Document Reference	Appendix No.	Title
4.01.5	6.2	Glint and Glare Assessment

CKKR Limited

Detailed Glint and Glare Report

30th August 2022

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50MW Solar PV and Battery Storage Project: Oaklands Farm

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 Drivers, be caught by hedgerow however it is the opinion of the author that, even without this hedgerow, 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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3. Glossary of Terms

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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4. 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 (see Fig1).

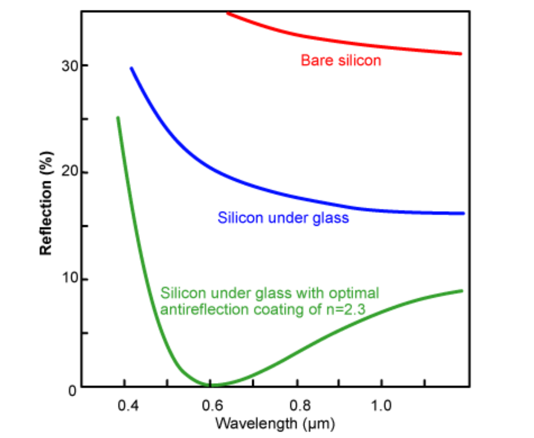

Fig 1. Reduction in reflected light due to anti-reflection coating on solar cells. Note visible wavelengths are from appx 0.4 to 0.75µm

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).

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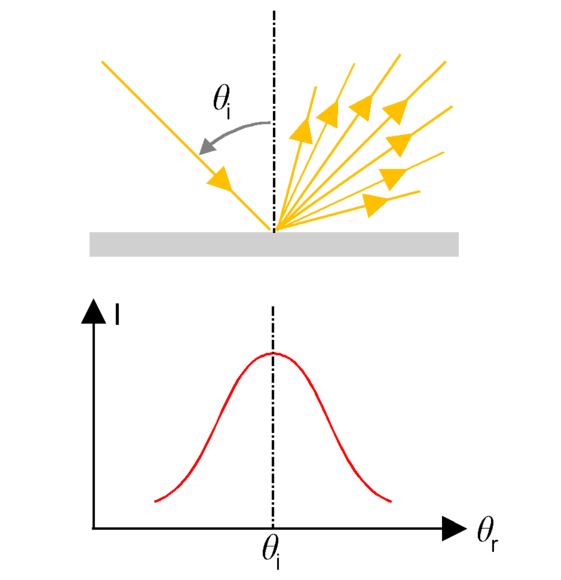

Fig 2 – Scatter from the solar panel glass surface

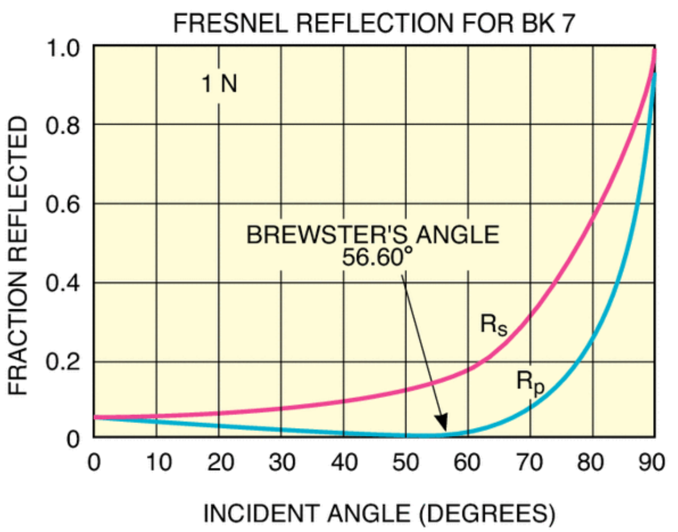

Fig 3 - Reflected fraction versus incident angle

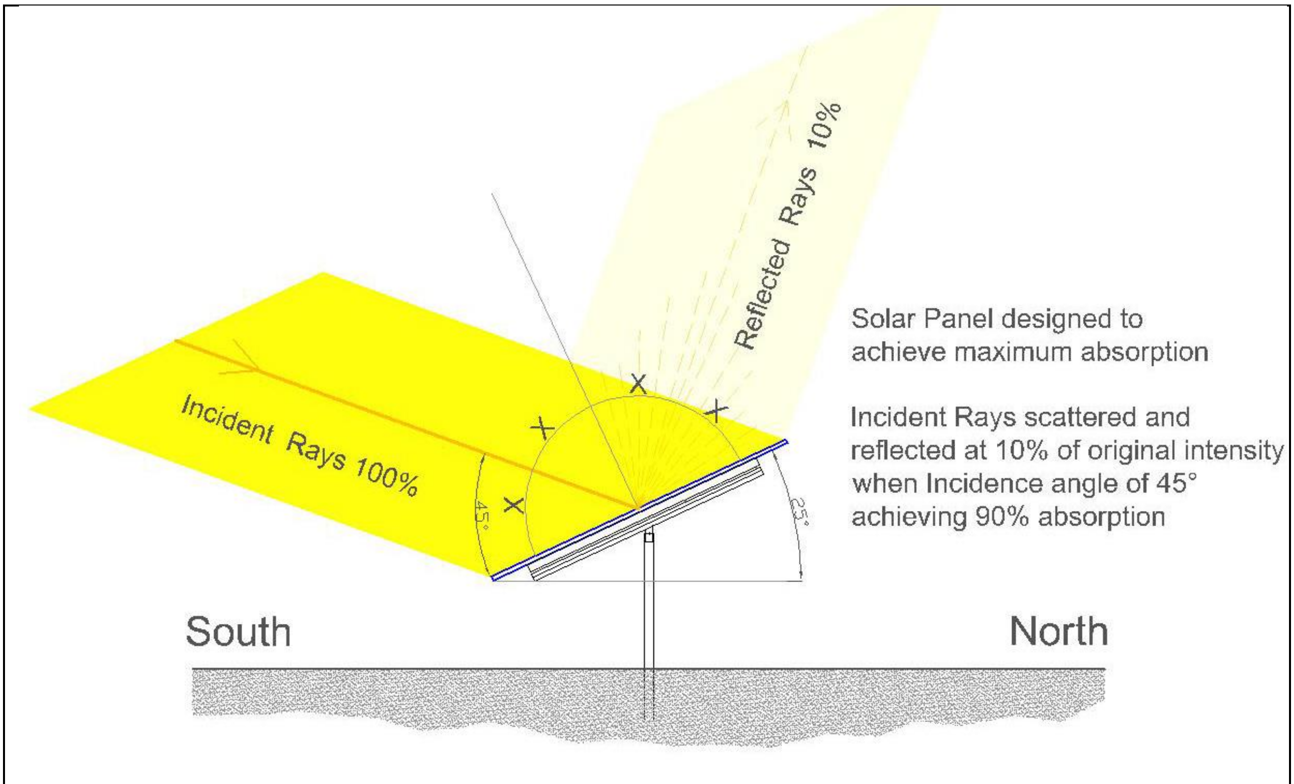

Fig.4 (see graph of % reflected light versus incident angle [Fig 2])

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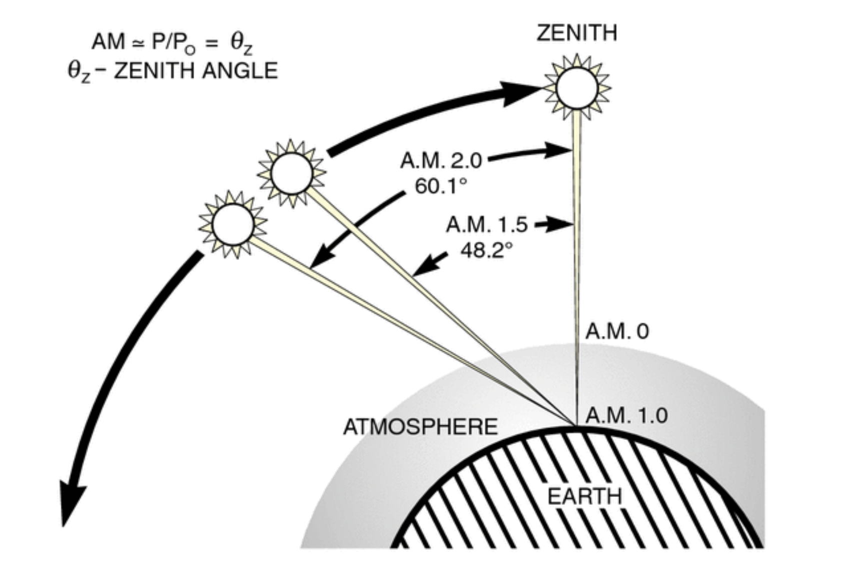

Fig 5 – Air Mass (A.M.) Index

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.

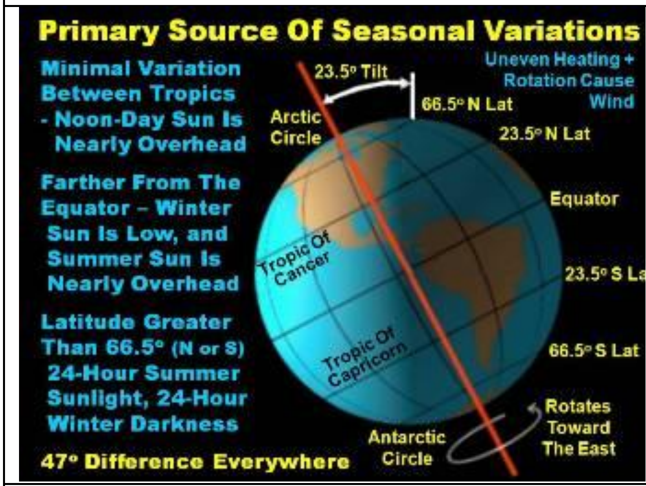

Fig 6 – Earths tilt

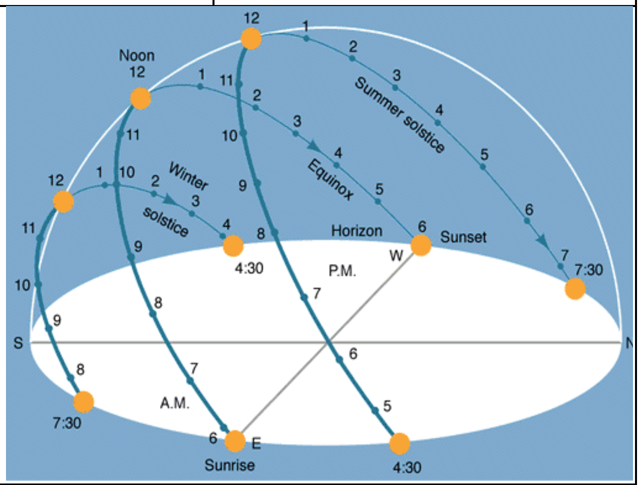

Fig 7 – Path of the sun

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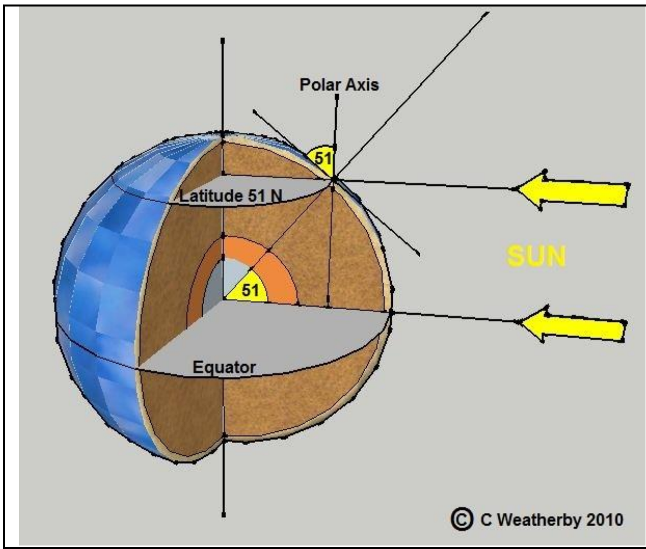

Fig 8 – Latitude influence

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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5. Details of the site under scrutiny

Site Co-ordinates

Latitude 51.4461 Degrees (North)
Longitude -3.3352 Degrees (West)

Solar panel slope angle: 25 degrees

Site Layout & Orientation

Fig 9 - Site overview showing relationship to local roads and properties and areas of concern (circled in green)

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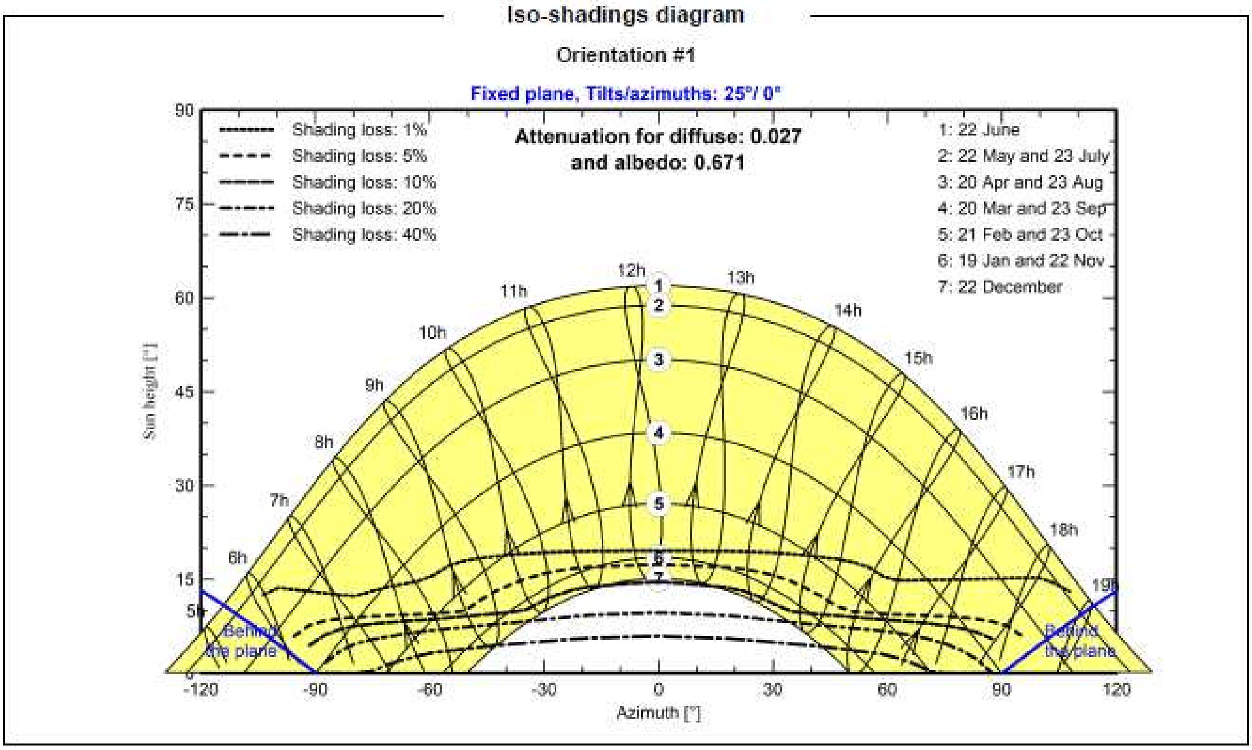

Fig 10 - Graphical representation of the path of the sun and solar panel shading varying with season. The lower path is taken in the Winter and the higher path is taken in the Summer

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C
January	23.7	15.60	4.72
February	40.9	24.40	6.49
March	80.0	45.30	6.86
April	121.1	62.40	6.99
May	153.6	77.50	11.79
June	159.4	81.20	13.76
July	158.1	80.80	15.35
August	126.4	69.90	16.03
September	90.6	51.40	15.55
October	54.6	32.70	12.37
November	28.7	17.80	9.17
December	19.4	12.70	7.29
Year	1056.5	571.70	10.55

Fig 11. Graph of, total global, diffuse irradiation and average ambient temperatures by month

Fig 10 illustrates that for this part of Wales, the solar radiation has a very significant diffuse element making up a little over half of the 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.

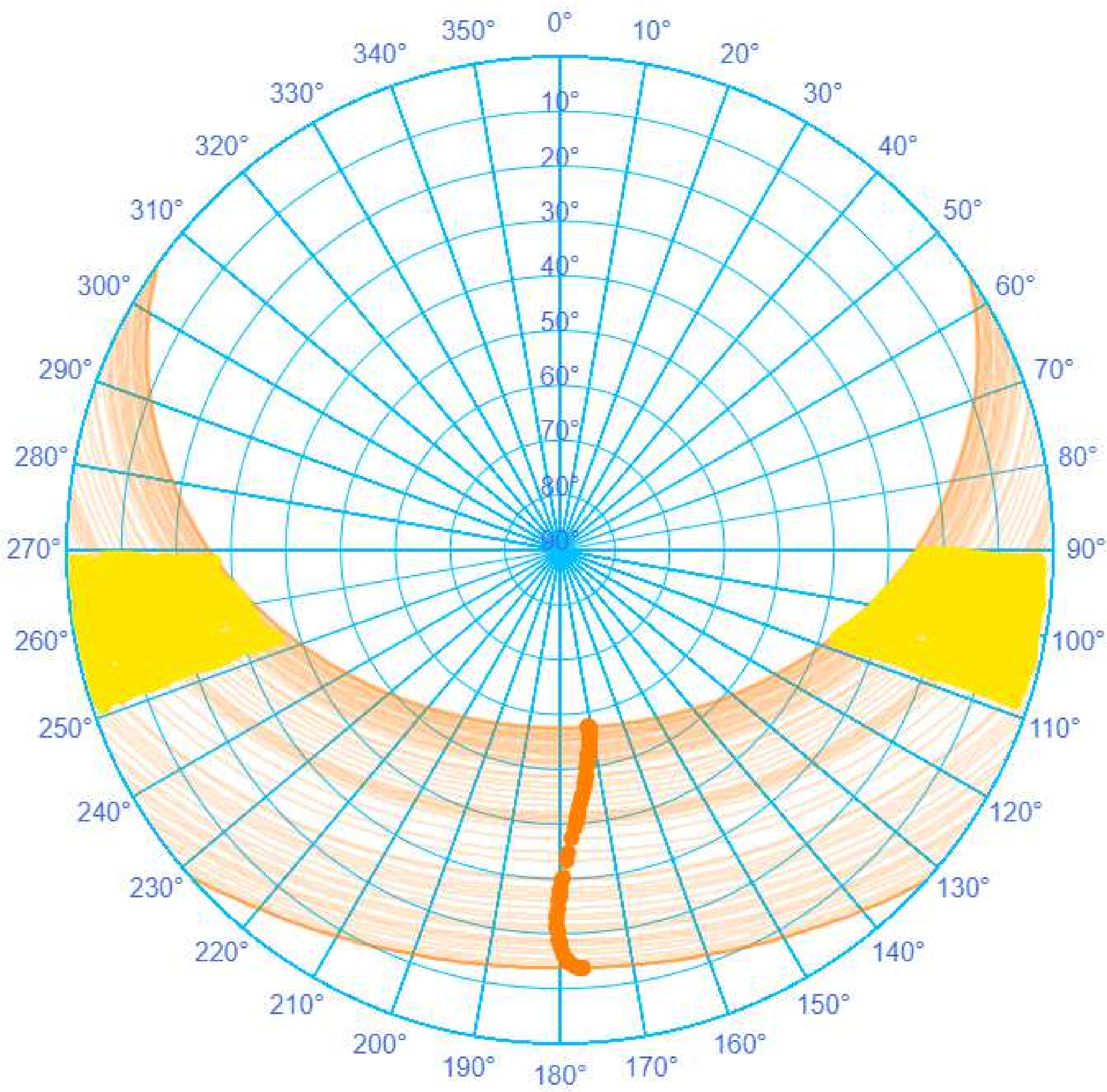

Fig 12 - Solar Path throughout the year at this latitude Note: Yellow areas denote glancing (low) sun angles of the type that could give rise to eye-level reflections

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 cause any reflections from the surface of the E-W oriented panels.

6. 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 10] 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. These conditions (Figs 13-15 below) are 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 3] 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.

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

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Fig 13 –Setting Sun Incident rays showing potential for glint in the direction of the A4226 but being caught by the existing hedgerow & trees (see inset).

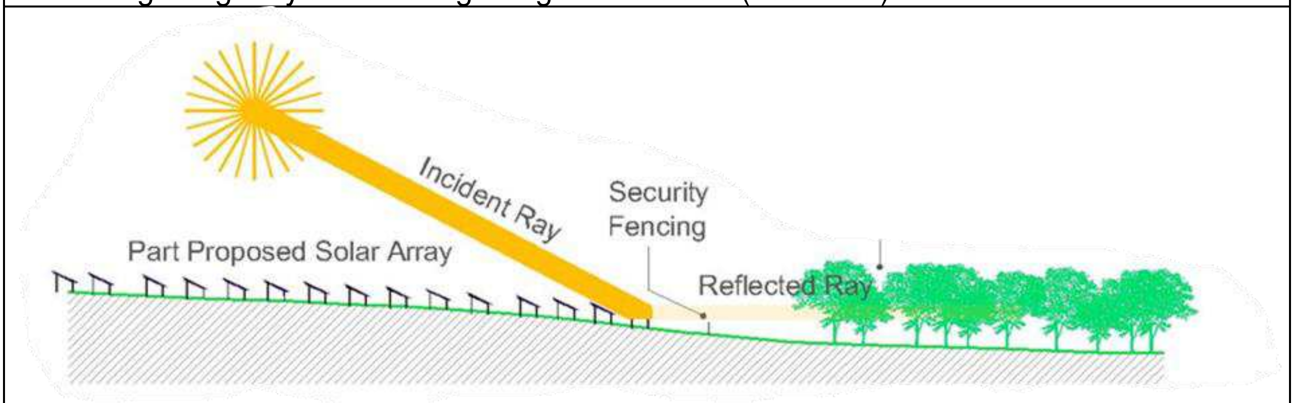

Fig 14: Section not to scale - for illustration purposes only

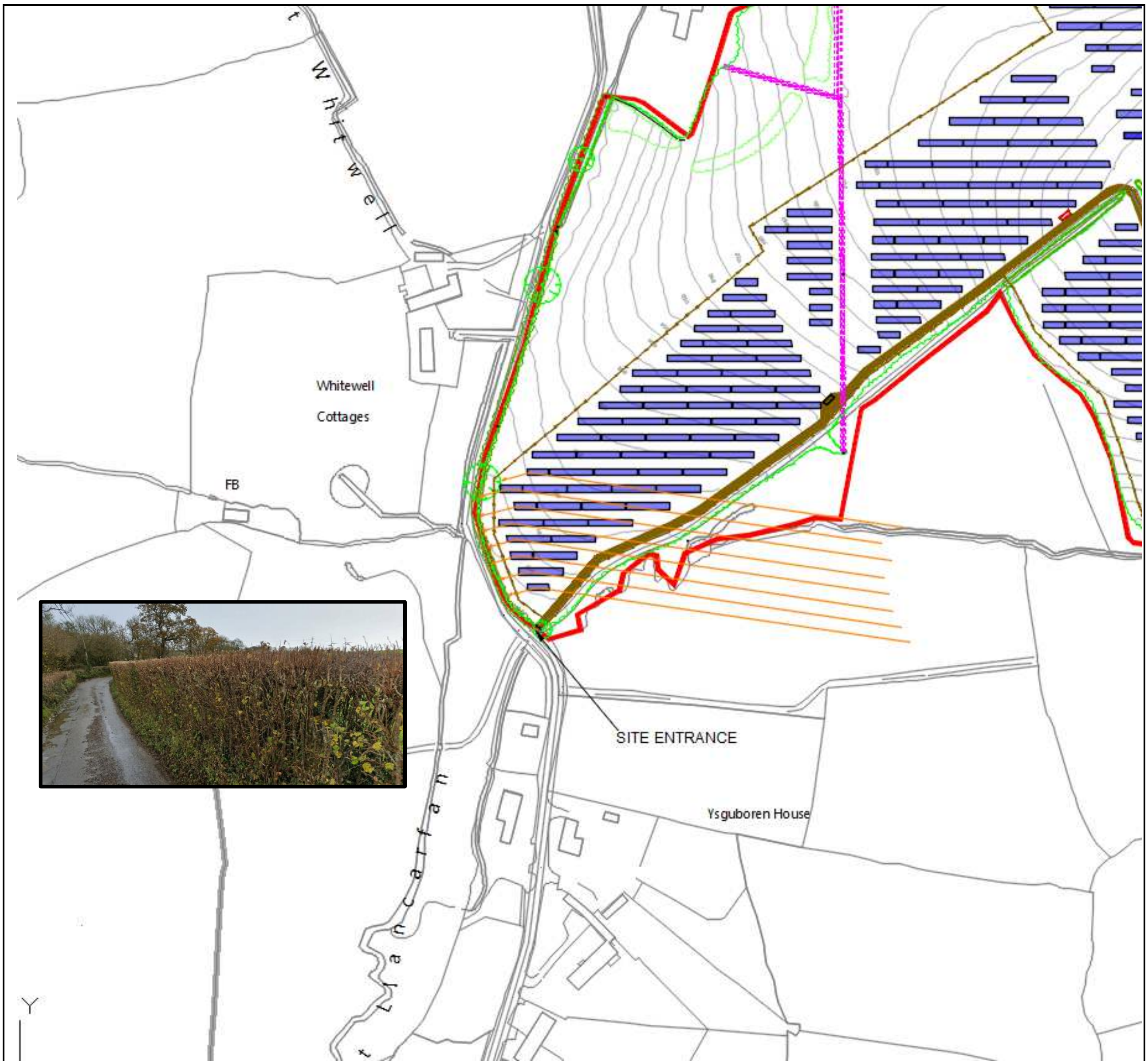

Fig 15: Reflected diffuse rays of the morning sun heading towards the road near to the site entrance are attenuated by hedgerow (see inset)

7. Aviation General Observations

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

8. Aviation at Cardiff & Bro Tathan (MOD St Athan) Airfields

Despite numerous studies stating that solar farms pose no risk to aviation, care has been taken to assess any possibility of glint or glare affecting aircraft approaching or leaving Cardiff and Bro Tathan airfields. An analysis of the flight paths (Fig 16) show that these do not pass over or close to the proposed site (seen bordered in red to the East of the image).

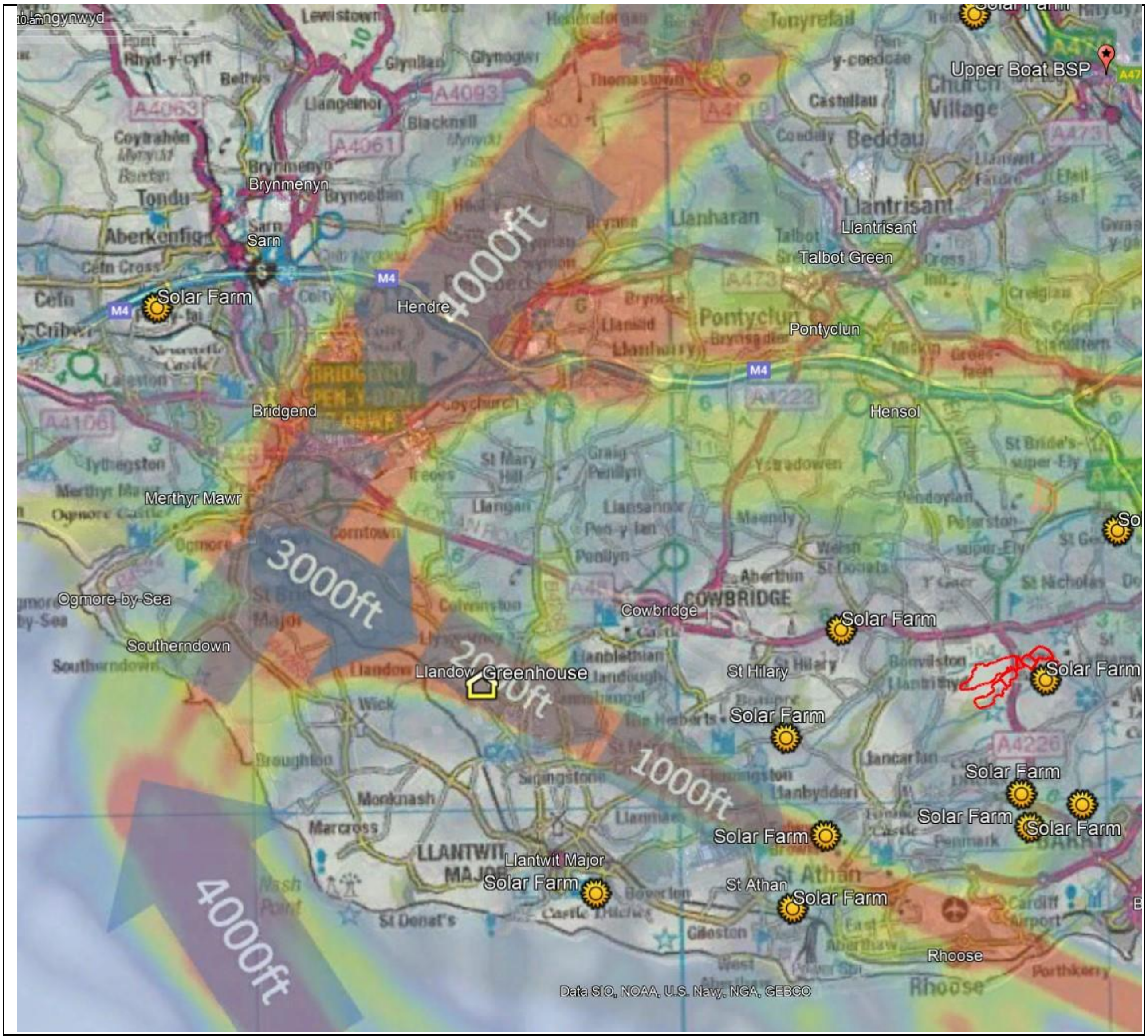

Fig 16: Cardiff airport approaches over land showing height information and solar farms

During research for the proposed solar farm, it was noted that there exist at least 8 solar farms in closer proximity to the airport than the proposed as indicated in fig 16. In addition to these there is a large greenhouse in the flight path. Greenhouses are considered to reflect much more light than solar panels due to the glass having 2 reflective edges (changes of refractive index – i.e. each side of the glass) whereas a solar panel is optically coupled to a low-reflective (solar cell) surface where little or no reflection occurs. Solar radiation

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reflecting from solar panels from angles that project skyward are in the region of 10% or less than the incident radiation and are scattered at the surface (see Fig 4). This makes them less bright than reflections from surface water (e.g. the sea).

-

Fig 17: The two airfields showing runways in black and flight paths in yellow
Note the solar farm at the crossing of both flight paths. From fig 16 this is considered to be at circa 500 feet below the normal flight path for large aircraft. The proposed solar farm is out of this frame (see Fig 16 for location)

9. Summary of findings for Cardiff and Bro Tathan airports

Studies show that the site is almost 5km from Cardiff airport and not close to either the approach or the exit flight paths. There exist at least 8 closer solar farms and one within 500 feet of the major landing approach. These existing farms have posed no hazards to aircraft which is consistent to numerous studies of the subject [1 et al]. The author considers that there are no circumstances that exist where the proposed solar farm would constitute a hazard from glint and glare to approaching or leaving aircraft from either airport.

10. 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,

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for drivers, be caught by hedgerow. Drivers proceeding North on the A4226 are likely to be aware of minor reflections to the West but the sun itself will be by far the brightest object. There exists a 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 hedgerow, 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.

In terms of Cardiff and Bro Tathan airports the report concludes that there are at least 8 closer pre-existing solar farms to the airport and that there are no conditions where the proposed solar farm would pose a hazard to aircraft.

11. 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

[3] Cardiff Airport Consultation Document 2014

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