ForgeSolar Glare Analysis Report

Project: ON- 2023-18-184

Report: PVTL-18-221

Appendix A – Quantum 1

Generated by: Dr FJ Vorster

Date generated: 2023/04/12

Reviewed by: Dr JL Crozier McCleland

FORGESOLAR GLARE ANALYSIS

Project: **Quantum 1**

South Africa Mainstream Renewable Power Developments (Pty) Ltd (Reg. No. 2009/007850/07) ("Mainstream") is proposing the development of a 10 megawatt Solar Photovoltaic (PV) Energy Facility (SEF) and associated infrastructure (including Battery Energy Storage Systems – BESS), as well as the associated grid connection infrastructure (substation and powerline) ("Project"), located approximately 7.2 km east from the town of Krugersdorp in the Mogale City Local Municipality of the West Rand District Municipality, Gauteng Province of South Africa.

Site configuration: **Quantum 1-temp-0**

Client: Mainstream Renewable Power

Created 23 Aug, 2023
Updated 23 Aug, 2023
Time-step 1 minute
Timezone offset UTC2
Minimum sun altitude 0.0 deg
DNI peaks at 1,000.0 W/m^2
Category 5 MW to 10 MW
Site ID 98551.17165

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 low potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
Quantum 1	SA tracking	SA tracking	684	11.4	0	0.0	29,500,000.0

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
N14	0	0.0	0	0.0
R24	0	0.0	0	0.0
Runway 11	684	11.4	0	0.0
Runway 18	0	0.0	0	0.0
Runway 29	0	0.0	0	0.0
Runway 36	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

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
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: Quantum 1
Axis tracking: Single-axis rotation
Backtracking: Shade-slope
Tracking axis orientation: 0.0°
Max tracking angle: 60.0°
Resting angle: 0.0°
Ground Coverage Ratio: 0.4
Rated power: 10000.0 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	-26.072179	27.651166	1572.75	1.53	1574.28
2	-26.071253	27.649160	1573.25	1.53	1574.78
3	-26.070704	27.649235	1573.41	1.53	1574.94
4	-26.070482	27.650383	1573.29	1.53	1574.82
5	-26.069538	27.650061	1573.25	1.53	1574.78
6	-26.069740	27.648634	1573.75	1.53	1575.28
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8	-26.070829	27.648183	1573.75	1.53	1575.28
9	-26.071215	27.648033	1573.25	1.53	1574.78
10	-26.071263	27.645834	1572.75	1.53	1574.28
11	-26.067023	27.644890	1577.22	1.53	1578.75
12	-26.067697	27.648140	1574.78	1.53	1576.31
13	-26.067890	27.648291	1574.77	1.53	1576.30
14	-26.067900	27.648634	1574.76	1.53	1576.29
15	-26.067832	27.648934	1574.96	1.53	1576.49
16	-26.068198	27.650436	1573.36	1.53	1574.89
17	-26.068700	27.650855	1573.25	1.53	1574.78
18	-26.069095	27.650705	1573.30	1.53	1574.83
19	-26.069567	27.652121	1572.25	1.53	1573.78

Route Receptors

Name: N14
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-26.074249	27.650555	1566.75	2.00	1568.75
2	-26.073729	27.652186	1564.11	2.00	1566.11
3	-26.073237	27.653956	1557.93	2.00	1559.93
4	-26.073006	27.655512	1555.19	2.00	1557.19
5	-26.072707	27.657465	1557.16	2.00	1559.16
6	-26.072360	27.659900	1559.46	2.00	1561.46

Name: R24
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
1	-26.062917	27.642808	1580.23	2.00	1582.23
2	-26.063592	27.643076	1579.23	2.00	1581.23
3	-26.064305	27.643345	1578.86	2.00	1580.86
4	-26.065269	27.643742	1578.25	2.00	1580.25
5	-26.065885	27.644031	1577.99	2.00	1579.99
6	-26.067823	27.644514	1575.25	2.00	1577.25
7	-26.069336	27.644868	1573.81	2.00	1575.81
8	-26.070521	27.645158	1573.25	2.00	1575.25
9	-26.071398	27.645383	1572.76	2.00	1574.76
10	-26.072217	27.645576	1571.87	2.00	1573.87
11	-26.072950	27.645834	1570.59	2.00	1572.59
12	-26.073653	27.646134	1569.49	2.00	1571.49

Flight Path Receptors

Name: Runway 11
Description:
Threshold height: 15 m
Direction: 99.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-26.037322	27.591264	1545.56	15.24	1560.80
Two-mile	-26.032799	27.559444	1538.03	191.45	1729.49

Name: Runway 18
Description:
Threshold height: 15 m
Direction: 159.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-26.033605	27.593556	1553.44	15.24	1568.68
Two-mile	-26.006613	27.582011	1506.47	230.89	1737.36

Name: Runway 29
Description:
Threshold height: 15 m
Direction: 279.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-26.038607	27.600589	1563.22	15.24	1578.46
Two-mile	-26.043130	27.632409	1571.39	175.76	1747.15

Name: Runway 36
Description:
Threshold height: 15 m
Direction: 339.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (m)	Height above ground (m)	Total elevation (m)
Threshold	-26.045464	27.598516	1558.40	15.24	1573.64
Two-mile	-26.072456	27.610062	1568.94	173.39	1742.32

Discrete Observation Point Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (m)	Height (m)
OP 1	1	-26.066163	27.652230	1572.47	1.80
OP 2	2	-26.066470	27.649741	1575.82	1.80
OP 3	3	-26.065795	27.645493	1577.87	1.80
OP 4	4	-26.067703	27.648518	1575.34	1.80
OP 5	5	-26.064619	27.652037	1574.60	1.80
OP 6	6	-26.064210	27.647091	1580.09	1.80
OP 7	7	-26.066735	27.647513	1576.76	1.80
OP 8	8	-26.066513	27.646751	1577.09	1.80
OP 9	9	-26.067198	27.650431	1574.42	1.80
OP 10	10	-26.070417	27.649358	1573.88	1.80

Glare Analysis Results

Summary of Results

Glare with low potential for temporary after-image predicted

PV Array	Tilt	Orient	Annual Green Glare		Annual Yellow Glare		Energy
	°	°	min	hr	min	hr	kWh
Quantum 1	SA tracking	SA tracking	684	11.4	0	0.0	29,500,000.0

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

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	min	hr	min	hr
N14	0	0.0	0	0.0
R24	0	0.0	0	0.0
Runway 11	684	11.4	0	0.0
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Runway 36	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: Quantum 1 low potential for temporary after-image

Receptor results ordered by category of glare

Receptor	Annual Green Glare		Annual Yellow Glare	
	min	hr	min	hr
N14	0	0.0	0	0.0
R24	0	0.0	0	0.0
Runway 11	684	11.4	0	0.0
Runway 18	0	0.0	0	0.0
Runway 29	0	0.0	0	0.0
Runway 36	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

Quantum 1 and Route: N14

No glare found

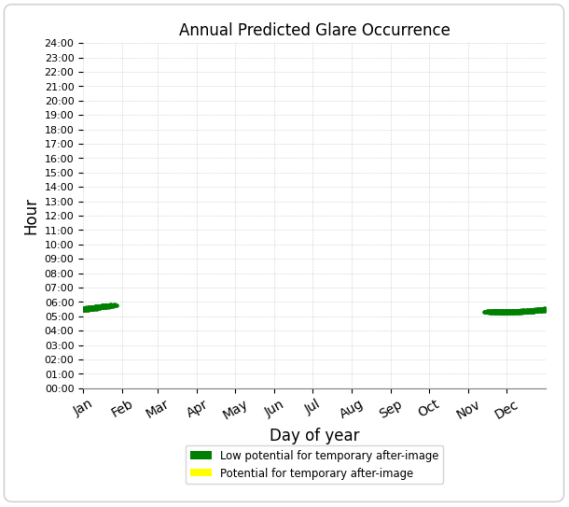
Quantum 1 and Route: R24

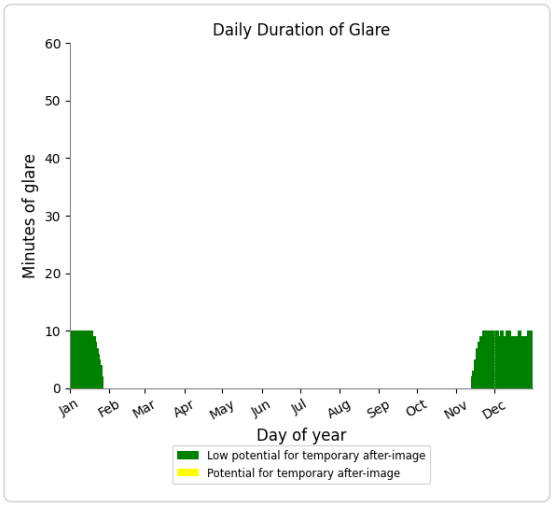
No glare found

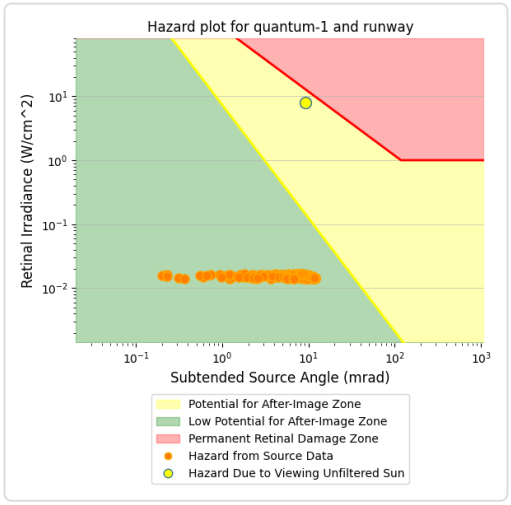
Quantum 1 and FP: Runway 11

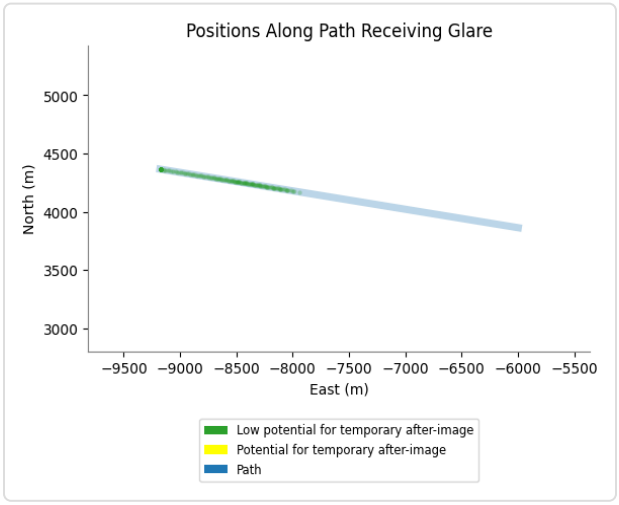
Yellow glare: none

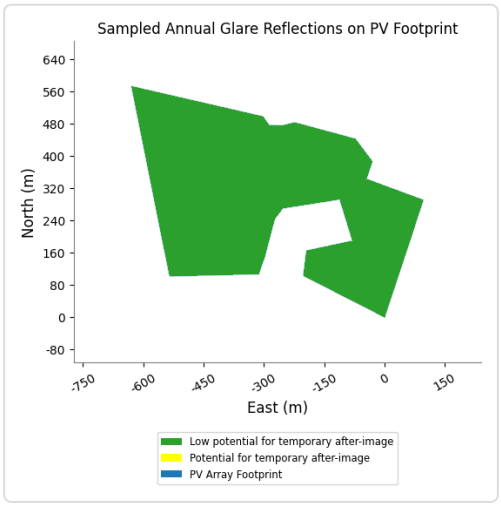
Green glare: 684 min.

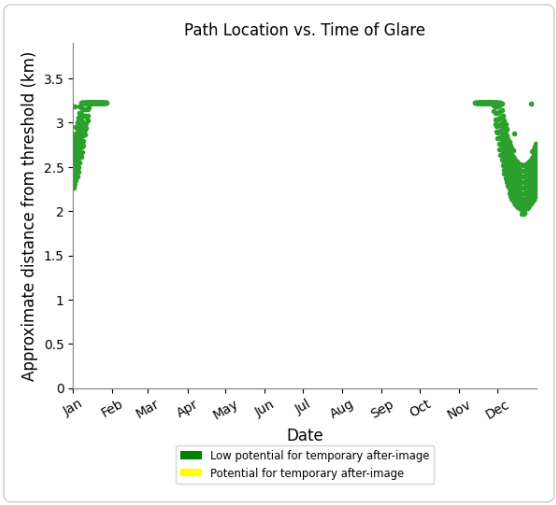












Quantum 1 and FP: Runway 18

No glare found

Quantum 1 and FP: Runway 29

No glare found

Quantum 1 and FP: Runway 36

No glare found

Quantum 1 and OP 1

No glare found

Quantum 1 and OP 2

No glare found

Quantum 1 and OP 3

No glare found

Quantum 1 and OP 4

No glare found

Quantum 1 and OP 5

No glare found

Quantum 1 and OP 6

No glare found

Quantum 1 and OP 7

No glare found

Quantum 1 and OP 8

No glare found

Quantum 1 and OP 9

No glare found

Quantum 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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ForgeSolar Aviation Report

Project: ON- 2023-18-184

Report: PVTL-18-221

Appendix B – Quantum 1

Generated by: Dr FJ Vorster

Date generated: 2023/04/12

Reviewed by: Dr JL Crozier McCleland

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Project: **Quantum 1**

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DNI peaks at 1,000.0 W/m^2
Site ID 98551.17165

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

Glare Policy Adherence

The following table estimates the policy adherence of this glare analysis according to the **2021** U.S. Federal Aviation Administration Policy:

Review of Solar Energy System Projects on Federally-Obligated Airports

This policy may require the following criteria be met for solar energy systems on airport property:

- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics, including 1-minute time step.

ForgeSolar is not affiliated with the U.S. FAA and does not represent or speak officially for the U.S. FAA. ForgeSolar cannot approve or deny projects - results are informational only. Contact the relevant airport and FAA district office for information on policy and requirements.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
ATCT(s)	N/A	No ATCT receptors assessed

The referenced policy can be read at https://www.federalregister.gov/d/2021-09862

Component Data

This report includes results for PV arrays and Observation Point ("OP") receptors marked as ATCTs. Components that are not pertinent to the policy, such as routes, flight paths, and vertical surfaces, are excluded.

PV Arrays

Name: Quantum 1
Axis tracking: Single-axis rotation
Backtracking: Shade-slope
Tracking axis orientation: 0.0°
Max tracking angle: 60.0°
Resting angle: 0.0°
Ground Coverage Ratio: 0.4
Rated power: 10000.0 kW
Panel material: Smooth glass with AR coating
Reflectivity: Vary with sun
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Observation Point ATCT Receptors

No ATCT receptors were included in the analysis.

Glare Analysis Results

Summary of Results No glare predicted

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PV: Quantum 1

No ATCT receptors assessed.

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