

APPENDIX L – GLARE STUDY

FORGESOLAR GLARE ANALYSIS

Project: **ILKN188**
 Site configuration: **ILKN188**

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/m²
 Category 1 MW to 5 MW
 Site ID 99545.17365

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 kWh
			min	hr	min	hr	
PV array 1	25.0	180.0	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: Fixed (no rotation)

Tilt: 25.0°

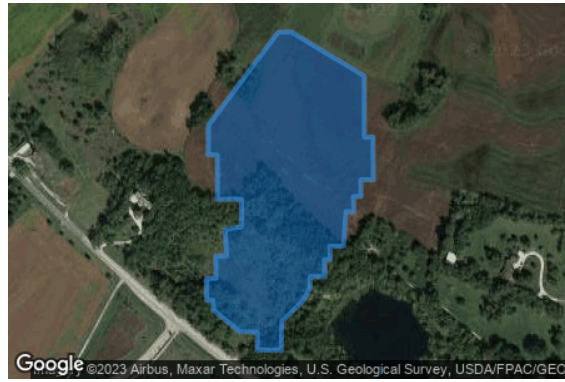
Orientation: 180.0°

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	41.796037	-88.467724	732.28	5.00	737.28
2	41.796046	-88.468133	730.37	5.00	735.37
3	41.796271	-88.468135	736.25	5.00	741.25
4	41.796277	-88.468439	735.65	5.00	740.65
5	41.796555	-88.468892	761.56	5.00	766.56
6	41.796673	-88.468892	760.64	5.00	765.64
7	41.796681	-88.469005	762.99	5.00	767.99
8	41.796957	-88.469004	738.93	5.00	743.93
9	41.796959	-88.468845	741.60	5.00	746.60
10	41.797242	-88.468846	740.38	5.00	745.38
11	41.797246	-88.468664	741.67	5.00	746.67
12	41.797582	-88.468685	734.34	5.00	739.34
13	41.797614	-88.468401	731.53	5.00	736.53
14	41.797966	-88.468406	725.11	5.00	730.11
15	41.797966	-88.468819	722.88	5.00	727.88
16	41.798528	-88.468821	719.73	5.00	724.73
17	41.798536	-88.468976	721.33	5.00	726.33
18	41.798908	-88.468976	717.43	5.00	722.43
19	41.800100	-88.467776	705.93	5.00	710.93
20	41.800102	-88.467553	705.53	5.00	710.53
21	41.799540	-88.466296	704.26	5.00	709.26
22	41.798761	-88.466294	705.04	5.00	710.04
23	41.798761	-88.466146	704.53	5.00	709.53
24	41.798214	-88.466139	705.04	5.00	710.04
25	41.798216	-88.466359	705.63	5.00	710.63
26	41.798002	-88.466351	706.31	5.00	711.31
27	41.798000	-88.466482	706.60	5.00	711.60
28	41.797806	-88.466474	707.90	5.00	712.90
29	41.797810	-88.466608	707.93	5.00	712.93
30	41.797370	-88.466654	710.62	5.00	715.62
31	41.797364	-88.466887	714.85	5.00	719.85
32	41.797197	-88.466882	732.42	5.00	737.42
33	41.797197	-88.466981	736.02	5.00	741.02
34	41.796978	-88.466973	734.19	5.00	739.19
35	41.796978	-88.467225	727.78	5.00	732.78
36	41.796840	-88.467225	729.46	5.00	734.46
37	41.796680	-88.467335	723.63	5.00	728.63
38	41.796406	-88.467710	726.54	5.00	731.54

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	41.798447	-88.472442	732.73	5.00	737.73
2	41.797277	-88.470833	731.52	5.00	736.52
3	41.796375	-88.469467	733.28	5.00	738.28
4	41.794367	-88.465723	730.95	5.00	735.95

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	41.793684	-88.462019	724.46	5.00	729.46
2	41.794768	-88.462422	720.47	5.00	725.47
3	41.795960	-88.462631	714.24	5.00	719.24
4	41.796696	-88.462640	710.47	5.00	715.47
5	41.797530	-88.462508	708.42	5.00	713.42
6	41.801739	-88.461304	707.31	5.00	712.31

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	41.805342	-88.473924	737.48	5.00	742.48
2	41.805850	-88.473130	740.66	5.00	745.66
3	41.806977	-88.471092	711.58	5.00	716.58
4	41.809254	-88.466621	705.66	5.00	710.66

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	41.797936	-88.470075	757.38	10.00
OP 2	2	41.792422	-88.465762	718.74	10.00
OP 3	3	41.800882	-88.460895	704.27	10.00
OP 4	4	41.799649	-88.460941	702.49	10.00
OP 5	5	41.801626	-88.465009	721.80	10.00
OP 6	6	41.801732	-88.465457	719.82	10.00
OP 7	7	41.801796	-88.466050	717.17	10.00
OP 8	8	41.797068	-88.463782	711.28	10.00
OP 9	9	41.793970	-88.470344	720.40	10.00
OP 10	10	41.801373	-88.470671	714.67	0.00

Obstruction Components

Name: Obstruction 1

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.799400	-88.465632	703.12
2	41.800394	-88.468054	705.80
3	41.800434	-88.468019	705.77
4	41.799444	-88.465595	703.07
5	41.799400	-88.465632	703.12

Name: Obstruction 2

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.797073	-88.465169	708.57
2	41.798060	-88.464669	702.78
3	41.797744	-88.462674	703.49
4	41.797552	-88.462757	703.94
5	41.797730	-88.463974	706.02
6	41.797512	-88.464460	707.63
7	41.797166	-88.464672	707.32
8	41.796872	-88.463714	707.57
9	41.796627	-88.463765	707.53
10	41.797073	-88.465169	708.57

Name: Obstruction 3

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.798600	-88.470269	716.58
2	41.798460	-88.469430	726.45
3	41.797976	-88.469274	726.98
4	41.796914	-88.469837	720.78
5	41.797182	-88.470395	732.13
6	41.797912	-88.469803	755.89
7	41.798349	-88.470533	721.16
8	41.798600	-88.470269	716.58

Name: Obstruction 4

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.796268	-88.463000	708.50
2	41.795542	-88.463115	716.67
3	41.793802	-88.462810	725.26
4	41.793826	-88.462456	724.42
5	41.795100	-88.462796	714.46
6	41.795884	-88.462885	708.51
7	41.796274	-88.462866	707.43
8	41.796268	-88.463000	708.50

Name: Obstruction 5

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.796769	-88.469852	734.92
2	41.795603	-88.467942	729.20
3	41.795865	-88.467666	730.81
4	41.796045	-88.468243	731.68
5	41.796919	-88.469691	711.25
6	41.796769	-88.469852	734.92

Name: Obstruction 6

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.798816	-88.469295	724.59
2	41.799082	-88.469244	719.60
3	41.799328	-88.468995	711.84
4	41.799123	-88.468854	713.33
5	41.798917	-88.469041	718.43
6	41.798816	-88.469295	724.59

Name: Obstruction 7

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.799525	-88.468828	709.52
2	41.799830	-88.468597	707.48
3	41.799749	-88.468412	706.69
4	41.799385	-88.468640	708.24
5	41.799525	-88.468828	709.52

Name: Obstruction 8

Top height: 30.0 ft



Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)
1	41.798221	-88.471373	729.73
2	41.798953	-88.472218	735.56
3	41.799097	-88.471910	734.54
4	41.798295	-88.471175	728.94
5	41.798221	-88.471373	729.73

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	25.0	180.0	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

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