CKKR Limited

Detailed Glint and Glare Report

25th March 2022

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Disciplines: Solar Energy, Optics, Cybernetics & Control Engineering

16MW Solar PV and Battery Storage Project: Keithick Estate

1. Introduction & Scope

There exists concern about the potential for solar farms of this type to cause unwanted reflections of the sun that may distract drivers, aircraft or cause a nuisance to local residents. This report has been collated to inform readers, in a scientific way, about these concerns. Following a note on the various definitions it covers the basic background information about the characteristics of the solar panel and the nature of the optical parameters which govern the outcome. A more detailed study of the exact design in question then gives rise to a ray path analysis and conclusions are drawn from this.

2. Executive Summary

The reader is made aware that Solar PV modules are intended to absorb as much light as possible and to do this they have non-specular surfaces and anti-reflection coatings. 2 main references give further credibility to the report. In this report the analysis of the site reveals that, for the most part, reflected light is of low intensity and scattered and is generally reflected upwards away from the ground. Reports[1,2] suggest there is no risk to aviation from these minor reflections. There exist some conditions when reflected sun rays can travel parallel to the ground in the South East and South West direction. These conditions exist in early and late summer when the sun is low in the sky and when air mass index is high (reducing intensity) and when the sky in this region is clear. Under these specific condition's rays, which are scattered at the surface of the module, will, for residential properties, be caught by trees. Drivers proceeding down the minor road are likely to be aware of minor reflections but the sun itself will be by far the brightest object. It is proposed to plant hedgerow which acts both as screening and as a barrier to any glint or glare. It is the opinion of the author that, even without this planting, the development will not give rise to any additional hazardous or troublesome reflections beyond those that exist in the natural environment such as from house windows or greenhouses. It is documented [1] that solar panels produce glare no brighter than standing water.

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Photovoltaic Panel: Photovoltaic panels also known as PV panels are made up of a laminate of up to 72 thin square slices of silicon semiconductor material joined together in series with two surrounding layers of thermoplastic EVA insulating adhesive, a glass top sheet and a white Tedlar backsheet. This laminate is bound and sealed in an aluminium frame.

Glint: Also known as specular reflection, produced as a direct reflection of the sun on the surface of the PV panel. This is a potential source of the visual issues regarding viewer distraction.

Glare: A continuous source of brightness, relative to diffused lighting. This is not a direct reflection of the sun but rather a reflection of the bright sky around the sun. Glare is significantly less intense than glint.

Incident light ray: Is a light ray under consideration at the object of study.

Reflected light ray: Is the component of the Incident light ray that is reflected, in this case from the solar panel, according to the laws of Optics.

Refracted light ray: Is a component of the Incident light ray that passes into the material (glass) and is bent according to Snells Law towards the medium of higher refractive index.

Time: Refers to local solar time (LST) which is defined when the sun is highest in the sky being the solar noon which for practical purposes is close to 12:00 noon on a 24 hour time scale (depends to some extent on daylight savings time).

Azimuth Angle: The compass direction from which the sunlight is emanating from, in relation to the
PV panel position. North is 0° East is 90° South is 180° West is 270°

Elevation Angle: (Altitude Angle): Is the angular height of the sun in the sky measured from the horizontal. At sunrise and sunset, the Elevation Angle is close or at 0°.

Zenith Angle: Is the angle subtended by the sun and a line perpendicular to the horizontal and is equal to 90 degrees minus the Elevation angle.

Latitude: The angular geographical co-ordinate that specifies a North South position of a point on the Earth's surface.

Longitude: The angular geographical co-ordinate that specifies an East West position of a point on the Earth's surface.

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3. Useful Background Information

Photo voltaic solar panels are specifically designed to absorb light rather than reflect it. Light rays that reflect from solar panels result in a loss of energy output. PV modules are dark in colour due to the cells Silicon Nitride anti-reflective coatings and are manufactured with low-iron, ultra-clear glass with specialized coatings and textures to enable maximum absorption. The combination of these factors significantly increases electrical energy production of the panels and at the same time significantly reduces reflected rays. The textured surface of the panel also acts to reduce specular reflection i.e. to scatter incident light so that where light is reflected it has less localised intensity. The graph [Fig 1] below illustrates this effect where the textured surface gives rise not to a specular or direct reflection (like a mirror) but to a Gaussian or Lambertian (dispersed or hazy) distribution of the reflected light intensity. The majority of light is refracted through the glass onto the solar panels and the amount of reflected light is proportional to the Cosine of the angle of incidence of the light onto the surface of the glass. Figure 2 shows that little is reflected until a critical angle (Brewsters angle) is reached. This is normally at about 60 degrees (from the normal) for float glass and higher angles for solar panels with coatings designed to reduce the refractive index. Reflection also varies according to the polarization (red and blue curves) however for these purposes it is clear that very little reflection occurs at a wide range of incidence angles [Fig 2]. In the diagram 0 degrees is a ray perpendicular to the surface and 90 degrees is a ray along the plane of the module. It should be noted immediately that all rays coming at high incidence angles are those from the sun when it is low in the sky and therefore must penetrate more atmosphere before landing on the panel. This atmospheric affect is referred to as air mass [Fig 4] where A.M.1 is a single atmosphere thickness. It is this effect that gives rise to red sunrises and sunsets as the shorter (Blue, Green etc.) wavelengths are attenuated (reduced).

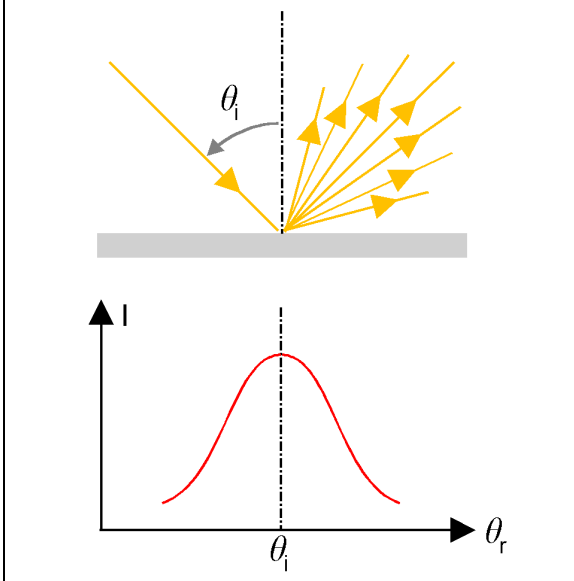

Fig 1 – Scatter from the solar panel glass surface

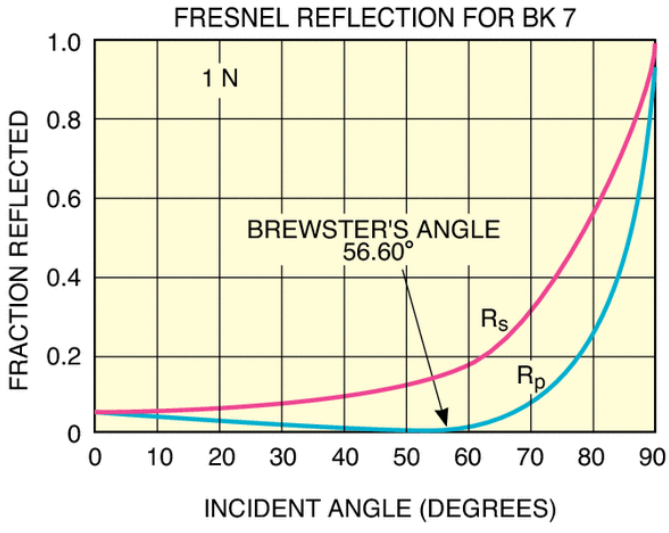

Fig 2 - Reflected fraction versus incident angle

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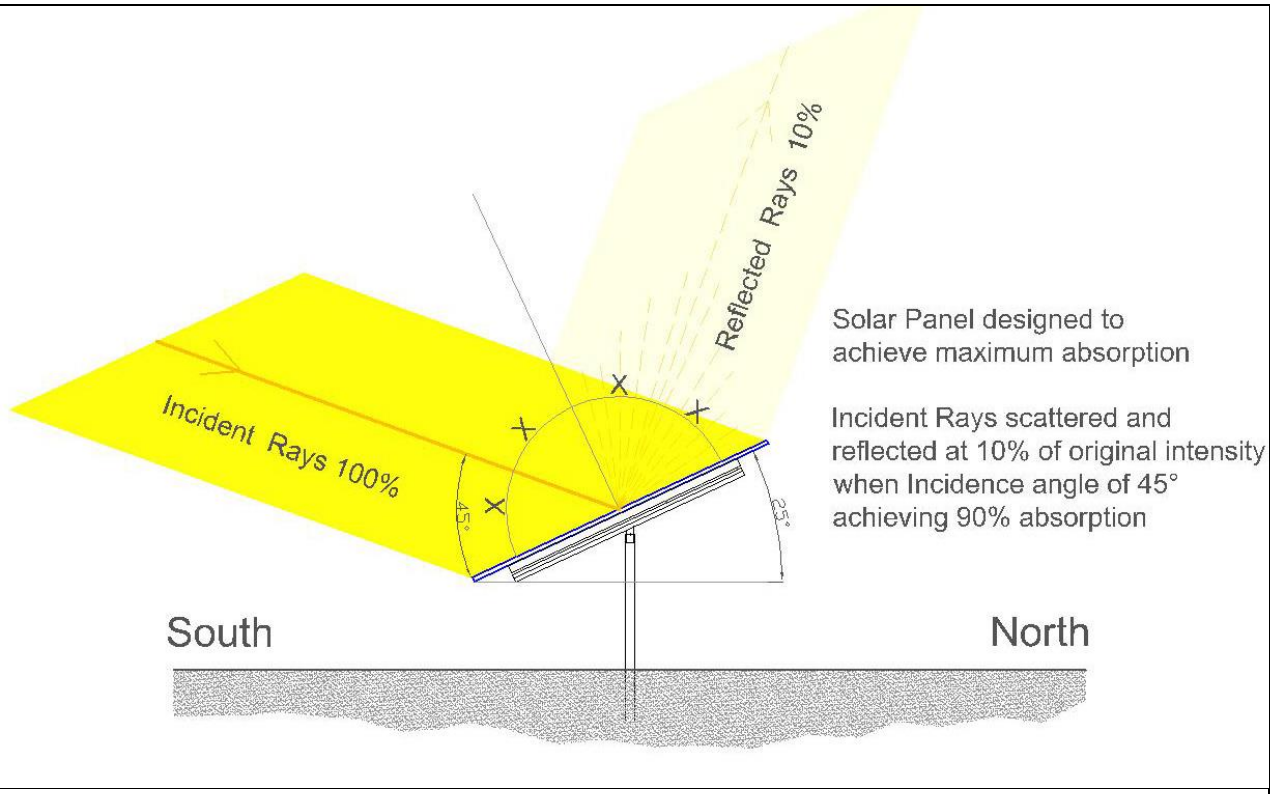

Fig.3 (see graph of % reflected light versus incident angle [Fig 2])

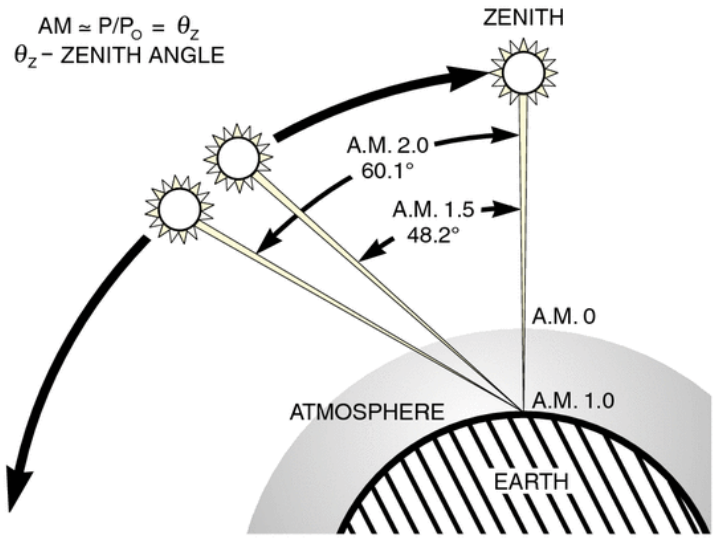

Fig 4 – Air Mass (A.M.) Index

The sun travels across the sky due to the Earth's rotation one 360 degree revolution in 24 hours, which is equivalent to 15 degrees per hour, or 1 degree every 4 minutes. The sun itself subtends approximately 0.5 degrees of arc to an observer at the surface of the Earth. It takes approximately 2 minutes therefore for the sun to set below the horizon. This gives an idea of the dwell time of any reflection that may occur.

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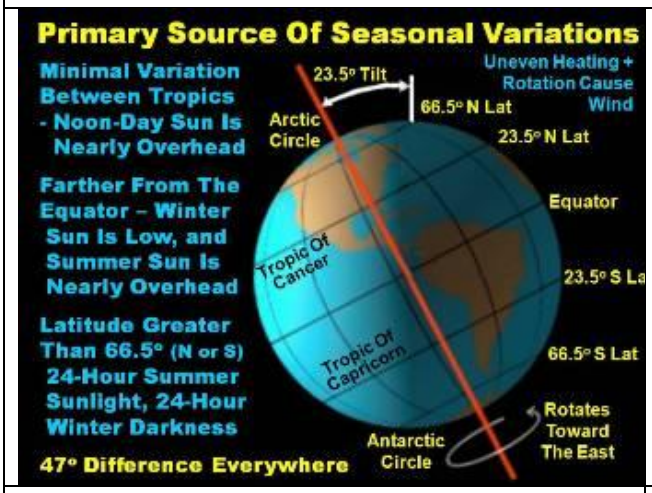

Fig 5 – Earths tilt

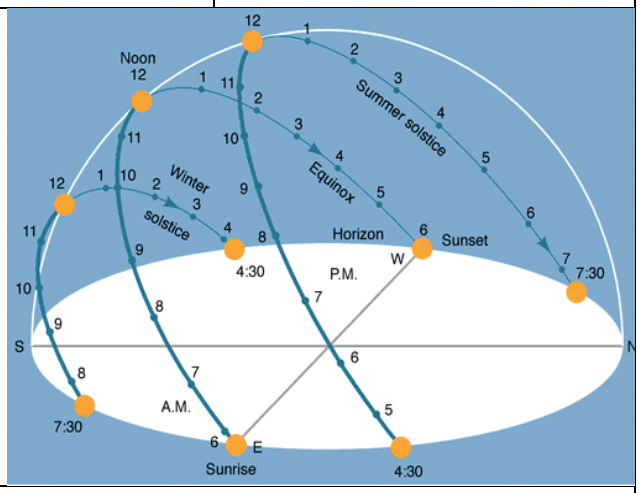

Fig 6 – Path of the sun

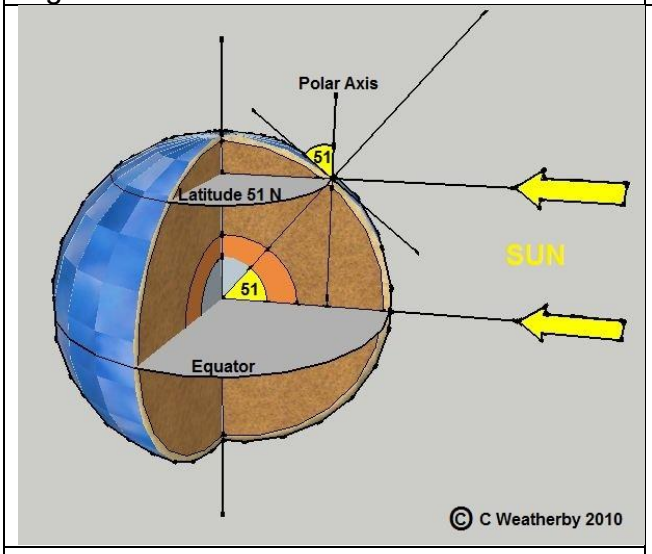

Fig 7 – Latitude influence

Suns Path: The diagrams illustrate the tilt of the Earth towards the sun in the Summer and away from the sun in the Winter. This variation is +- 23.5 degrees. This reveals that the mid-day sun is low on the horizon during the winter. For London which is at 51 degrees latitude this is equal to ((90-51) – 23.5 = 15.5 degrees) with a short day length. Conversely it is high in the sky in the Summer with a long day length which for London is at ((90-51)+23.5 = 62.5 degrees). Also note that the sun can rise and set behind the E/W line of the array in the summer.

If we take the vernal and autumnal equinox positions, when the sun is normal to the equator, then in order to tilt solar panels to the correct angle to be normal to the sun, we must elevate them at the latitude angle, as shown on the diagram above. During the midsummer solstice this angle decreases to the latitude angle less the 23.5 deg. tilt (51-23.5 = 27.5 deg.) and during the winter solstice it increases to 51 + 23.5 deg. = 74.5 deg. Thus since more energy is available during the summer months, due to the longer day lengths, it follows that a low slope angle favors the summer collection resulting in more energy capture.

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4. Details of the site under scrutiny

Site Co-ordinates

Latitude 56.5396 Degrees (North)
Longitude -3.2933 Degrees (West)

Solar panel slope angle: 25 degrees

Site Layout & Orientation

Fig 8 - Site overview showing relationship to local roads and properties

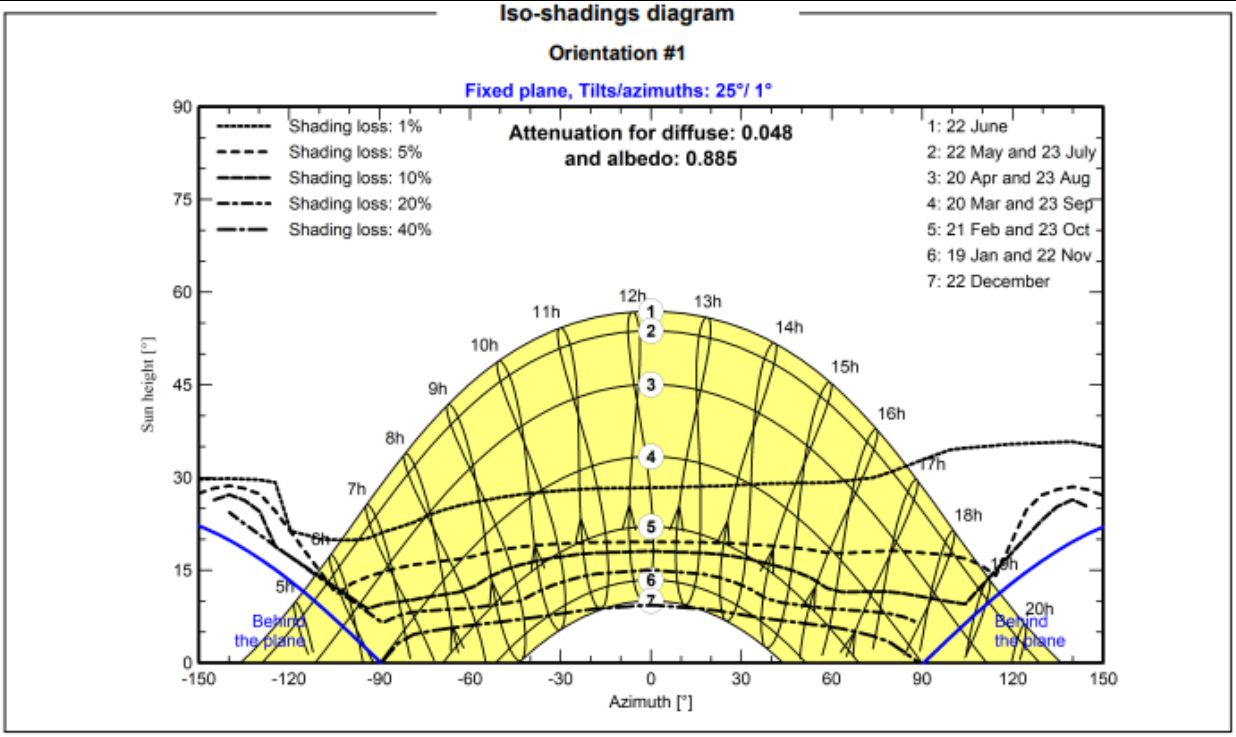

Fig 9 - Graphical representation of the path of the sun varying with season
The lower path is taken in the Winter and the higher path is taken in the Summer

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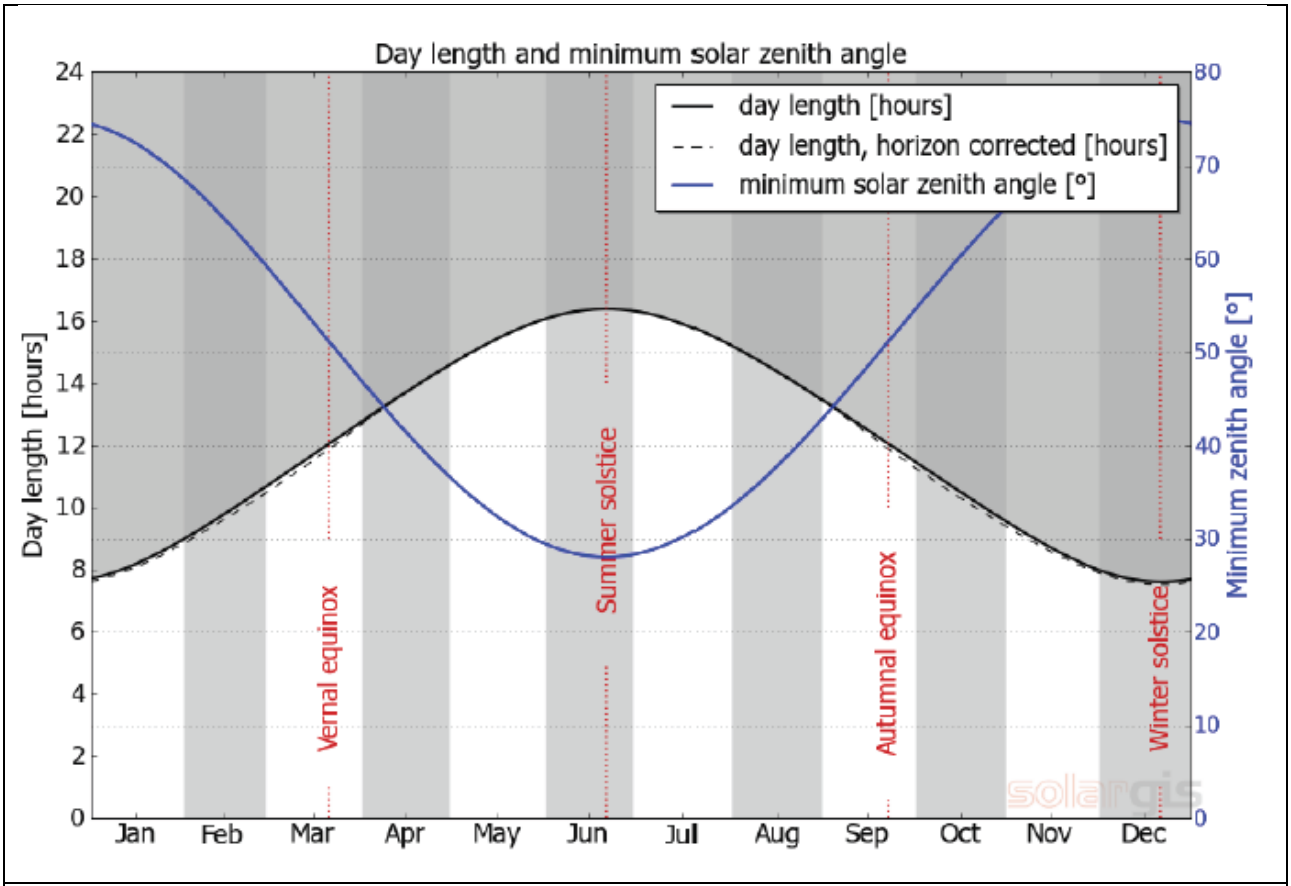

Fig 10 - Graphic of the angle of the sun from the Zenith (Azimuth = 90-Zenith) = 13 deg. above the horizon at noon on the Winter Solstice

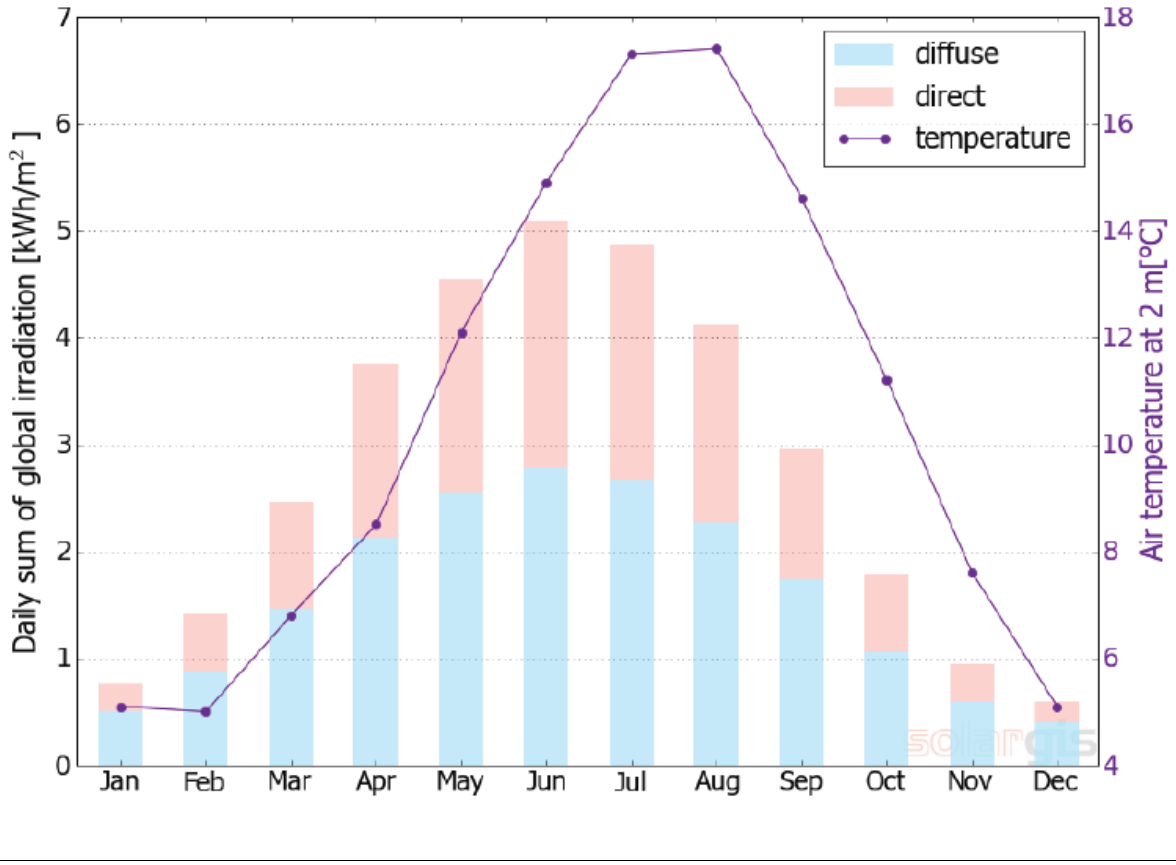

Fig 11. Graph of average temperature, direct and diffuse irradiation month by month

Fig 11 illustrates that for this part of Scotland the solar radiation has a very significant diffuse element of total irradiation. This simply means that for much of the time the sun is behind cloud formations giving diffuse multi-directional radiation of the type that cannot cause glint and glare would be insignificant.

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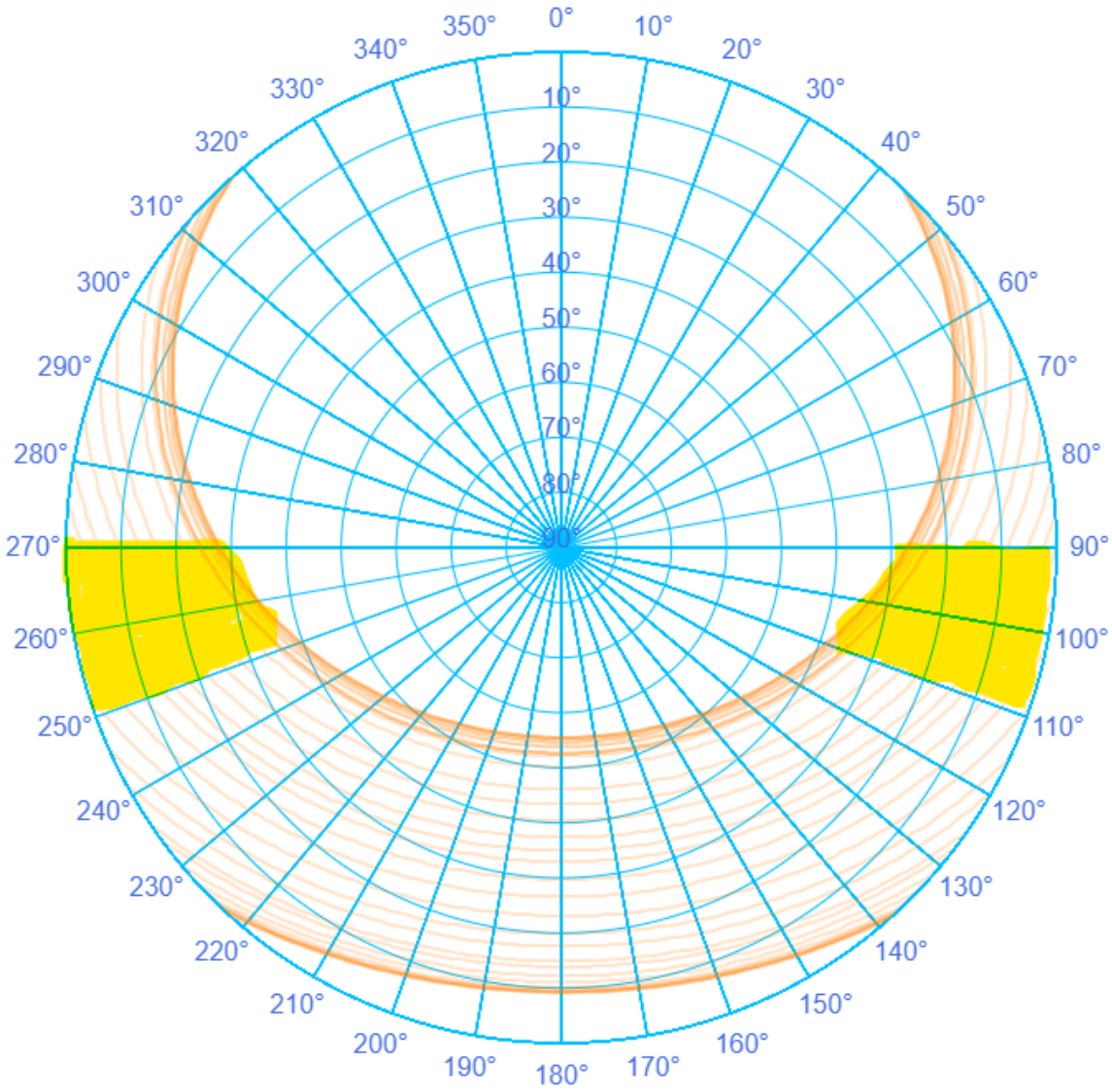

Fig 12 - Solar Path throughout the year at this latitude Note: Yellow areas denote glancing (low) sun angles

Notes for Fig 12:
You can see sun trajectories throughout the year with the Summer Solstice trajectory being the top arc and the Winter Solstice the bottom one. The line from 90 to 270 degrees represents East to West respectively with 180 deg being South and 0 degrees being North. The closer a point is to the center, the higher is the sun above the horizon. In the summer the sun rises and sets to the North of the E/W line and for the purposes of this study cannot therefore case any reflections from the surface of the E-W oriented panels.

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5. Optical Analysis of the Site

With reference to the sun's position at different times of day and season we are able to calculate the angle of incidence of any direct rays landing on the solar panels.

It should be noted however that at least 50% of light energy in the UK is regarded as diffuse [Fig 11] or omni-directional light and no glint or glare from this is significant.

For all periods from the Autumnal Equinox though to the Vernal Equinox the sun rises and sets behind the slightly elevated horizon South of the E/W line. From all sun elevations in these conditions any reflected rays are elevated by the panels and would exit above the line of sight. There exist however two sets of conditions where it is possible for rays to have some reflection towards the nearby road and properties. These conditions (Figs 13-17 below) is when the sun is just South of the the E/W line of the panels and yet still elevated in the sky. These conditions occur in early and late-Summer at the beginning and end of the day and when the sun is penetrating a large air mass (see illustration for air mass index). In this situation it is possible for a reflection to occur in or around a horizontal plane. It should be noted however that in this situation the reflection is closely aligned with the direction of the sun and the sun will be much the brightest object with respect to the reflection.

From the graph of % reflected light versus incident angle [Fig 2] we can see that even at an angle of incidence as low as 13 degrees the reflection from a float glass surface is only 50% and with the scattering effect of the surface texture this is much reduced. In this scenario, should there be a cloudless period, it would be unpleasant to look directly into the sun. The reflection, being significantly (much less than half) less bright than the sun will not be obvious to the onlooker as the onlooker will be forced to look away in any case. Any glint under these conditions will be short-lived as the sun travels at 1 degree every 4 minutes and thus quickly moves from the line of sight.

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http://pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator

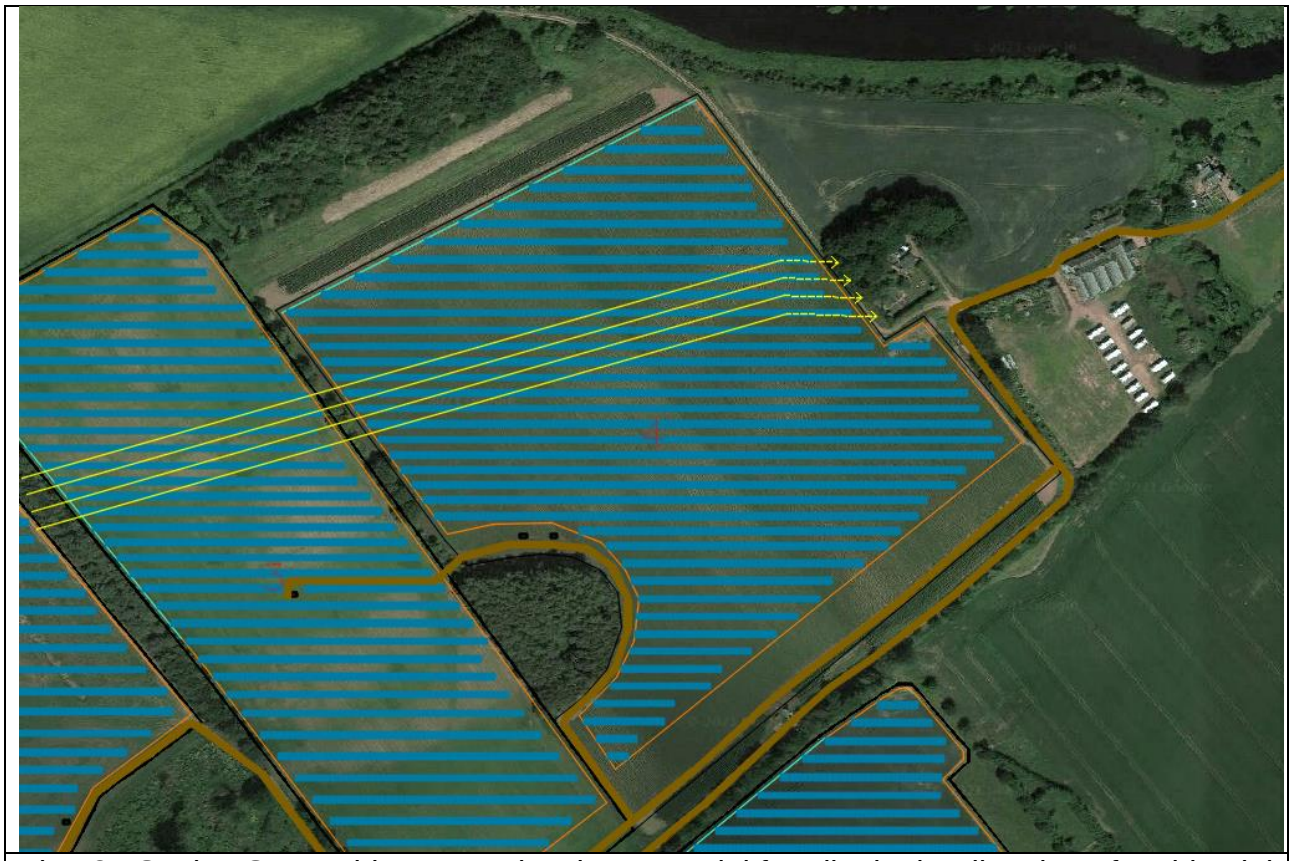

Fig 13 –Setting Sun Incident rays showing potential for glint in the direction of residential properties but being caught by the existing trees.

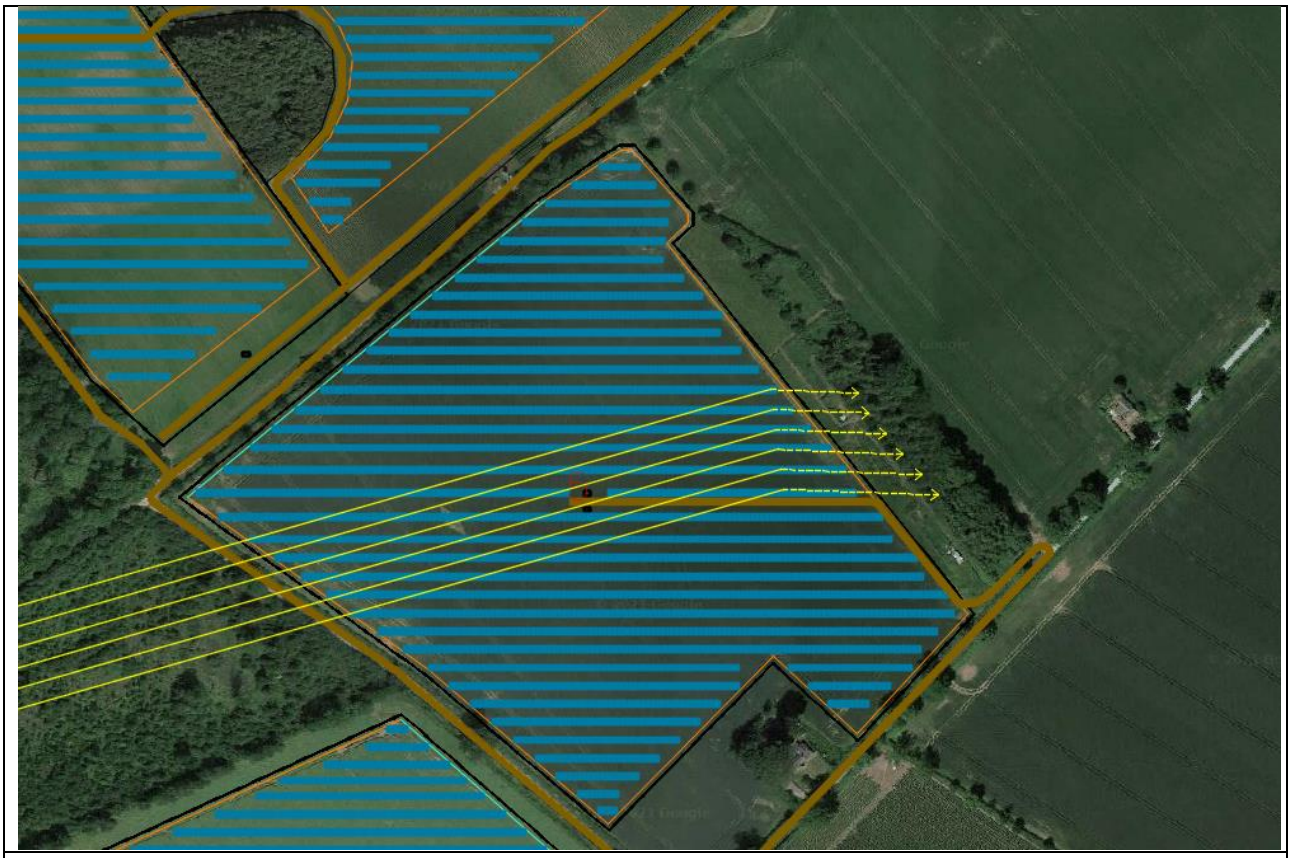

Fig 14: Reflected rays heading towards a residence to the East of field 5 are attenuated by trees

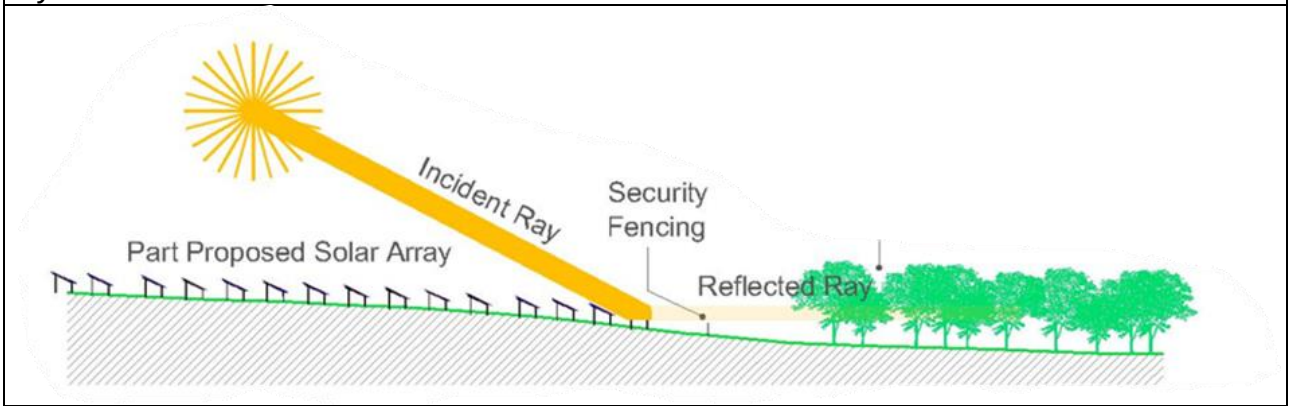

Fig 15: Section not to scale - for illustration purposes only

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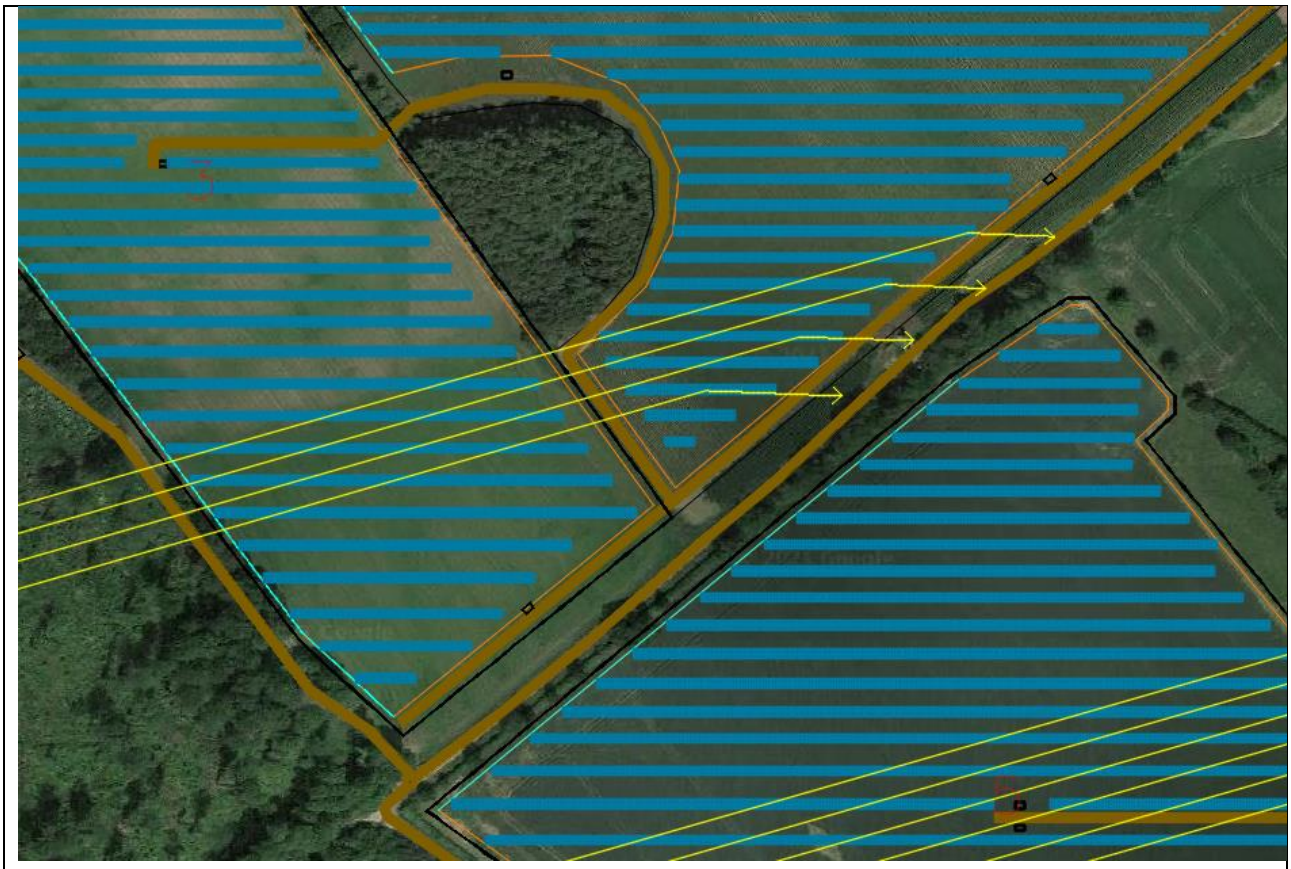

Fig 16: Suns rays emanating from the West South West have the potential to reflect towards the minor public road through the site however the planting of hedgerow is proposed as screening (see Fig 17). Drivers proceeding SW down this road will be driving into the sun which will be much brighter than any reflected light.

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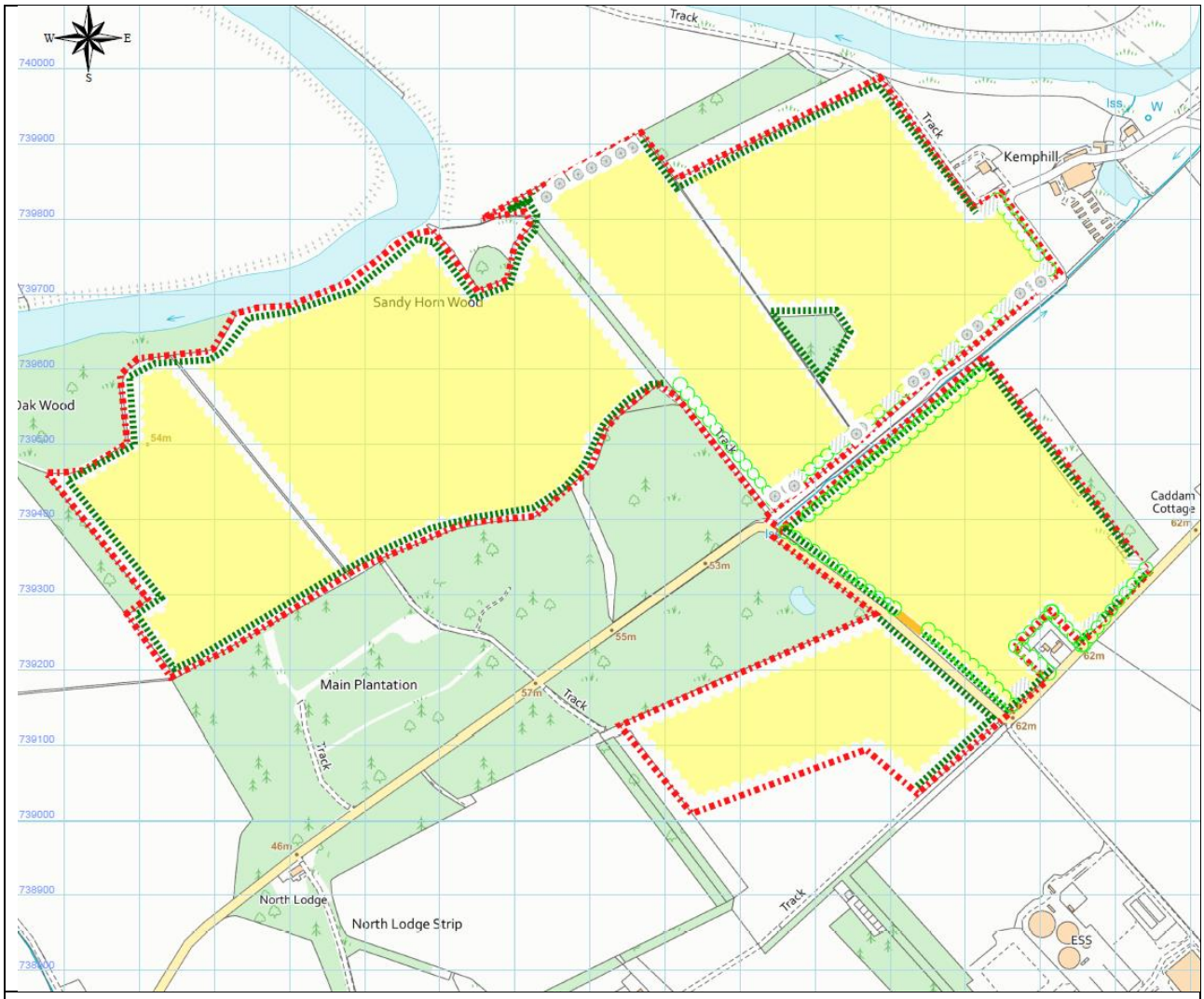

Fig 17: Proposed landscape and planting overview

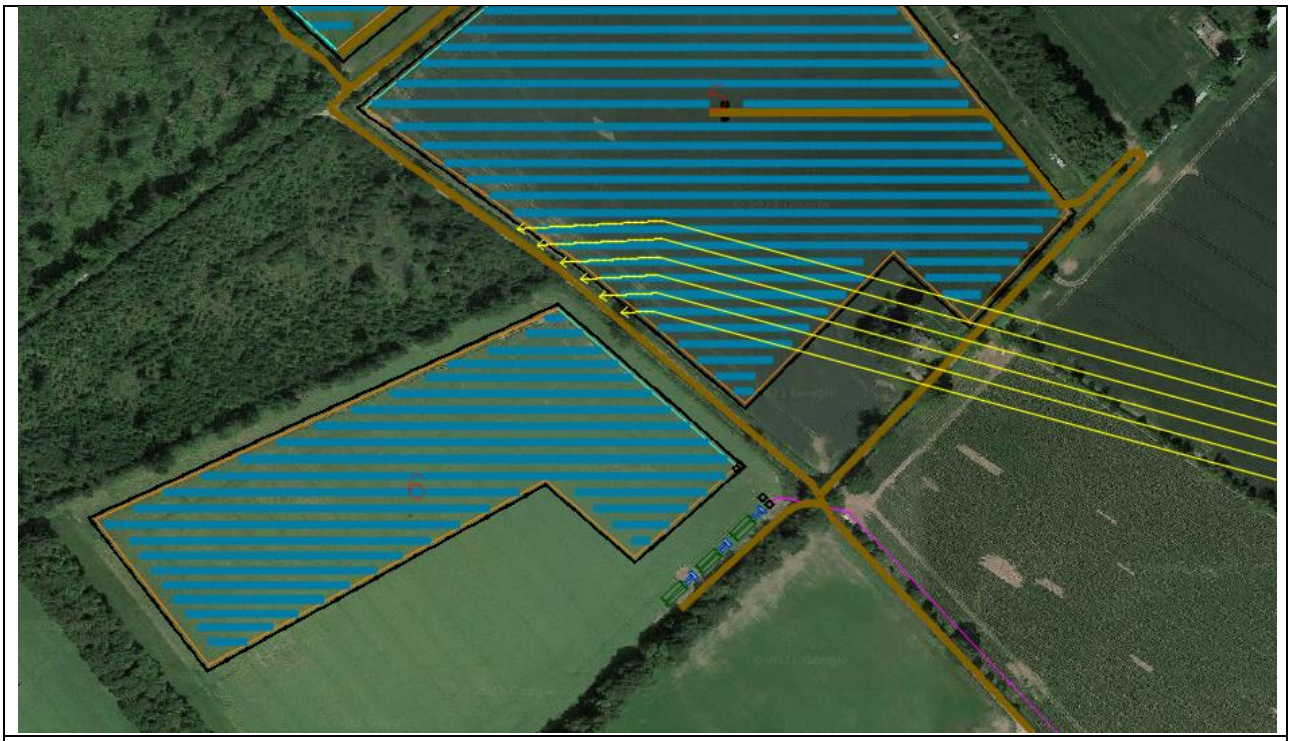

Fig 18: Suns rays emanating from the East South East have the potential to be reflected towards the road running NW to SE. These rays will be caught by the proposed hedgerow (see Fig 17) Drivers heading SE down this road will be heading towards the rising sun which will be by far the brightest object when compared to any reflected light.

6. Aviation

An analysis of solar plants by the Massachusetts Department of Energy in America [1] concluded the following:

"An analysis of a proposed 25-degree fixed-tilt flat-plate polycrystalline PV system located outside of Las Vegas, Nevada showed that the potential for hazardous glare from flat-plate PV systems is similar to that of smooth water and is not expected to be a hazard to air navigation."

"Many projects throughout the U.S. and the world have been installed near airports with no impact on flight operations. United Kingdom and U.S. aircraft accident databases contain no cases of accidents in which glare caused by a solar energy facility was cited as a factor."

Referring to a paper from a reputable UK company titled *"Solar Photovoltaic Energy Facilities: Assessment of Potential Impact on Aviation"* [1] where records of accidents involving glint & glare were studied from both US and UK databases the report states the following:

> 8.4 No evidence could be found from existing solar energy projects around the world of any reported problems of glare affecting pilots. This includes many projects in the USA where the Federal Aviation Administration routinely assess such projects for potential glare impacts.
>
> 8.5 UK and US aircraft accident databases contain no cases of accidents in which glare caused by a solar energy facility was cited as a factor.

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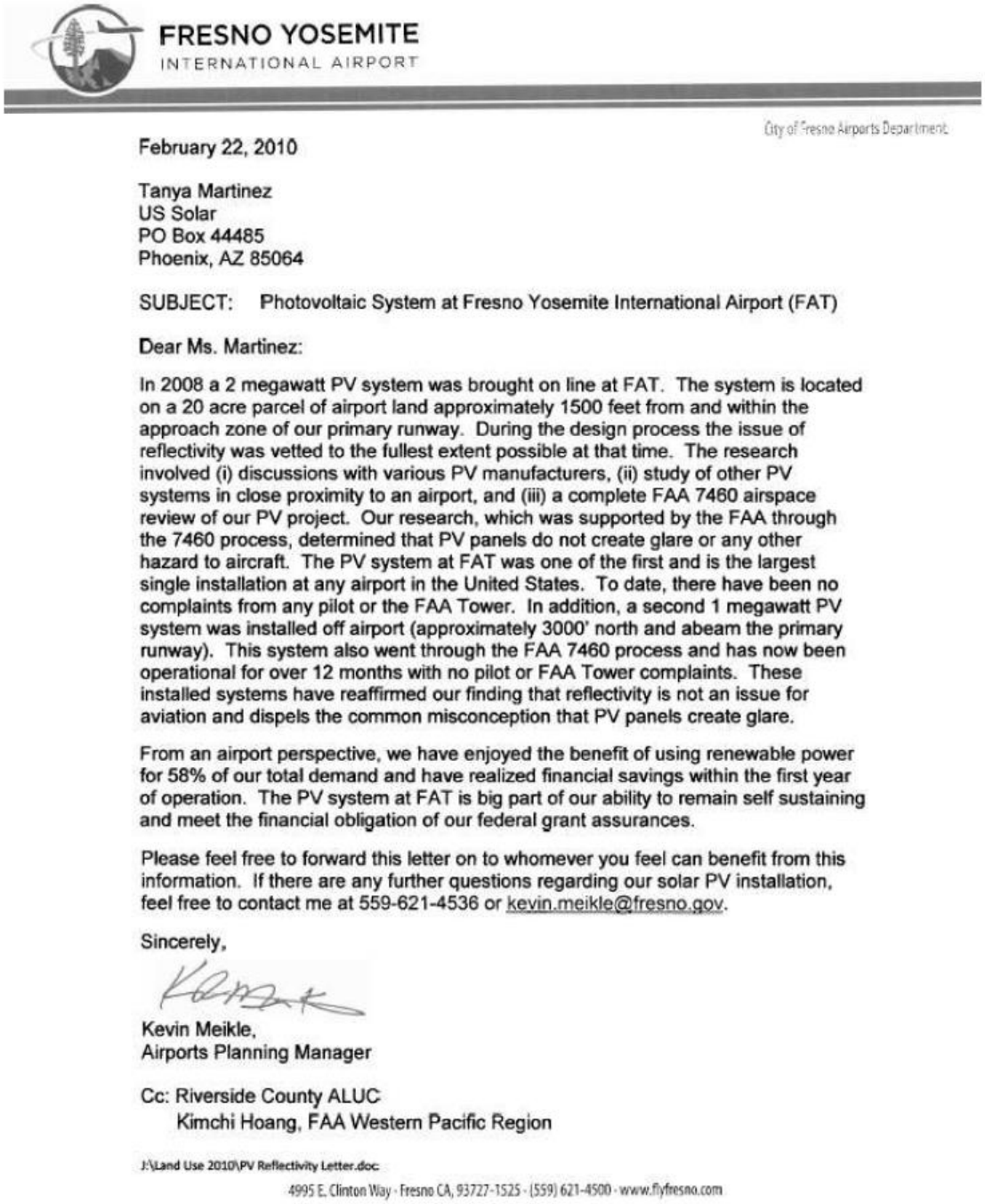
The same paper has a valuable letter in the appendix which has been reproduced here:



FRESNO YOSEMITE
INTERNATIONAL AIRPORT

City of Fresno Airports Department

February 22, 2010

Tanya Martinez
US Solar
PO Box 44485
Phoenix, AZ 85064

SUBJECT: Photovoltaic System at Fresno Yosemite International Airport (FAT)

Dear Ms. Martinez:

In 2008 a 2 megawatt PV system was brought on line at FAT. The system is located on a 20 acre parcel of airport land approximately 1500 feet from and within the approach zone of our primary runway. During the design process the issue of reflectivity was vetted to the fullest extent possible at that time. The research involved (i) discussions with various PV manufacturers, (ii) study of other PV systems in close proximity to an airport, and (iii) a complete FAA 7460 airspace review of our PV project. Our research, which was supported by the FAA through the 7460 process, determined that PV panels do not create glare or any other hazard to aircraft. The PV system at FAT was one of the first and is the largest single installation at any airport in the United States. To date, there have been no complaints from any pilot or the FAA Tower. In addition, a second 1 megawatt PV system was installed off airport (approximately 3000' north and abeam the primary runway). This system also went through the FAA 7460 process and has now been operational for over 12 months with no pilot or FAA Tower complaints. These installed systems have reaffirmed our finding that reflectivity is not an issue for aviation and dispels the common misconception that PV panels create glare.

From an airport perspective, we have enjoyed the benefit of using renewable power for 58% of our total demand and have realized financial savings within the first year of operation. The PV system at FAT is big part of our ability to remain self sustaining and meet the financial obligation of our federal grant assurances.

Please feel free to forward this letter on to whomever you feel can benefit from this information. If there are any further questions regarding our solar PV installation, feel free to contact me at 559-621-4536 or kevin.meikle@fresno.gov.

Sincerely,

Kevin Meikle,
Airports Planning Manager

Cc: Riverside County ALUC
Kimchi Hoang, FAA Western Pacific Region

J:\Land Use 2010\PV Reflectivity Letter.doc

4995 E. Clinton Way · Fresno CA, 93727-1525 · (559) 621-4500 · www.flyfresno.com

7. Conclusions

Analysis of the site has revealed that for the most part reflected light is of low intensity and scattered and is generally reflected upwards away from roads and residential properties. There exist conditions however when reflected sun rays can travel in a direction parallel to the ground. These conditions exist in early and late summer when the sun is low in the sky and when air mass index is high (reducing intensity) and when the sky in this region is clear. Under these specific condition's rays, which are scattered at the surface of the module, will, for residential properties, be caught by trees. Drivers proceeding down the minor road are likely to be aware of minor reflections but the sun itself will be by far the brightest object. It is proposed to plant hedgerow which acts both as screening and as a barrier to any glint or glare. It is the opinion of the author that, even without this planting, the development will not give rise to any additional hazardous or troublesome reflections beyond those that exist in the natural environment such as from house windows or greenhouses. It is documented [1] that solar panels produce glare no brighter than standing water.

8. References

[1] Clean Energy Results *"Questions and Answers – Ground Mounted Solar Photovoltaic Systems"*, Massachusetts: Dept. of Energy Resources, Dept. of Environmental Protection, Clean Energy Center, December 2012

[2] "Solar Photovoltaic Energy Facilities: Assessment of Potential for Impact on Aviation", Spaven Consulting (Midlothian, UK), January 2011, Report No.10/344/RPS/1

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