.00	783.80
13	41.852554	-88.402653	772.64	5.00	777.64
14	41.852557	-88.402707	772.64	5.00	777.64
15	41.852856	-88.402698	773.21	5.00	778.21
16	41.852854	-88.401814	768.25	5.00	773.25
17	41.853134	-88.401808	768.63	5.00	773.63
18	41.853162	-88.397535	742.04	5.00	747.04
19	41.852865	-88.397536	738.40	5.00	743.40
20	41.852870	-88.397706	739.60	5.00	744.60
21	41.852593	-88.397709	736.65	5.00	741.65
22	41.852597	-88.398319	740.11	5.00	745.11
23	41.852242	-88.398320	737.89	5.00	742.89
24	41.852243	-88.398377	738.90	5.00	743.90
25	41.851920	-88.398383	735.81	5.00	740.81
26	41.851921	-88.398662	738.53	5.00	743.53
27	41.851719	-88.398655	736.12	5.00	741.12
28	41.851647	-88.398769	736.33	5.00	741.33
29	41.851650	-88.398935	737.95	5.00	742.95
30	41.851299	-88.398931	735.09	5.00	740.09
31	41.851297	-88.399425	739.20	5.00	744.20
32	41.851022	-88.399426	737.62	5.00	742.62
33	41.851022	-88.399482	738.18	5.00	743.18
34	41.850748	-88.399478	737.47	5.00	742.47
35	41.850748	-88.399584	738.48	5.00	743.48
36	41.850398	-88.399589	736.51	5.00	741.51
37	41.850396	-88.399912	740.07	5.00	745.07

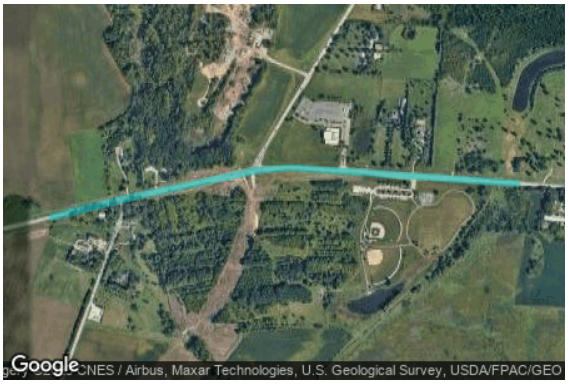
Route Receptors

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



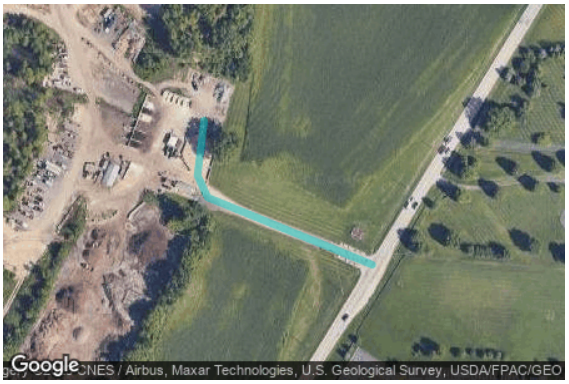
Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	41.847031	-88.401793	733.69	5.00	738.69
2	41.847559	-88.401427	737.37	5.00	742.37
3	41.850148	-88.399273	734.26	5.00	739.26
4	41.853229	-88.396735	740.89	5.00	745.89
5	41.853791	-88.396242	746.86	5.00	751.86
6	41.854333	-88.395574	747.94	5.00	752.94
7	41.855423	-88.393762	747.52	5.00	752.52

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	41.845797	-88.408737	733.94	5.00	738.94
2	41.846278	-88.406143	739.80	5.00	744.80
3	41.846981	-88.401746	732.62	5.00	737.62
4	41.847053	-88.400500	726.97	5.00	731.97
5	41.846652	-88.392784	707.36	5.00	712.36

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	41.849400	-88.399943	736.04	5.00	741.04
2	41.849829	-88.401356	763.07	5.00	768.07
3	41.849970	-88.401443	763.24	5.00	768.24
4	41.850318	-88.401387	766.54	5.00	771.54

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	41.849880	-88.401561	763.69	10.00
OP 2	2	41.847842	-88.399284	726.54	10.00
OP 3	3	41.849726	-88.397992	732.04	10.00
OP 4	4	41.850401	-88.397637	729.64	10.00
OP 5	5	41.851155	-88.397598	730.42	10.00
OP 6	6	41.851758	-88.396686	728.95	10.00
OP 7	7	41.852509	-88.395909	735.55	10.00
OP 8	8	41.852952	-88.395829	740.92	10.00
OP 9	9	41.853604	-88.395990	745.69	10.00
OP 10	10	41.854193	-88.395219	746.07	10.00
OP 11	11	41.853901	-88.394622	744.09	10.00
OP 12	12	41.848360	-88.397030	727.07	10.00
OP 13	13	41.847972	-88.396072	723.05	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
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	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
OP 11	0	0.0	0	0.0
OP 12	0	0.0	0	0.0
OP 13	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

PV array 1 and OP 11

No glare found

PV array 1 and OP 12

No glare found

PV array 1 and OP 13

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