Solar Glare Analysis Report

Dixon Run Solar Project

Bloomfield Township, Jackson County, Ohio

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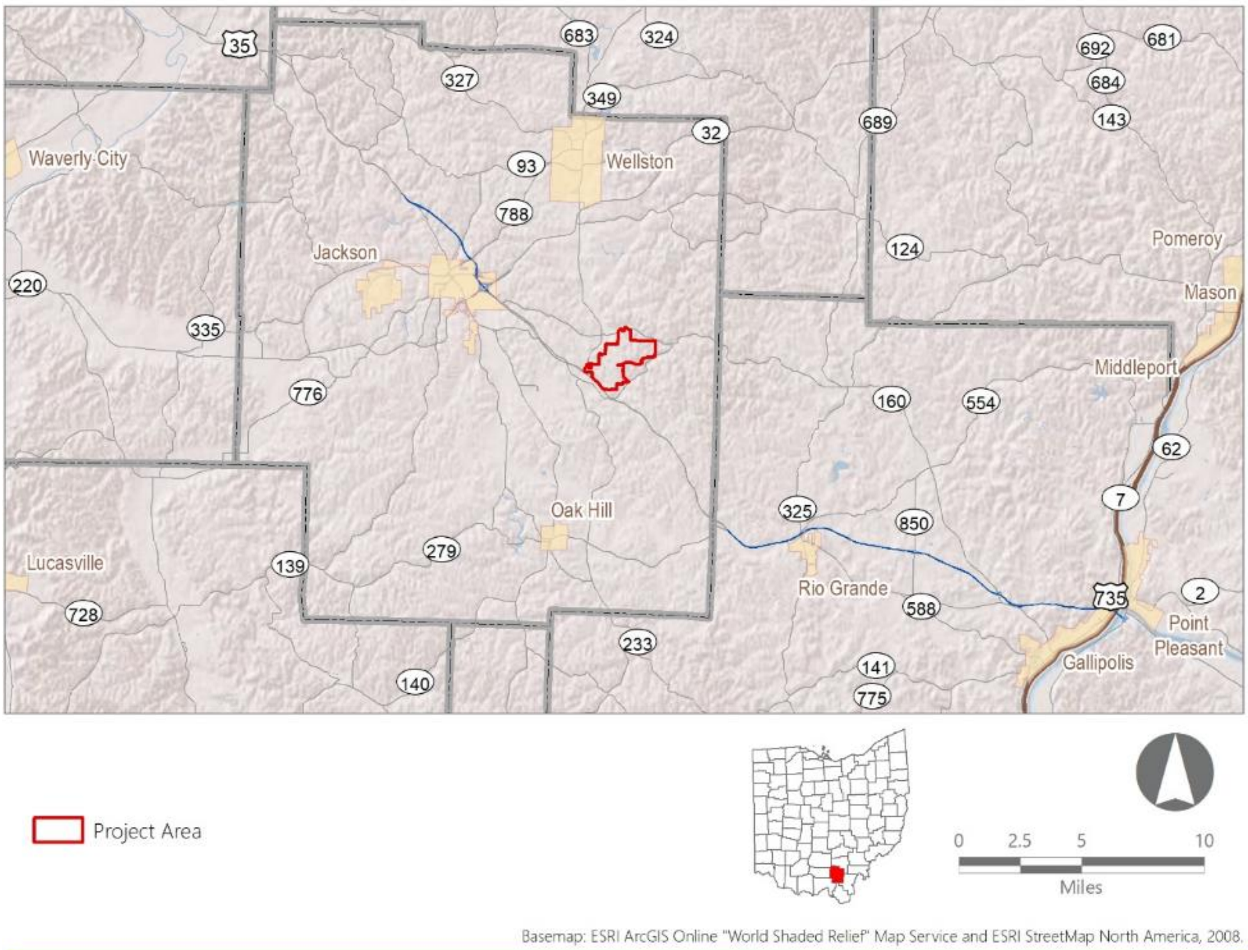
INTRODUCTION

Dixon Run Solar, LLC (Dixon Run Solar or Applicant), is proposing to construct an up to 140-megawatt (MW) solar energy generation facility in Bloomfield Township, Jackson County, Ohio (hereafter referred to as the Facility) (see Figure 1). This report provides an assessment of potential glare impacts resultant from the operation of the Facility.

Figure 1. Regional Project Location

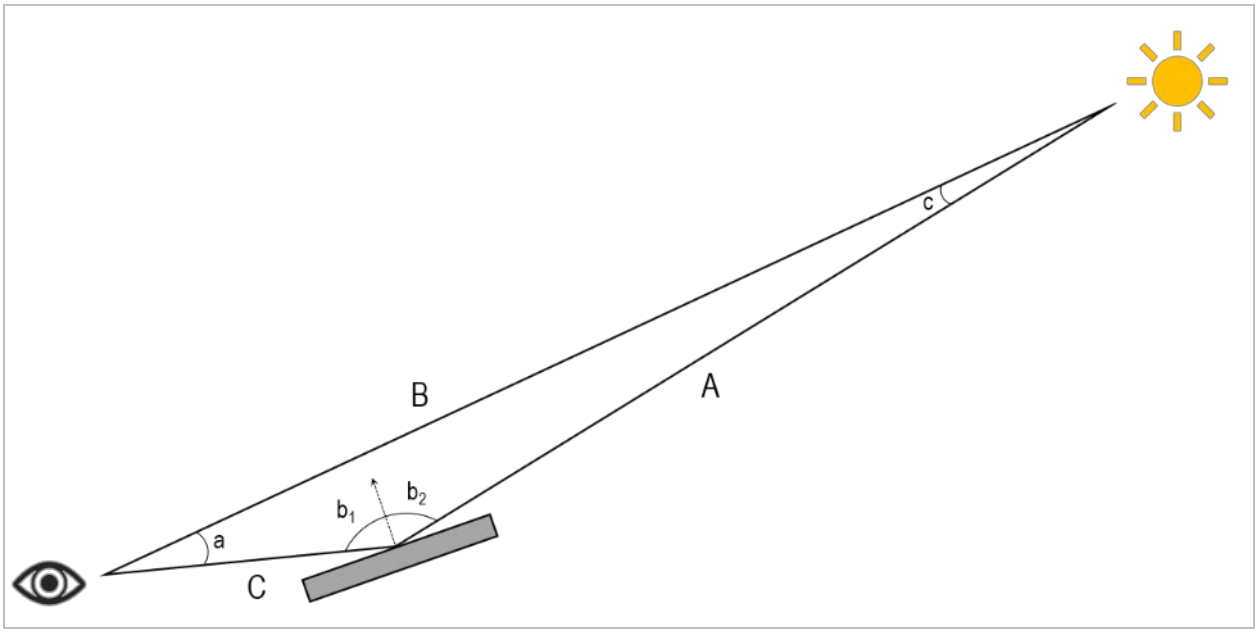


Definitions

The following terms are used throughout this assessment.

Direct Normal Irradiance (DNI):	The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.
Diffuse Solar Radiation:	Solar radiation scattered by molecules and particles in the atmosphere.
Direct Solar Radiation:	Solar radiation that has travelled from the sun to the earth's surface in a straight line without scattering. Direct radiation is the component of solar radiation that causes visible glare from flat-plate photovoltaic systems.
Facility:	All components of the proposed project, including PV panels and support structures, inverters, transformers, access roads, collection lines, a collection substation, a POI switchyard, and laydown areas.
Facility Site:	The parcels of land proposed to host the Facility components.
Glare:	A continuous source of bright light.
Glint:	A momentary flash of bright light.
Incidence Angle:	The angle between the direct component of insolation (i.e., the sun) and a ray perpendicular to the PV panel (angle b_2 in Figure 2 below). The incidence angle is equal to the reflectance angle.
Receptors:	Non-participating residences, commercial buildings, and institutional buildings (e.g., churches) within 1,500 feet of the Facility Site with the potential to receive glare from the Facility's PV arrays.
PV Panels:	Photovoltaic panels that are fixed to a ground mounted racking system. On this Facility, a fixed-tilt racking system is proposed.
PV Array:	A contiguous group of PV panels which collectively will be enclosed by security fencing and landscape screening plantings, where applicable.
Reflectance Angle:	The angle between the reflected component of insolation and a ray perpendicular to the PV panel (angle b_1 in Figure 2 below). The reflectance angle is equal to the incidence angle.
Retinal Irradiance	The flux of radiant energy per unit area impacting the retina.
Specular Reflection:	The mirror-like reflection of waves, such as light, from a surface.

Figure 2. Trigonometric Depiction



A trigonometric depiction of a receptor, a PV panel, and the sun. Reflectance Angle = b1; Incidence Angle = b2. The distance between the sun and the earth (sides A and B; approximately 91 million miles) is great enough, relative to side C (less than 1,500 feet or 0.28 mile), that angle c is effectively 0 degrees.

Project Overview

The Applicant is proposing the use of fixed tilt photovoltaic (PV) arrays. Fixed-tilt racking designs usually consist of a steel frame that creates a "table" on which the individual PV modules are mounted. The tables are fastened together to create a continuous row. The rows of PV panels will generally follow the existing topography of the Facility Site. Rows will be aligned east to west, with the PV panels tilted to the south at an angle of 15 degrees from horizontal. The PV panels will have a typical maximum height of 9.5 feet above the ground at their highest point. In total, the solar arrays will occupy approximately 439 acres (Figure 3).

The Facility is located within Bloomfield Township, Jackson County, Ohio, approximately 7.5 miles southwest of Jackson and 6 miles north of Oak Hill. Topography in the vicinity of the Facility is undulating, with elevations ranging from approximately 600 feet above mean sea level (amsl) to 975 feet amsl. Land cover within the vicinity of the Facility is dominated by forest, reclaimed mining activities, and active agriculture, with single-family residences generally located along road frontages.

Figure 3. Proposed Facility Layout

Photovoltaic Systems and Solar Glare

Glare is defined as a continuous source of bright light and differs from glint in its duration. Where glint is a momentary flash of bright light, the effects of glare are generally only realized after 0.15 second or more of exposure (Ho et al., 2011; Zehndorfer Engineering, 2019). Both glint and glare are common in the existing environment. The sun and artificial light sources can cause glare or glint either directly (such as from a sunset when driving westbound) or indirectly (such as from the sun's reflection off of a lake or glass window). The potential effects of glare include annoyance impacts, such as distraction, after-image in the viewer's vision, or temporary avoidance of a view due to the presence of reflected light (Dwyer, 2017; Slana, 2018); safety impacts, such as the potential to disorient road users or pilots (Auffray et al., 2008; Ho et al., 2011; Riley and Olson, 2011); and human health impacts, such as permanent retinal damage (Ho et al., 2009). It is important to note here that human health impacts are typically only associated with concentrating solar power plants or other convex reflective surfaces (e.g., convex curtain wall buildings) that concentrate the incoming solar radiation. Flat-plate photovoltaic systems, such as the proposed Facility, are incapable of producing the retinal irradiance levels necessary to result in permanent retinal damage.

Although photovoltaic systems are designed to absorb as much of the solar spectrum as possible, PV panels can reflect a significant proportion of the incoming solar radiation at high incidence angles (Parretta et al., 1999). As a result, under clear sky conditions, fixed-tilt photovoltaic systems, such as the proposed Facility, may produce glare in the early morning and evening when the sun is low on the horizon and there are no obstructions (e.g., topography, vegetation, structures, etc.) limiting the production and receipt of glare.

Modeling Glare

To develop a general estimate of the occurrence, duration, and intensity of glare produced by a PV system and received at a given observation point, the following information is needed:

- Location, size, height, spacing, orientation, and reflectance of the PV panels;
- Location and height of the observation point;
- Position of the sun;
- Direct Normal Irradiance (DNI);[1] and
- Geospatial characteristics of topography, vegetation, buildings, or other potential obstructions between the observation point and the PV panels producing glare and between the PV panels and the sun.

ForgeSolar is the only company the Applicant is aware of that provides software that allows a user to model glare using the Solar Glare Hazard Analysis Tool (SGHAT). This software, "GlareGauge," is entirely based on the SGHAT model,[2] a conceptual model that was initially developed for use by the Federal Aviation Administration (FAA) in evaluating safety impacts to pilots while landing aircraft (Ho et al., 2015). This tool has since expanded and can be used to identify the potential for a photovoltaic system to produce glare receivable by ground-based receptors (Forge Solar, 2021). However, the application of this tool is limited,

[1] As DNI varies with both the sun position and changing atmospheric conditions, site-specific data with high temporal resolution is needed to accurately estimate glare.

[2] For the purposes of this assessment, the terms "GlareGauge software" and "SGHAT model" are used interchangeably.

as described in Section 1.3.2, as this software is based on a clear sky and bare earth model that assumes each PV array is a uniform surface. As discussed further below, this model does not consider atmospheric conditions that scatter incoming solar radiation, terrestrial obstructions that block PV panels from receiving direct radiation and/or block an observer from receiving glare, other intense sources of radiation that might mask the effect of glare (i.e., the sun), and other variables that would affect the production and receipt of glare from potentially sensitive receptors. In addition, the model does not allow a user to provide site-specific information on the spacing, size, or characteristics of the PV panels that make up an array.

SGHAT Model Limitations

Atmospheric Obstructions

Direct solar radiation is the component of solar radiation that causes visible glare from flat-plate PV systems (Riley and Olson, 2011). Direct radiation is radiation that has travelled from the sun to the earth's surface in a straight line without scattering. In order for PV panels to produce glare, direct solar radiation must strike PV panels at a high incidence angle.[3] Clouds, humidity, and other atmospheric elements scatter and absorb a certain percentage of solar radiation as it travels through the earth's atmosphere, reducing the amount of sunlight that reaches the earth's surface as direct radiation. Under some conditions (e.g., overcast skies), little to no solar radiation reaches the earth's surface without scattering.

The SGHAT model assumes a clear sky with limited radiative scattering. DNI values built into the model represent the maximum values possible for the site, considering the latitude and position of the sun. In the desert southwest, where most of the studies that support the SHGAT model were conducted (e.g., Ho et al., 2011 and Ho, 2013), this assumption is not likely to be problematic. However, in the northeastern United States, where high humidity levels and cloudy or overcast conditions are common, this assumption contributes to an overestimation of glare occurrence, duration, and intensity, as DNI has a direct relationship with glare intensity (Ho et al., 2011).

As an example, the models presented by Ho et al. (2011) were validated at the National Solar Thermal Test Facility located just outside of Albuquerque, NM. The annual percent average of possible sunshine in Albuquerque, NM is 76%, one of the highest values in the nation (NOAA, 2021). In comparison, the annual average percent of possible sunshine in Columbus, OH (located approximately 60 miles north of the Facility Site) is 45% (NOAA, 2021). Sites such as the Facility Site that have a high occurrence of cloudy or overcast conditions are expected to have lower glare occurrence, duration, and intensity in the real world as compared to the SGHAT model outputs.

Terrestrial Obstructions

Another primary limitation of the SGHAT model is its assumption of a bare earth condition. To produce glare at a given observation point, there must be a clear line-of-sight between the sun and the PV panels, and between the PV panels producing glare and the observer. In the area within and adjacent to the Facility Site, topography, vegetation, buildings, and other obstructions significantly limit the visibility of the Facility's solar arrays. Where these terrestrial obstructions do not completely block a receptor's view of the PV arrays,

[3] Specular reflectance is limited at low incidence angles (Parretta et al., 1999).

they often disrupt that view, breaking it into smaller, less contiguous sections. The SGHAT model does not consider these obstructions that currently exist in the landscape.

As noted above, the SGHAT model was designed to meet the FAA's glare analysis requirements (78 FR 63276[4]). In assessing potential glare for pilots and airports, the relevant sensitive receptors (e.g., aircraft and air traffic control towers) are well above the ground surface and terrestrial obstructions are typically limited.[5] In contrast, the proposed Facility is comprised of multiple PV arrays spread out across miles of variable terrain that includes a patchwork of existing vegetative communities (e.g., forests and farmland).

No commercial or municipal airports or air traffic control towers are found within 2 miles of the Facility Site. Potentially sensitive receptors are limited to residents and road users, which are located near the ground surface and, in many cases, are lower in elevation than the PV panels. Many areas within the Facility Site are densely forested; the forests and hedgerows located adjacent to the PV panels substantially reduce the visibility of the Facility from adjacent observation points and shade the panels from direct radiation in the early morning and late evening. In heavily forested areas, such as the area surrounding the Facility Site, tall trees located adjacent to the PV arrays can significantly affect experienced sunrise and sunset times.

Considering that glare is almost exclusively produced in the morning and the evening—the times of day when the incidence angle between the sun and the PV panel (angle b_2 in Figure 2) is highest—this is a potentially significant model limitation. As an example, 40-foot trees located 120 feet west of a PV panel would delay sunset by roughly an hour and a half in mid-summer. Any glare predicted by the SGHAT model under these conditions would not be produced by the PV panel as direct radiation would be lacking.

As a final point, most PV panels have a maximum height of 8-12 feet. At these heights, the panels themselves can act as form of visual screening, preventing a receptor from viewing more than edges of a PV array, particularly for receptors located at an elevation equal to or less than that of the PV array or in cases with a PV array is located on a slope that grades away from a receptor.[6] This is problematic because, as described above, the SGHAT model assumes that a receptor has full visibility of the PV array. However, in many cases, inter-array panel screening may block most, or all of the glare potentially received by an adjacent receptor or roadway user. Considering the maximum height of most PV panels and the heights of most ground-based receptors (residences and road users), it is likely that the SGHAT frequently overestimates glare in failing to account for inter-array panel screening.

All of this being said, the SGHAT model is a tool, and in fact may be the only commercially available tool, to assess worst-case predictions of glare from the Facility Site and identify locations where the potential incidence of glare may be highest. The number of hours of glare output by the model can be used to characterize the potential impact and identify the potential need for minimization and mitigation.

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[4] Available at: https://www.govinfo.gov/content/pkg/FR-2013-10-23/pdf/2013-24729.pdf

[5] Airports are typically sited in locations with limited topographic relief. In addition, the height of adjacent vegetation is controlled.

[6] In some cases, depending on the topographic and trigonometric relationship between a receptor and the PV array, a receptor located nearly due east or due west of an array may have visibility of one full row of the PV array. However, in the northern hemisphere, such views are unlikely to produce glare with a sun masking angle of more than 10 degrees.

Sun-masking Angle

A variable that is not accounted for in the SGHAT model, but which is important in determining the effect glare may have on a receptor, is the sun-masking angle concept. When the sun is low on the horizon, the sun and PV panels producing glare can be viewed simultaneously by a potential receptor. As the intensity of retinal irradiance produced by the sun is several orders of magnitude greater than what is capable of being produced by flat plate (i.e., non-concentrating) PV panels (Ho et al., 2011), the sun's intensity can partially or wholly overshadow the glare produced by the PV panels, depending on the angle between the sun and the PV panels, as perceived from the receptor (i.e., angle a in Figure 2). Although there is some ambiguity regarding the angle at which the sun fully masks glare produced by PV panels (Zehndorfer Engineering, 2019), Germany and Austria have established a conservative sun-masking angle standard: glare received by PV panels can be discounted when the sun-masking angle is less than 10 degrees (LAI, 2012; Zehndorfer Engineering, 2019).

Additional Considerations

In addition to the limitations described above, the SGHAT model offers no opportunities for a user to modify the characteristics of a PV array to reflect site-specific details regarding the panel dimensions, the spacing between rows of PV panels, or component variation within a PV array (e.g., access road placement). All PV arrays are treated equally as a unified reflective surface; PV arrays with 40 feet of spacing between panels to allow continuing agricultural equipment access are treated the same as tightly packed arrays with less than half the spacing between panels.

All conceptual models are limited in their ability to represent or anticipate real world phenomena and require correction and validation in order to output accurate data. What is unusual about the SGHAT model, as applied to flat-plate PV systems and ground-based receptors, is the scope of the corrections needed to accurately assess glare receivable by ground-based receptors and—perhaps most importantly—the lack of model validation for this specific application. Ho et al. (2011) validated the accuracy of the model in the desert southwest in predicting the timing and duration of glare produced by concentrating solar energy facilities, and the model was applied and further validated in other locations in the United States, including the northeast (Ho et al., 2013), but none of these studies assessed the accuracy of the SGHAT model in predicting the occurrence, duration, and intensity of glare received by ground-based receptors, such as year-round residences. Neither the SGHAT Technical Reference Manual (Ho et al., 2015) or the studies cited on ForgeSolar's website provide any further information indicating that the GlareGauge software has been validated for this specific application.

The SGHAT model used by ForgeSolar appears to be the only software tool available to conduct a solar glare assessment. However, for flat-plate photovoltaic systems sited in areas with atmospheric and terrestrial conditions that are not favorable to the production or receipt of glare, the raw outputs of the SGHAT model may not be representative of potential on-site conditions.

METHODS

Receptors

Pre-processing

A total of 68 non-participating receptors are located within 1,500 feet of the Facility fence. In addition, there are a number of public roads running adjacent to the Facility. No commercial or municipal airports or heliports are located within 2 miles of the Facility. As intervening vegetation and topography (i.e., visual obstructions) are ubiquitous across the Facility, an initial desktop screening process was conducted using general viewshed modeling, aerial imagery, and the trigonometric relationships between receptors and the PV arrays to identify receptors with the potential to receive solar glare from the Facility.

Using 2007 Ohio Statewide Imagery Program (OSIP) lidar datasets for Jackson, Gallia, and Vinton Counties, a 5-foot resolution digital surface model (DSM) was created, which included the elevations of buildings, trees, and other objects large enough to be resolved by lidar technology. As part of the development of the DSM, woodlots and hedgerows that may potentially be cleared during construction of the Facility were removed from the resulting DSM to reflect the bare-earth elevation in these locations. The modified DSM was then used as a base layer for a general viewshed model of the Facility. In this viewshed analysis, the height of sensitive receptors was set to 5.4 feet, and the height of the proposed PV arrays was set to 9.5 feet.

At the Facility's latitude (38.9° N) and considering the proposed PV panel orientation (180 degrees, i.e., east-west) and tilt (15 degrees south), a receptor must be located generally due east, due west, east southeast, or west southwest of adjacent visible PV arrays in order to receive glare produced by that array. Receptors located north of adjacent PV arrays would not receive glare, as fixed tilt PV arrays that have a 180-degree orientation and a southern tilt are not capable of producing glare that can be received by terrestrial receptors located north of their east-west axis; the view of any receptor located north of this axis will be limited to the back or the side of the PV panels. Receptors located due south, southeast, or southwest of adjacent PV arrays would not receive glare as none of the solar position and receptor location combinations possible at this site would result in incoming solar radiation striking the panels at high incidence angles in a manner that could be received by such receptors. The potential for non-participating receptors to receive glare was analyzed further using the methods outlined below.

Observation Point Viewshed Analysis

An observation point viewshed analysis was completed for each of the receptors. This analysis utilized the DSM and model inputs identified above to identify the visibility of the PV arrays for each of the receptors. Figure 4 provides a representative example of the observation point viewshed analysis results, using Receptor 151. Considering PV panel orientation and panel visibility within a portion of panels that have the correct position to cause glare receivable at each receptor, 56 of the non-participating receptors were identified as not having visibility of the panels or being in the correct orientation to receive glare.

Figure 4. Example of Observation Viewpoint Analysis

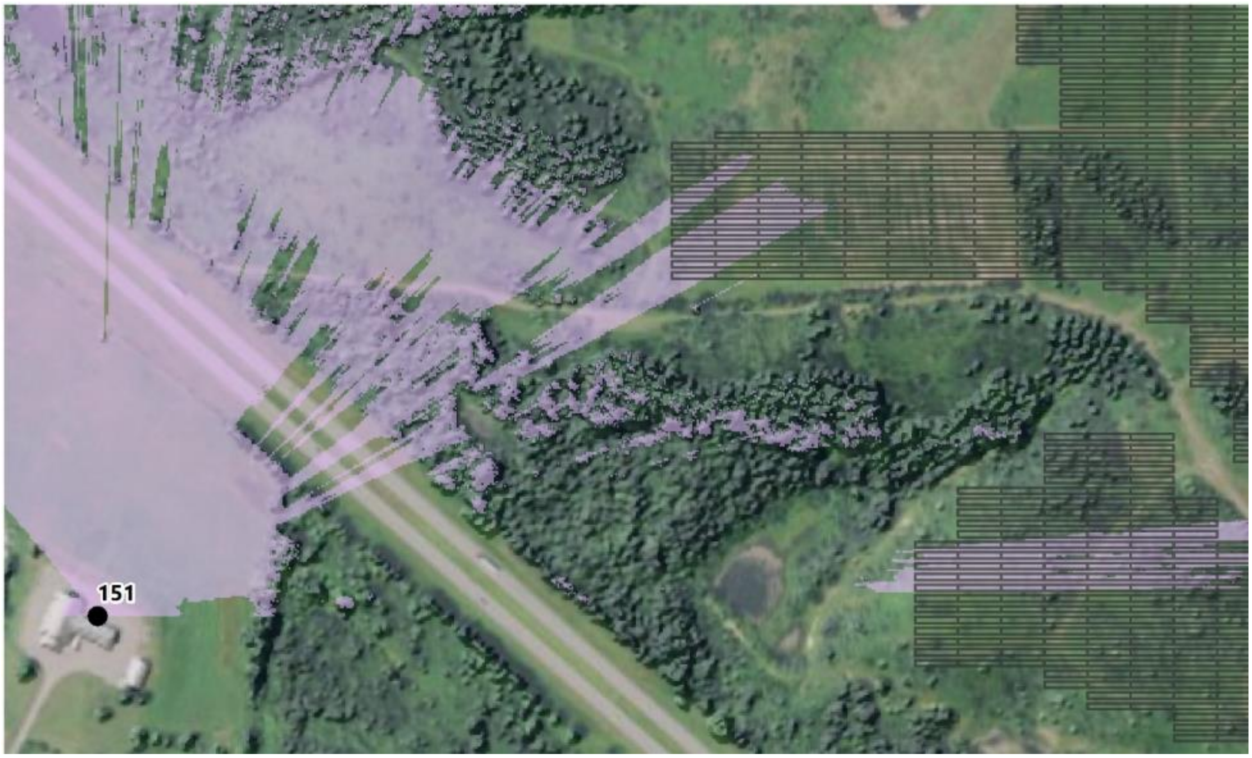

Figure 4 above shows the observation viewpoint analysis results for Receptor 151. The proposed photovoltaic (PV) panels are outlined in dark gray and the results of the viewshed analysis are shown in purple.

Field Verification

To verify the results of the observation point viewshed analysis, a field survey of receptor visibility was conducted in September 2021 by EDR staff. All sensitive receptors identified in the observation point viewshed analysis as having visibility of the PV panels with the potential to cause glare were visited and the existing viewshed of these receptors was assessed.[7] This field survey accounted for site-specific characteristics that could not be derived from the DSM, such as the composition and shape of intervening vegetation, specific characteristics of the receptor, unaccounted for changes in the vegetation or landscape (e.g., new buildings or removed trees), and other elements affecting the visibility of the PV arrays. The results of this field survey were documented in the field and geotagged photographs were taken from multiple angles at each assessment location.

SGHAT Modeling

The results of the observation point viewshed analysis and field verification were used to develop a final geospatial dataset identifying the specific PV panel areas likely to produce glare that can be received by the potentially affected receptors. This dataset accounted for all terrestrial obstructions known at the time of

[7] Where the Applicant lacked access to specific non-participating receptors, the field survey was conducted from public rights-of-way (ROW).

the field survey that could affect the receipt of glare.[8] Appendix A shows the final geospatial data for all receptors included in the final modeling. Figure 5 provides an example of the final geospatial data, using Receptor 151.

Figure 5. Example of Final Model Inputs

Figure 5 above shows the final model input data for Receptor 151 (shown in orange). These model input data were developed based on the results of the observation point viewshed analysis (shown in purple, for reference), the results of the field verification, and the results of the preliminary glare analysis. Proposed photovoltaic (PV) panels are outlined in dark gray.

This final geospatial dataset was then input into the ForgeSolar modeling software, along with the core assumptions outlined in Table 1 to produce the SGHAT model outputs.

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[8] It is important to note that in interpreting the results of a typical viewshed analysis where vegetation is incorporated in the DSM, some consideration needs to be made for leaf-off conditions. Lidar-derived viewshed data, which was utilized in this analysis, has the potential to underestimate visibility in the dormant season where the lack of deciduous foliage can improve visibility. However, as indicated in the results of this assessment (see Appendix A), leaf-off conditions are largely irrelevant to the Facility, because the Facility's potential to produce glare is almost exclusively limited to the late spring, summer, and early fall.

Table 1. SGHAT Model Inputs

Parameter	Input
Panel Height	9.5 feet[1]
Receptor Height	5.4 feet[2]
Axis Tracking	Fixed
Orientation	180 degrees
Tilt	15 degrees (facing south)
Panel Material	Glass with an anti-reflective coating
Slope Error	6.55 mrad

[1]The maximum height of the PV panels.
[2] Average eye height for males in the United States.

Post-processing

As discussed in Section 1.3, when a receptor views glare from PV panels and glare from the sun in the same general line-of-sight, the sun's significantly greater intensity overshadows (i.e., "masks") the glare produced by the PV panels. To address the masking effect of the sun, a 10-degree sun-masking angle threshold was set[9] and a logical equation was applied to the raw SGHAT model outputs to discount glare received at a sun-masking angle of less than 10 degrees (i.e., an incidence angle greater than 85 degrees).

The National Weather Service (NWS) typically measures percent of possible sunshine using Marvin sunshine recorders, devices that are sensitive to direct radiation, but which also measure diffuse radiation to some extent (American Meteorological Society, 2020). Direct radiation is the component of solar radiation that causes visible glare from flat-plate photovoltaic systems; diffuse radiation is radiation that has been scattered by molecules in the atmosphere. Diffuse radiation does not play a central role in producing glare (Riley and Olson, 2011). As Marvin sunshine recorders measure both direct and diffuse radiation, the percent possible sunshine values recorded by the NWS represent a conservative estimation of the climatic conditions under which glare may be produced.

Monthly average percent possible sunshine records for Columbus, Ohio were acquired from the National Oceanic and Atmospheric Administration (NOAA; NOAA, 2021) (see Table 2).

[9] Germany and Austria have established a similar threshold (LAI, 2012; Zehndorfer Engineering, 2019). See Section 1.3 for further discussion.

Table 2. Monthly Percent of Possible Sunshine Values for Columbus, Ohio

Month	Percent of Possible Sunshine
January	31
February	42
March	42
April	49
May	53
June	54
July	54
August	54
September	55
October	53
November	33
December	28

NOAA, 2021

Public Roadways

The limitations of the SGHAT model are even more difficult to address for road users traveling through the Facility Site. In modeling the potential for glare to be received at a receptor, the receptor can be assumed to be a relatively static point with known attributes. Road users travel in multiple directions on a three-dimensional surface at differing velocities. Although it would be possible to provide a general correction for climatic variables that affect the production of glare (as described in Section 2.1.5), all other model limitations would be difficult or impossible to address as each point along a travel route would have unique conditions (e.g., visibility, effective sunrise/sunset, inter-array PV panel screening, sun-masking angle, etc.). Although the SGHAT model provides the option to model glare along roadways, considering the limitations discussed in this assessment, the results are not anticipated to be representative of on-site conditions. Accordingly, a qualitative assessment of potential glare impacts was completed for public roadways within and adjacent to the Facility Site.

As an initial step, the viewshed modeling described in Section 2.1.1 was applied to determine which roadways in the vicinity of the Facility Site have some visibility of the PV panels. Portions of the following public roads were identified as having will have visibility of the Facility's PV arrays; US Highway 35, State Route 327, Keystone Furnace Road, Dixon Run Road, Ridgeland Road, Thornton Road, and Westchester Cemetery Road.

Although portions of these roads may have visibility of the Facility PV arrays, an additional consideration that is relevant for roadways is whether glare has the potential to be received within a road user's inner field of view. Pilots and road users have to deal with visual distractions, including glare, on a daily basis. This is typically not an issue unless such distractions are located within the operator's inner field of view, generally +/- 25 degrees for pilots and +/- 15 degrees for road users (Rogers et al., 2015; Zehndorfer et al., 2019). Glare received within a road user's inner field of view is less easily ignored and can more directly affect an operator. The likelihood that glare produced by the Facility's PV arrays would be received within a road user's inner field of view was analyzed qualitatively.

RESULTS AND DISCUSSION

Receptors

In completing the methods outlined in Sections 2.1.1, 2.1.2, and 2.1.3, it was determined that only 12 of the 68 non-participating receptors located within 1,500 feet of the Facility Site had the potential to receive glare produced by the Facility (Table 3). For the receptors where glare impacts are not anticipated, vegetation, existing structures (e.g., barns and outbuildings), and topography were found to be the most important terrestrial factors in limiting the potential receipt of glare. In most cases, intervening vegetation was often found to obscure or disrupt a receptor's view of potential glare-producing PV panels, as illustrated in Figure 4 and Figure 5.

The post-processed SGHAT model results, which account for terrestrial obstructions between the receptors and the potential glare-producing PV panels, average atmospheric conditions, and the masking effect of the sun, indicate that seven of the 68 non-participating receptors within 1,500 feet of the Facility (10%) may receive some amount of glare over the course of the year: receptors 142, 143, 144, 145, 146, 148, and 153. The average annual duration of glare at these receptors is estimated at 7 hours (Table 3). Timing and duration of glare at individual receptors vary depending on the position and proximity of the receptor relative to the potential glare-producing PV panels. In general, glare is anticipated primarily during the summer months before 7 AM and after 5 PM. Receptors with higher modeled glare levels receive glare somewhat evenly throughout the spring and summer months, whereas receptors with lower modeled glare levels receive glare generally around the summer equinox. See Table 3 for further details regarding the raw SGHAT model outputs.

Table 3. ForgeSolar Final Glare Modeling Results

Receptor	Yellow Glare (min)	Green Glare (min)	Initial Model Run Total Hours	Post Incidence (min)	Post Incidence (hrs)	Post Sunshine Reduction (min)	Post Sunshine Reduction (hrs)
85	757	499	20.93	0	0	--	--
86	743	125	14.47	0	0	--	--
87	602	60	11.03	0	0	--	--
142	0	1874	31.23	606	10.10	326	5.43
143	1120	3159	71	1272	21.20	684	11.40
144	1220	254	24.57	503	8.38	271	4.52
145	0	1792	29.87	628	10.47	338	5.63
146	819	2288	51.78	1110	18.50	596	9.93
148	1918	1721	60.65	1296	21.6	695	11.58
151	369	109	7.97	0	0	--	--
153	806	0	13.43	108	1.80	58	0.96
264	979	0	16.32	0	0	--	--

As discussed previously, these estimates represent a worst-case scenario of average conditions. These estimates do not account for terrestrial obstructions between the sun and the PV panels that would prevent the production of glare (i.e., the effects of PV panel shading in the morning and evening) or other model limitations that would further reduce the production and receipt of glare in the real world (e.g., panels in the viewing foreground blocking a receptor's view of glare being produced by panels deeper in the array). In effect, these results assume that (1) each of the seven receptors has full visibility of the PV array causing glare, (2) no trees or other terrestrial obstructions exist adjacent to the PV arrays that would shade the panels in the morning and evening, and (3) the PV arrays are uniform surfaces.

As one or more of these assumptions are incorrect for each of the seven receptors, the glare received by receptors adjacent to the Facility Site is anticipated to be substantially less than raw SGHAT model output data or the post-processed data.

The vegetative screening proposed throughout the Facility Site is anticipated to meaningfully contribute to the mitigation of glare impacts. Considering that (1) glare at this site is predicted to occur primarily in the summer, during the leaf-on period and (2) the majority of receptors have a narrow window of visibility of the panels predicted to produce glare (see Appendix A), for most receptors, vegetative screening plantings—once established—are likely to be an effective remedy in further mitigating the potential effects of glare. In addition, in the final design of the Facility, the Applicant will retain existing on-site vegetation wherever feasible, particularly along roadways and property lines, to retain the screening benefits of existing vegetation.

During operations, the Applicant will implement a complaint resolution plan that will require the Applicant to work proactively with residents and stakeholders in the community in responding to concerns with glare, if they should occur. If complaints arise that cannot be resolved, the Applicant will propose additional measures to mitigate potential glare impacts, which may include installing additional vegetative screening plantings, fencing, or other forms of visual screening, or potentially securing good neighbor agreements with impacted landowners.

Public Roadway Users

In locations where the Facility's PV arrays are visible only to the south (Keystone Furnace Road), glare will not be possible since the views will be of the back of the panels. Where the roads are all oriented north/south (State Route 327, Ridgeland Road, and Westchester Cemetery Road), glare received by road users traveling along these roads will only be viewable from +/- 60-90 degrees, well outside a road user's inner field of view. For this reason, glare received along these roadways will not be considered further in this analysis. Existing visual screening will largely block views of those portions of the PV arrays located north of the section of Dixon Run Road east of US Highway 35 that could produce glare receivable within a road user's inner field of view. The majority of the Facility's PV arrays are located in proximity to US Highway 35. However, with a few of exceptions, most of the panels sited along this road have been set back far enough from the edge of the road that glare produced by the panels will be screened by existing vegetation or will be received outside a road user's inner field of view. Any perceivable glare at these locations is not anticipated to impede traffic movements or create safety hazards.

Although the majority of glare produced by the Facility will be received outside a road user's inner field of view (i.e., +/- 15 degrees), glare is anticipated to be received within a road user's inner field of view under some conditions at the locations outlined above. In these locations, glare will be received in the morning and the evening, at times of the day when road users are accustomed to coping with glare from the sun and glare produced by other specular bodies (e.g., water bodies, curtain wall buildings, large windows, etc.). For all road users, glare is a common and well-studied phenomena (Auffray et al., 2008; Redweik, 2019). As evidence of this, all vehicles sold in the United States come standard with features intended to help a road user cope with glare received from the sun or other sources (sun visors and shade bands).

Furthermore, considering the timing of the glare anticipated and the east-west orientation of the roads where glare could occur, glare within a road user's inner field of view will be produced under conditions where a road user is already actively mitigating glare impacts from the sun in the evening and morning. In consideration of these factors and the Applicant's planned mitigation strategy (see Section 3.1), road users travelling near the Facility Site will not be exposed to glare in a manner that would impede traffic movements or create safety hazards.

CONCLUSIONS

Fixed-tilt photovoltaic systems, such as the proposed Facility, can produce glare in the morning and evening when the sun is low on the horizon. The receipt of this glare by potentially sensitive receptors can be modeled using ForgeSolar's GlareGauge tool, a commercial software program that is based on the Solar Glare Hazard Analysis Tool (SGHAT) developed by Sandia National Laboratories. However, this tool is a conceptual model with limited accuracy in quantifying potential glare impacts for ground-based receptors in locations such as the Facility where terrestrial and atmospheric obstructions that limit the production of glare are common.

In considering the effects of cloud cover, the sun masking angle, and terrestrial obstruction preventing the receipt of glare at non-participating receptors, this Solar Glare Assessment addresses some of the primary limitations of the SGHAT model. However, significant unresolved model shortcomings limit the accuracy of the quantitative aspects of the SGHAT model outputs. To account for this, a qualitative analysis of glare impact was completed for receptors that have the potential to be impacted by glare. This assessment incorporated the post-processed results of the SGHAT model, where applicable, and found minimal potential for glare to be received at seven non-participating receptors and portions of three public roadways located adjacent to the Facility Site.

Based on further qualitative analysis, the potential glare impacts to these receptors are anticipated to be limited in duration and intensity, when compared to the raw or post-processed SGHAT results. Potential glare impacts to roadways will occur around sunrise and sunset, times of the day that road users are accustomed to dealing with glare impacts from the sun. To mitigate potential glare impacts, the Applicant is committed to working with members of the community to proactively resolve concerns. These measures will be sufficient to ensure solar glare exposure is avoided or minimized, and will not result in complaints, impede traffic movements, or create safety hazards.

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Appendix A

ForgeSolar Glare Analysis