Development of national significance in the renewable energy sector

Glint and Glare Assessment

Penderi Solar Farm, Land at Blaenhiraeth Farm, Langennech, Llanelli, SA14 8PX

APPLICATION SUBMISSION

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EXECUTIVE SUMMARY

Report Purpose

Pager Power has been retained to assess the possible effects of glint and glare from 18 proposed solar photovoltaic (PV) layout options to be located north of Llanelli in Wales, United Kingdom.

This assessment pertains to the possible effects upon ground-based receptors near the proposed development. In particular, the nearby dwellings and A476 road.

Pager Power

Pager Power has undertaken over 400 glint and glare assessments in the UK, Europe and further afield. The company's own glint and glare guidance is based on industry experience and extensive consultation with industry stakeholders including airports and aviation regulators.

Assessment Results – Road

The results of the analysis have shown that the reflections from the proposed development towards the identified road receptors are possible. Any reflection towards drivers travelling in both directions on the A476 will be either screened or generating outside the drivers' field of view.

Overall, no significant impact is expected therefore no mitigation strategy should be implemented.

Assessment Results – Dwellings

The results show that a solar reflection is possible for 13 dwellings of the 14 assessed. Receptor 18 will experience a solar reflection for circa 7 months per year during the early morning (see the solar reflection chart on the following page). The impact is therefore deemed moderate based on the duration of the solar reflection and expected visibility (see Figure 1 below).

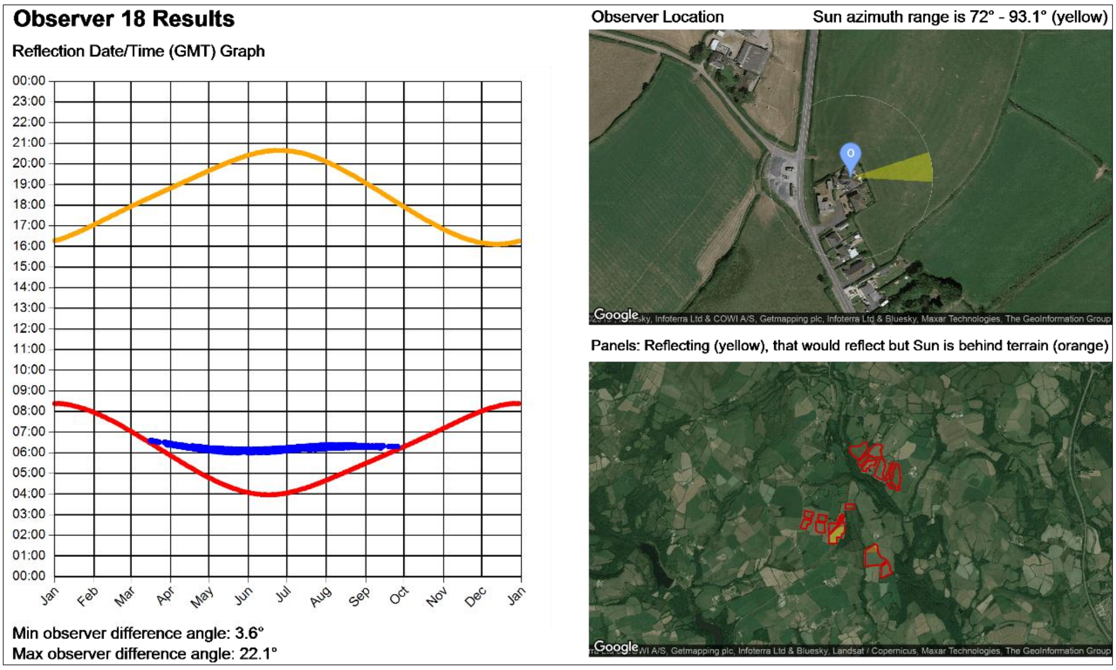

Figure 1 – Receptor 18

A view of a solar reflection from assessed location would only occur where there is a clear view of the reflecting solar panels at the particular time of day when a solar reflection is geometrically possible on a clear and sunny day. Any solar reflection could last for up to 10 minutes however only when all of the above criteria are met.

Reflection originates from the southern portion of Site 6 and Site 17 before 7am. While reflections generating from Site 17 are sufficiently screened, reflections generating from Site 6 are not. At this specific time, a resident would also be looking in the general direction of the Sun. This means that the viewer will likely be able to see the glare from the reflecting solar panels as well as the Sun directly. It is important to note that the direct sunlight would be a significantly brighter source of light when compared to the solar reflection. At any one location, only a particular area of solar panels will produce a solar reflection towards it, not the whole panel area.

In conclusion, the impact toward this dwelling is deemed as moderate and mitigation is recommended. The mitigation should consist of screening (which might be in form of vegetation) and it should be enough high to block any view of the panels from the top floor. Two screening strategies are proposed in Figure 9 below. Planting of hedgerows/trees with a minimum height of 3 metres will ensure the development is screened and not visible from the dwelling. The blue lines define the reflective panel area and its visibility from the receptor location. Screening is proposed on the west boundary of the proposed development (orange line). However, the amount of screening will reduce if deployed closer to the dwelling.

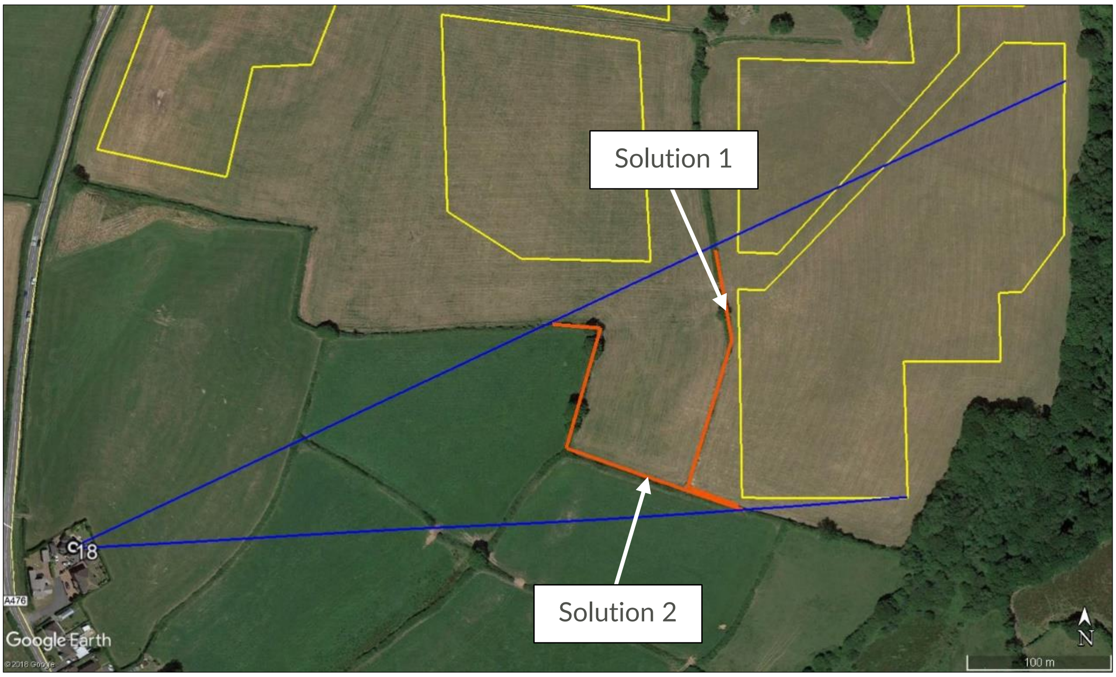

Figure 2 – Location of dwelling 24 relative to the proposed development

Recommendation

Pager Power recommends an on-site assessment to establish the visibility of the land for Site 6 from dwelling 18.

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ABOUT PAGER POWER

Pager Power is a dedicated consultancy company based in Suffolk, UK. The company has undertaken projects in 46 countries within South Africa, Europe, America, Asia and Australasia.

The company comprises a team of experts to provide technical expertise and guidance on a range of planning issues for large and small developments.

Pager Power was established in 1997. Initially the company focus was on modelling the impact of wind turbines on radar systems. Over the years, the company has expanded into numerous fields including:

- Renewable energy projects.
- Building developments.
- Aviation and telecommunication systems.

Pager Power prides itself on providing comprehensive, understandable and accurate assessments of complex issues in line with national and international standards. This is underpinned by its custom software, longstanding relationships with stakeholders and active role in conferences and research efforts around the world.

Pager Power's assessments withstand legal scrutiny and the company can provide support for a project at any stage.

1 INTRODUCTION

1.1 Overview

Pager Power has been retained to assess the possible effects of glint and glare from 18 proposed solar photovoltaic (PV) layout options to be located north of Llanelli in Wales, United Kingdom.

This assessment pertains to the possible effects upon ground receptors nearby the proposed development. In particular, the nearby dwellings and road A476. A report has therefore been produced that contains the following:

- Details of the proposed solar development layouts;
- Explanation of glint and glare;
- Overview of relevant guidance;
- Overview of relevant studies;
- Identification of aviation concerns and receptors;
- Assessment methodology;
- Glint and glare assessment for:
    - Road user locations;
    - Dwelling locations.
- Results discussion.

The relevant technical analysis is presented in each section. Following the assessment, conclusions and recommendations are made.

1.2 Pager Power's Experience

Pager Power has undertaken over 400 Glint and Glare assessments internationally. The studies have included assessment civil and military aerodromes, railway infrastructure and other ground-based receptors including roads and dwellings.

1.3 Guidance and Studies

Guidelines exist in the UK, which have been produced by the Civil Aviation Authority (CAA) with respect to glint, glare and aviation activity for solar photovoltaic panels. There is no existing guidance for the assessment of solar reflections from solar panels towards roads and nearby dwellings. Pager Power has however produced guidance for glint and glare and solar photovoltaic developments which was published in early 2017, with the second edition published in 2018. The guidance document sets out the methodology for assessing roads, dwellings and railway operations with respect to solar reflections from solar panels.

The Pager Power approach is to identify receptors, undertake geometric reflection calculations whilst comparing the results against available solar reflection studies.

Studies have measured the intensity of solar reflections from various naturally occurring and manmade surfaces. The results show that the intensity of solar reflections from glass are slightly higher than those from still water but significantly less than those from steel[1].

1.4 Glint and Glare Definition

The definition of glint and glare can vary, however, the definition used by Pager Power is as follows:

- Glint – a momentary flash of bright light typically received by moving receptors or from moving reflectors;
- Glare – a continuous source of bright light typically received by static receptors or from large reflective surfaces.

These definitions are aligned with those of the Federal Aviation Administration (FAA) in the United States of America. The term 'solar reflection' is used in this report to refer to both reflection types i.e. glint and glare.

[1] SunPower, 2009, SunPower Solar Module Glare and Reflectance (appendix to Solargen Energy,2010).

2 PROPOSED DEVELOPMENT LOCATION AND DETAILS

2.1 Proposed Solar Panel Design

The location and layout of the proposed development[2] (yellow line areas) is shown in Figure 3[3] below.

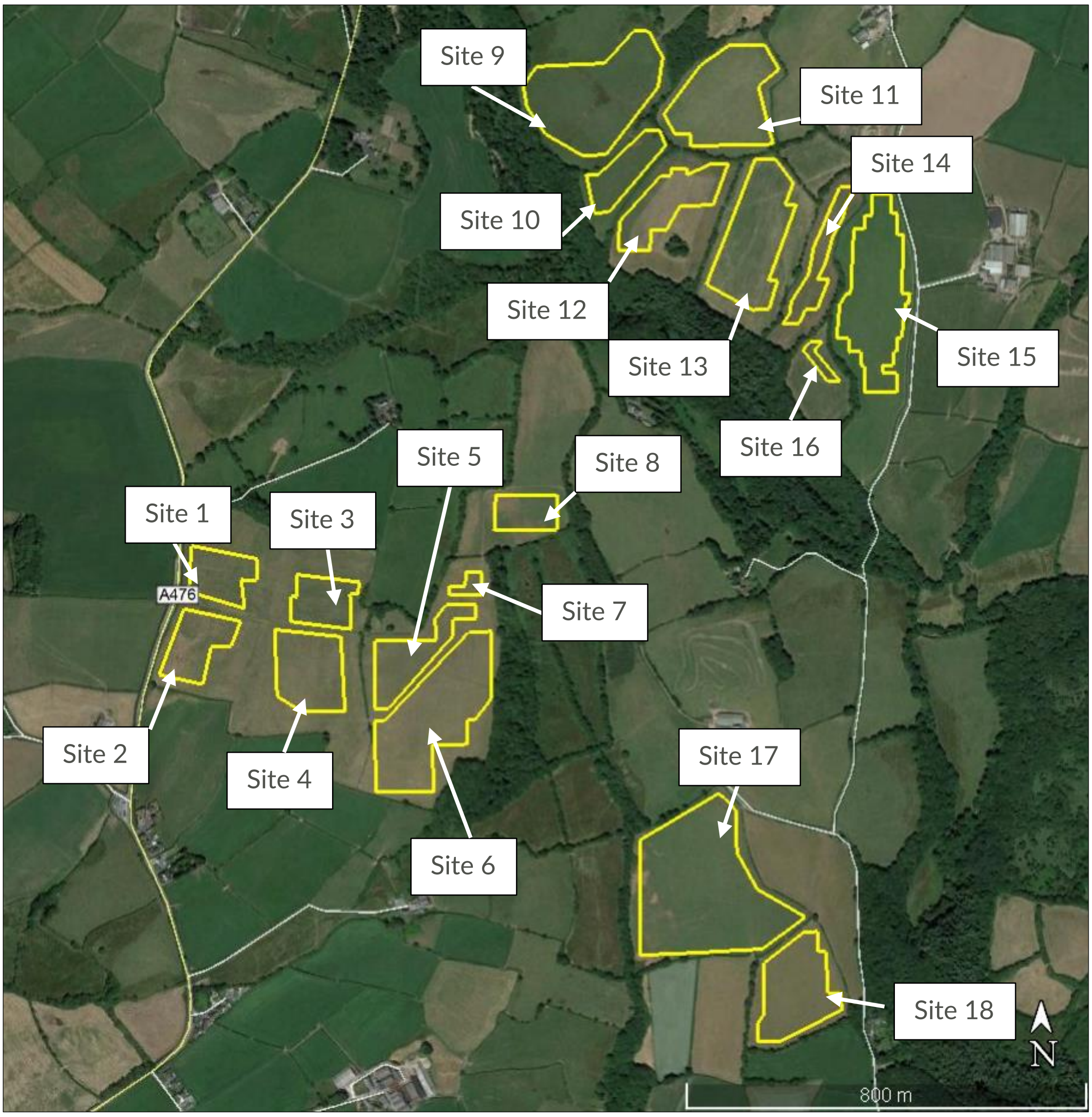

Figure 3 – Indicative ideas factory photovoltaic layout.

[2] Site Layout-review – meeting 21.11.2019, Pegasus, n.d., cropped

[3] Source: Copyright © 2019 Google.

2.2 Proposed Development Location and Details

The solar panels have the same characteristics. The details are as follows:

- Maximum height of solar panels: 2.44m; assessed centre height: 1.5m;
- Tilt: 20 degrees;
- Orientation: south facing.

3 GLINT AND GLARE ASSESSMENT METHODOLOGY

3.1 Overview

The following sub-sections provide a general overview with respect to the guidance studies and methodology which informs this report. Pager Power has also produced its own Glint and Glare Guidance which draws on assessment experience, consultation and industry expertise.

3.2 Guidance and Studies

Appendix A and B present a review of relevant guidance and independent studies with regard to glint and glare issues from solar panels and glass. The overall conclusions from the available studies are as follows:

- Specular reflections of the Sun from solar panels and glass are possible;
- The measured intensity of a reflection from solar panels can vary from 2% to 30% depending on the angle of incidence;
- Published guidance shows that the intensity of solar reflections from solar panels are equal to or less than those from water and similar to those from glass. It also shows that reflections from solar panels are significantly less intense than many other reflective surfaces, which are common in an outdoor environment.

3.3 Background

Details of the Sun's movements and solar reflections are presented in Appendix C.

3.4 Methodology

The assessment methodology is based on guidance, studies, previous discussions with stakeholders and Pager Power's practical experience. Information regarding the methodology of Pager Power's and Sandia National Laboratories' methodology is presented below.

3.4.1 Pager Power's Methodology

The glint and glare assessment methodology has been derived from the information provided to Pager Power through consultation with stakeholders and by reviewing the available guidance. The methodology for the glint and glare assessment is as follows:

- Identify receptors in the area surrounding the proposed development;
- Consider direct solar reflections from the proposed development towards the identified receptors by undertaking geometric calculations;
- Consider the visibility of the reflectors from the receptor's location. If the reflectors are not visible from the receptor then no reflection can occur;
- Based on the results of the geometric calculations, determine whether a reflection can occur, and if so, at what time it will occur;
- Consider the solar reflection intensity, if appropriate;

- Consider both the solar reflection from the proposed development and the location of the direct sunlight with respect to the receptor's position;
- Consider the solar reflection with respect to the published studies and guidance;
- Determine whether a significant detrimental impact is expected in line with Appendix D.

Within the Pager Power model, the reflector area is defined, as well as the relevant receptor locations. The result is a chart that states whether a reflection can occur, the duration and the panels that can produce the solar reflection towards the receptor.

3.5 Assessment Methodology and Limitations

Further technical details regarding the methodology of the geometric calculations and limitations are presented in Appendix E and Appendix F.

4 IDENTIFICATION OF RECEPTORS

4.1 Overview

There is no formal guidance with regard to the maximum distance at which glint and glare should be assessed. From a technical perspective, there is no maximum distance for potential reflections.

However, the significance of a solar reflection decreases with distance. This is because the proportion of an observer's field of vision that is taken up by the reflecting area diminishes as the separation distance increases.

Terrain and shielding by vegetation are also more likely to obstruct an observer's view at longer distances for ground-based receptors.

4.2 Road

The analysis has considered through-roads that:

- Are within, or close to one kilometre of the proposed development; and
- Have a potential view of the panels.

The assessed road receptor points are shown as white icons and green lines in Figure 4[4] on the following page. The A476 is located circa 20 meters (at its closest point) south of the solar development. A height above ground level of 1.5 metres has been taken as typical eye level for a road user for all roads. In total 10 road receptor points[5] have been identified for the assessment.

Drivers travelling on both directions of A476 will only be able to see Sites 1 to 8 since the view of the other sites will be screened by existing vegetation (see Figure 4[6] on the following page). Therefore, only receptors west of site 1 to 8 have been considered.

[4] Source: Copyright © 2019 Google.
[5] The co-ordinates of the road receptor points are presented in Appendix H.
[6] Source: Copyright © 2019 Google.

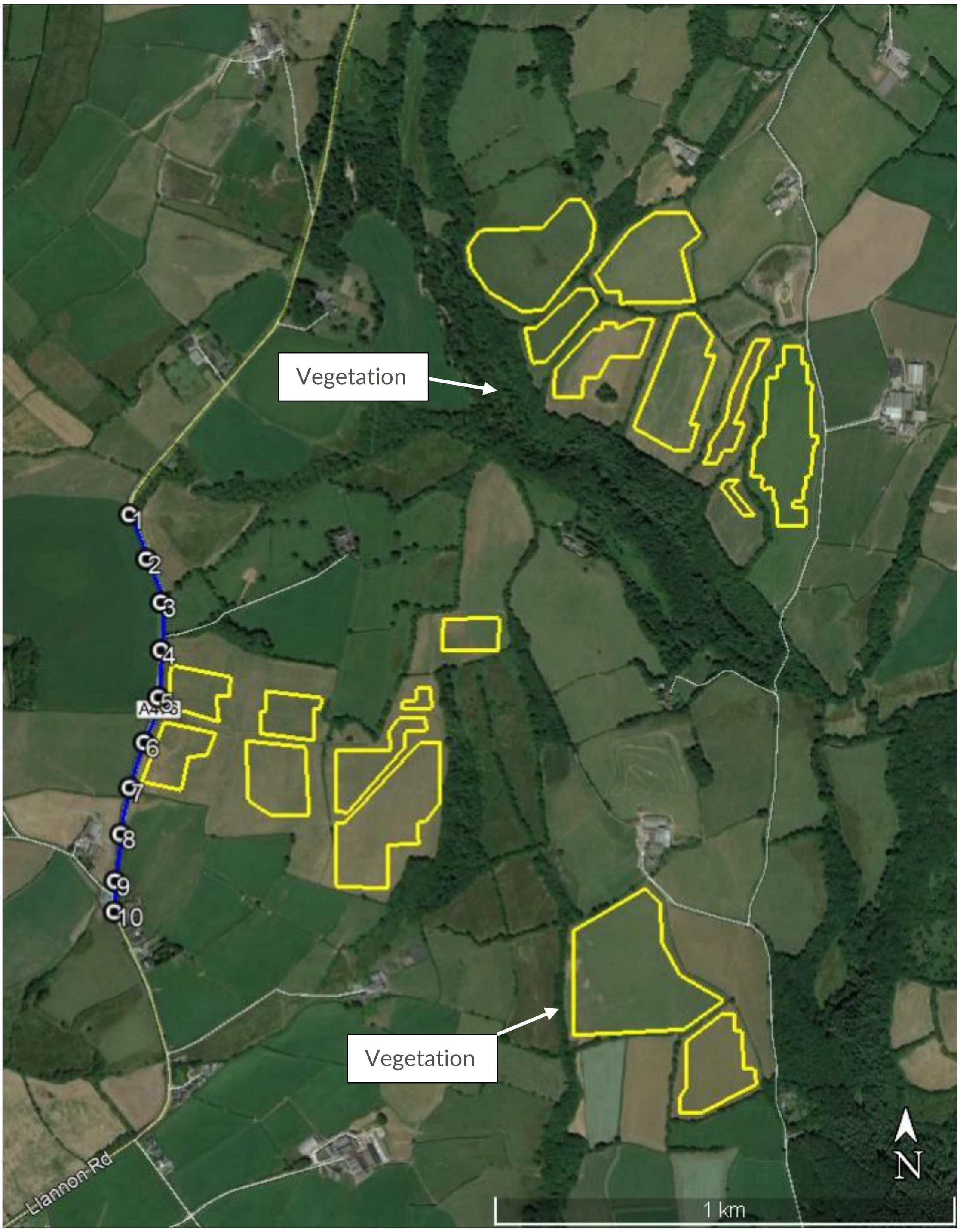

Figure 4 – Road receptors

4.3 Dwellings

The analysis has considered dwellings that:

- Are within, or close to one kilometre of the proposed development; and
- Have a potential view of the panels.

The assessed dwellings are shown in Figure 5[7] on the following page. A height above ground level of 1.8 metres has been taken as the typical eye level for an observer on the ground floor of each dwelling. In total 14 dwelling receptors points[8] have been identified for the assessment.

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[7] Source: Copyright © 2019 Google.

[8] The co-ordinates of the dwelling receptor points are presented in Appendix H.

Figure 5 – Assessed dwellings

5 ASSESSED REFLECTOR AREAS

5.1 Overview

The following section presents the modelled reflector areas.

5.2 Reflector Areas

The proposed development is divided into 18 distinct solar development areas.

A resolution of 10m has been chosen for this assessment. This means that a geometric calculation is undertaken for each identified receptor every 10m from within each defined area. This resolution is sufficiently high to maximise the accuracy of the results – increasing the resolution further would not significantly change the modelling output. The number of modelled reflector points are determined by the size of the reflector area and the assessment resolution. The bounding co-ordinates for each area have been extrapolated from the site maps.

Figure 6[9] below presents the solar panels details for each area.

Figure 6 – Assessed solar development area details

The full assessment data can be found in Appendix G.

[9] Aerial image copyright © 2019 Google.

6 GLINT AND GLARE ASSESSMENT RESULTS

6.1 Overview

The following section presents an overview of the glare for the identified receptors.

The tables in the following subsections summarise the months and times during which a solar reflection could be experienced by a receptor.

<u>This does not mean that reflections would occur continuously between the times shown</u>.

The range of times at which reflections are geometrically possible is generally greater than the length of time for any particular day. This is because the times of day at which reflections could start and stop vary throughout the days/months.

The results of the analysis are presented in the following sections. Appendix H presents the results charts and is provided separately.

6.2 Geometric Calculation Results Overview –Road Receptors

The results of the geometric calculation for the road receptors are presented in Table 1 below.

Receptor	Pager Power Results		Comment
	Reflection possible toward the road receptors? (GMT)		
	am	pm	
1	Between 05:58 and 06:32 from mid- March to late September.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section 7.2
2	Between 06:01 and 06:27 from late March to mid-September.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section 7.2
3	Between 06:39 and 06:47 during early March. Between 06:00 and 06:22 from early April to early September. Between 06:20 and 06:25 during the beginning of October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section 7.2

Receptor	Pager Power Results		Comment
	Reflection possible toward the road receptors? (GMT)		
	am	pm	
4	Between 06:30 and 06:42 from late March to early April. Between 06:01 and 06:22 from mid-April to late August. Between 06:23 and 06:28 from early September to late September.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2
5	Between 06:02 and 06:46 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2
6	Between 06:01 and 06:46 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2

Receptor	Pager Power Results		Comment
	Reflection possible toward the road receptors? (GMT)		
	am	pm	
7	Between 05:56 and 06:45 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2
8	Between 06:00 and 06:41 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2
9	Between 05:57 and 06:42 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2

Receptor	Pager Power Results		Comment
	Reflection possible toward the road receptors? (GMT)		
	am	pm	
10	Between 05:58 and 06:43 from early March to early October.	None.	Solar reflection geometrically possible. Reflections generating outside the drivers' field of view. Low impact expected. See Section 7.2

Table 1 – Geometric analysis results for the road receptors

6.3 Geometric Calculation Results Overview – Dwellings

The results of the geometric calculations for the identified dwellings are presented in Table 2 below.

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
11	None.	None.	No impact.
12	None.	Between 17:52 and 18:44 from early March to early October.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section **Error! Reference source not found.**
13	None.	Between 17:52 and 18:42 from early March to early October.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section **Error! Reference source not found.**

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
14	None.	Between 18:21 and 18:34 from mid-April to the beginning of June. At circa 18:40 during late June. Between 18:24 and 18:42 from mid- July to late August.	Solar reflection geometrically possible. Screening in the form of terrain and vegetation has been identified. Low impact expected. See Section **Error! Reference source not found.**
15	None.	Between 18:27 and 18:28 during late March. Between 18:23 and 18:41 from late April to mid- August. Between 18:16 and 18:18 during mid-September.	Solar reflection geometrically possible. Screening in the form of terrain and vegetation has been identified. Low impact expected. See Section **Error! Reference source not found.**

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
16	None.	Between 18:20 and 18:53 from the end of March to mid- September.	Solar reflection geometrically possible. Screening in the form of terrain and vegetation has been identified. Low impact expected. See Section **Error! Reference source not found.**
17	Between 06:00 and 06:40 from early March to early October.	None.	Solar reflection geometrically possible. Screening in the form of buildings has been identified. Low impact expected. See Section **Error! Reference source not found.**
18	Between 06:00 and 06:45 from early March to early October.	None.	Solar reflection geometrically possible. Moderate Impact expected. See Section **Error! Reference source not found.**

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
19	Between 05:59 and 06:45 from early March to early October.	None.	Solar reflection geometrically possible. Screening in the form of buildings and terrain has been identified. No impact expected. See Section **Error! Reference source not found.**
20	Between 06:26 and 06:44 from early March to the end of March. Between 05:58 and 06:20 from mid-April to the end of August. Between 06:16 and 06:23 from mid-September to early October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified and are likely to screen reflection from Site 17. No impact expected. See Section **Error! Reference source not found.**
21	Between 06:25 and 06:44 from early March to the beginning of April. Between 05:59 and 06:20 from mid-April to late August. Between 06:16 and 06:23 from mid- September to early October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified and are likely to screen reflection from Site 17. No impact expected. See Section **Error! Reference source not found.**

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
22	Between 06:23 and 06:44 from early March to the beginning of April. Between 05:59 and 06:20 from late April to late August. Between 06:16 and 06:23 from early September to early October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified and are likely to screen reflection from Site 17. No impact expected. See Section **Error! Reference source not found.**
23	Between 06:21 and 06:44 from early March to early April. Between 05:59 and 06:18 from the end of April to mid-August. Between 06:15 and 06:23 from early September to early October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified. No impact expected. See Section 7.3.

Receptor	Pager Power Results		Reflection Expected
	Reflection possible toward the identified dwellings? (GMT)		
	am	pm	
24	Between 06:19 and 06:44 from early March to mid- April. Between 05:58 and 06:18 from early May to the beginning of August. Between 06:15 and 06:24 from the beginning of September to early October.	None.	Solar reflection geometrically possible. Screening in the form of vegetation has been identified No impact expected. See Section **Error! Reference source not found.**

Table 2 – Geometric analysis results for the identified dwellings

7 GEOMETRIC ASSESSMENT RESULTS, DISCUSSION AND CONCLUSIONS

7.1 Overview

The results of the road and dwellings glint and glare calculations are presented in the following sub-sections.

7.2 Road Receptors

The results of the analysis have shown that the reflections from the proposed development towards the identified road receptors are possible. For receptors location 1 to 3, a solar reflection will originate from panels which are not visible therefore no impact is expected. For receptors location 4 to 10, the reflection will generate outside the driver's field of focus. Also screening in the form of vegetation located between the road and the reflecting solar panels has been identified (see Figure 7 below).

Figure 7 – A476 street view

No or low impact expected. No mitigation required.

7.3 Dwelling Receptors

The results of the analysis have shown that the reflections from the proposed development towards the identified dwelling receptors are possible for 13 dwellings out of 14 assessed. For only one dwelling the impact is considered to be moderate, the other 12 will experience a low impact. Table 3 below explains the results for dwelling 18 where a moderate impact has been identified.

Dwelling	Dwelling Details/Visibility	Comment
18	Views of the reflecting areas are likely	Views of the development’s reflecting areas are likely considering baseline conditions. The reflecting solar panels would be over 430m away.

Table 3 – Dwellings with moderate impact: comments

Receptor 18 will experience a solar reflection for circa 7 months per year during the early morning (see Figure 8 below).

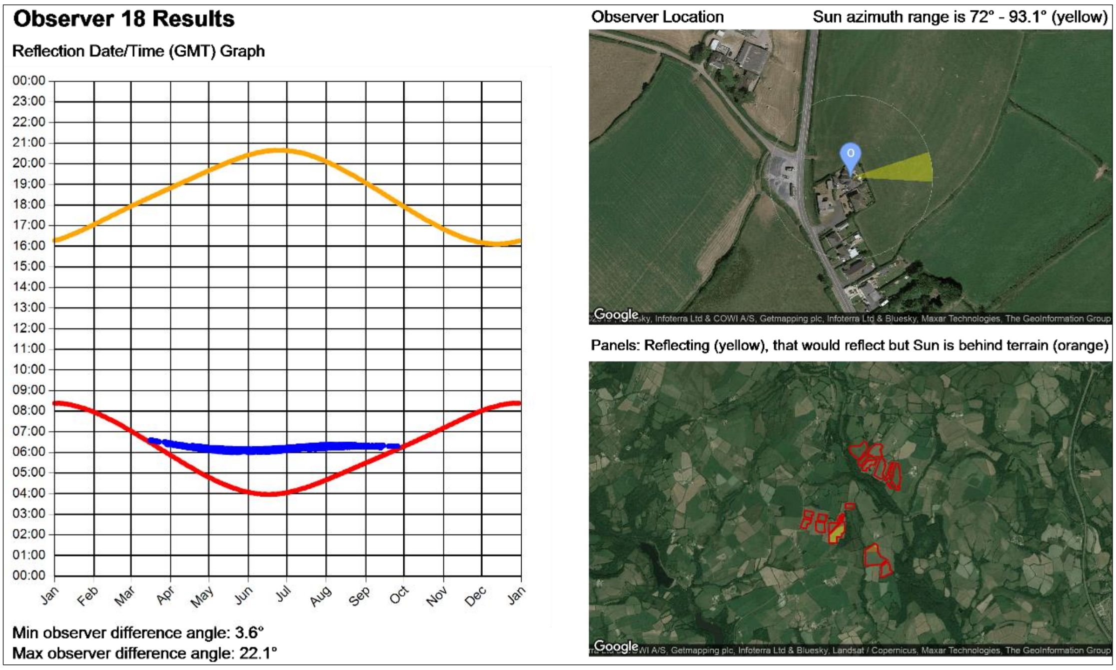


Figure 8 – Receptor 18

A view of a solar reflection from the assessed location would only occur where there is a clear view of the reflecting solar panels at the particular time of day when a solar reflection is geometrically possible on a clear and sunny day. Any solar reflection could last for up to 10 minutes however only when all of the above criteria are met.

The reflection originates from the southern portion of Site 6 and Site 17 before 7am GMT. While reflections generating from Site 17 are sufficiently screened, reflection generating from Site 6 are not.

At this specific time, a resident would also be looking in the general direction of the Sun. This means that the viewer will likely be able to see the glare from the reflecting solar panels as well as the Sun directly. It is important to note that the direct sunlight would be a significantly brighter source of light when compared to the solar reflection. At any one location, only a particular area of solar panels will produce a solar reflection towards it, not the whole panel area.

In conclusion, the impact toward this dwelling is deemed to be moderate and mitigation is recommended. The mitigation should consist of screening (which might be in form of vegetation) and it should be enough high to block any view of the panels from the top floor. Two screening strategies are proposed in Figure 9 below. Planting of hedgerows/trees with a minimum height of 3 metres will ensure the reflecting solar panels are screened and not visible from the dwelling. The blue lines define the reflective panel area and its visibility from the receptor location. Screening is proposed on the west boundary of the proposed development (orange line). However, the amount of screening will reduce if deployed closer to the dwelling.

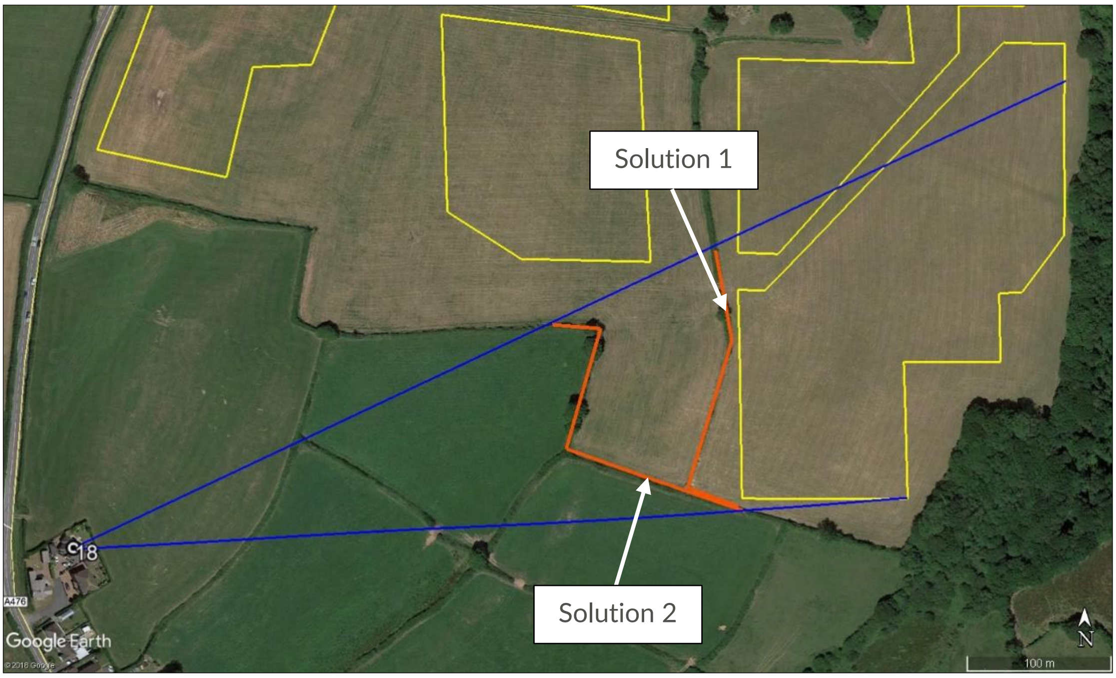


Figure 9 – Location of dwelling 24 relative to the proposed development

8 OVERALL CONCLUSIONS

8.1 Assessment Results – Road

The results of the analysis have shown that the reflections from the proposed development towards the identified road receptors are possible. Any reflection towards drivers travelling in both directions on the A476 will be either screened or generating outside the drivers' field of view.

Overall, no significant impact is expected therefore no mitigation strategy should be implemented.

8.2 Assessment Results – Dwellings

The results show that a solar reflection is possible for 13 dwellings of the 14 assessed. Only dwelling 18 will experience a moderate impact. Dwelling 18 is expected to have an unobstructed view of the reflecting solar panel area at a distance of 430m. The solar reflection would last for circa 7 months per year during the early morning. A moderate impact is therefore predicted, and mitigation is recommended in this instance. Planting hedgerows/trees at the recommended location with a minimum height of 3 metres will ensure the reflecting solar panel are screened and not visible from the dwelling.

8.3 Recommendation

Pager Power recommend an on-site assessment to establish the visibility of the land from the dwelling 18.

APPENDIX A – OVERVIEW OF GLINT AND GLARE GUIDANCE

Overview

This section presents details regarding the relevant guidance and studies with respect to the considerations and effects of solar reflections from solar panels, known as 'Glint and Glare'.

This is not a comprehensive review of the data sources, rather it is intended to give an overview of the important parameters and considerations that have informed this assessment.

UK Planning Policy

UK National Planning Practice Guidance dictates that in some instances a glint and glare assessment is required however, there is no specific guidance with respect to the methodology for assessing the impact of glint and glare.

The planning policy from the Department for Communities and Local Government (paragraph 27[10]) states:

'Particular factors a local planning authority will need to consider include… the effect on landscape of glint and glare and on ***neighbouring uses and aircraft safety****.'*

The National Planning Policy Framework for Renewable and Low Carbon Energy[11] (specifically regarding the consideration of solar farms, paragraph 26 and 27) states:

'What are the particular planning considerations that relate to large scale ground-mounted solar photovoltaic Farms?

The deployment of large-scale solar farms can have a negative impact on the rural environment, particularly in undulating landscapes. However, the visual impact of a well-planned and well-screened solar farm can be properly addressed within the landscape if planned sensitively.

Particular factors a local planning authority will need to consider include:

- *the proposal's visual impact, the effect on landscape of glint and glare (see guidance on landscape assessment) and on* ***neighbouring uses and aircraft safety****;*
- *the extent to which there may be additional impacts if solar arrays follow the daily movement of the sun;*

[10] Planning practice guidance for renewable and low carbon energy, Department for Communities and Local Government, date: 06/2013, accessed on: 20/03/2019
[11] Planning practice guidance for renewable and low carbon energy, Department for Communities and Local Government, date: 06/2013, accessed on: 20/03/2019

The approach to assessing cumulative landscape and visual impact of large scale solar farms is likely to be the same as assessing the impact of wind turbines. However, in the case of ground-mounted solar panels it should be noted that with effective screening and appropriate land topography the area of a zone of visual influence could be zero.'

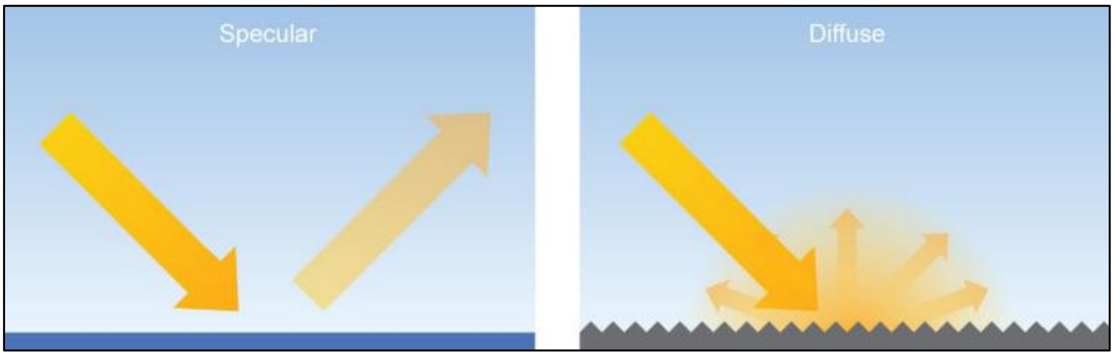
APPENDIX B – OVERVIEW OF GLINT AND GLARE STUDIES

Overview

Studies have been undertaken assessing the type and intensity of solar reflections from various surfaces including solar panels and glass. An overview of these studies is presented below.

Reflection Type from Solar Panels

Based on the surface conditions reflections from light can be specular and diffuse. A specular reflection has a reflection characteristic similar to that of a mirror; a diffuse will reflect the incoming light and scatter it in many directions. The figure below, taken from the FAA guidance[12], illustrates the difference between the two types of reflections. Because solar panels are flat and have a smooth surface most of the light reflected is specular, which means that incident light from a specific direction is reradiated in a specific direction.



Specular and diffuse reflections

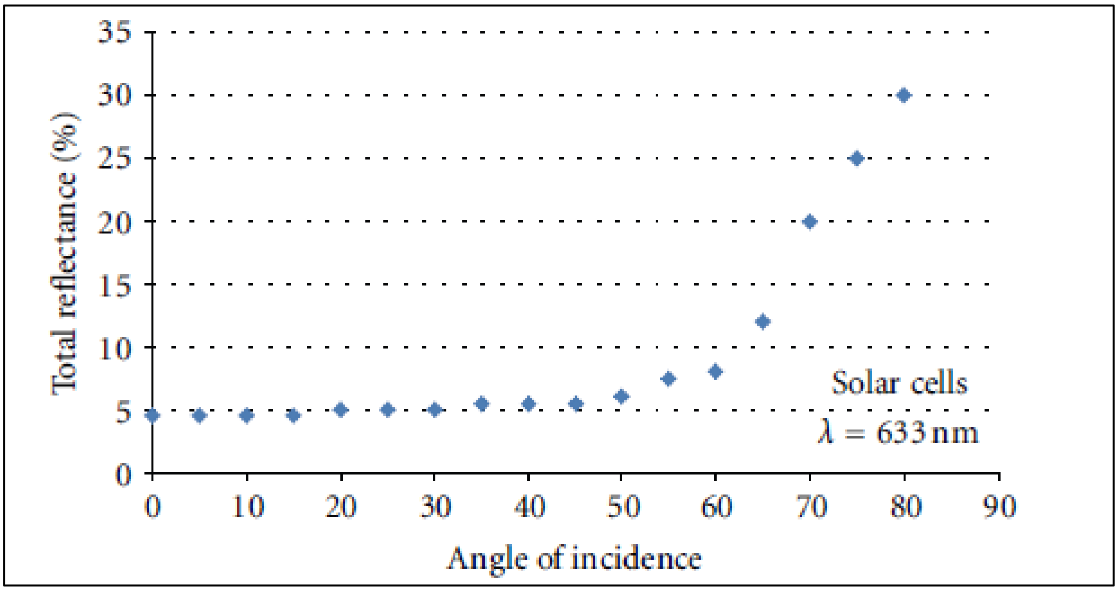
[12] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

Solar Reflection Studies

An overview of content from identified solar panel reflectivity studies is presented in the subsections below.

Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems"

Evan Riley and Scott Olson published in 2011 their study titled: *A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems*[13]". They researched the potential glare that a pilot could experience from a 25 degree fixed tilt PV system located outside of Las Vegas, Nevada. The theoretical glare was estimated using published ocular safety metrics which quantify the potential for a postflash glare after-image. This was then compared to the postflash glare after-image caused by smooth water. The study demonstrated that the reflectance of the solar cell varied with angle of incidence, with maximum values occurring at angles close to 90 degrees. The reflectance values varied from approximately 5% to 30%. This is shown on the figure below.



Total reflectance % when compared to angle of incidence

The conclusions of the research study were:

- The potential for hazardous glare from flat-plate PV systems is similar to that of smooth water;
- Portland white cement concrete (which is a common concrete for runways), snow, and structural glass all have a reflectivity greater than water and flat plate PV modules.

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[13] Evan Riley and Scott Olson, "A Study of the Hazardous Glare Potential to Aviators from Utility-Scale Flat-Plate Photovoltaic Systems," ISRN Renewable Energy, vol. 2011, Article ID 651857, 6 pages, 2011. doi:10.5402/2011/651857

FAA Guidance – "Technical Guidance for Evaluating Selected Solar Technologies on Airports"[14]

The 2010 FAA Guidance included a diagram which illustrates the relative reflectance of solar panels compared to other surfaces. The figure shows the relative reflectance of solar panels compared to other surfaces. Surfaces in this figure produce reflections which are specular and diffuse. A specular reflection (those made by most solar panels) has a reflection characteristic similar to that of a mirror. A diffuse reflection will reflect the incoming light and scatter it in many directions. A table of reflectivity values, sourced from the figure within the FAA guidance, is presented below.

Surface	Approximate Percentage of Light Reflected[15]
Snow	80
White Concrete	77
Bare Aluminium	74
Vegetation	50
Bare Soil	30
Wood Shingle	17
Water	5
Solar Panels	5
Black Asphalt	2

Relative reflectivity of various surfaces

Note that the data above does not appear to consider the reflection type (specular or diffuse).

An important comparison in this table is the reflectivity compared to water which will produce a reflection of very similar intensity when compared to that from a solar panel. The study by Riley and Olsen study (2011) also concludes that still water has a very similar reflectivity to solar panels.

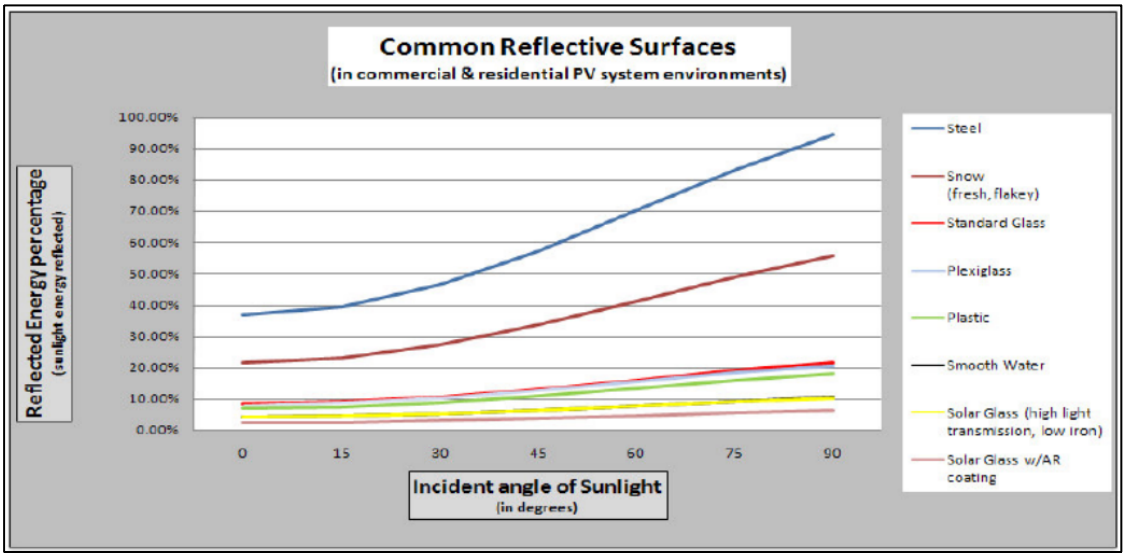
[14] Technical Guidance for Evaluating Selected Solar Technologies on Airports, Federal Aviation Administration (FAA), date: 04/2018, accessed on: 20/03/2019.

[15] Extrapolated data, baseline of 1,000 W/m^2 for incoming sunlight.

SunPower Technical Notification (2009)

SunPower published a technical notification[16] to '*increase awareness concerning the possible glare and reflectance impact of PV Systems on their surrounding environment'*.

The figure presented below shows the relative reflectivity of solar panels compared to other natural and manmade materials including smooth water, standard glass and steel.



Common reflective surfaces

The results, similarly to those from Riley and Olsen study (2011) and the FAA (2010), show that solar panels produce a reflection that is less intense than those of '*standard glass and other common reflective surfaces'*.

With respect to aviation and solar reflections observed from the air, SunPower has developed several large installations near airports or on Air Force bases. It is stated that these developments have all passed FAA or Air Force standards with all developments considered "No Hazard to Air Navigation". The note suggests that developers discuss any possible concerns with stakeholders near proposed solar farms.

[16] Source: Technical Support, 2009. SunPower Technical Notification – Solar Module Glare and Reflectance.

APPENDIX C – OVERVIEW OF SUN MOVEMENTS AND RELATIVE REFLECTIONS

The Sun's position in the sky can be accurately described by its azimuth and elevation. Azimuth is a direction relative to true north (horizontal angle i.e. from left to right) and elevation describes the Sun's angle relative to the horizon (vertical angle i.e. up and down).

The Sun's position can be accurately calculated for a specific location. The following data being used for the calculation:

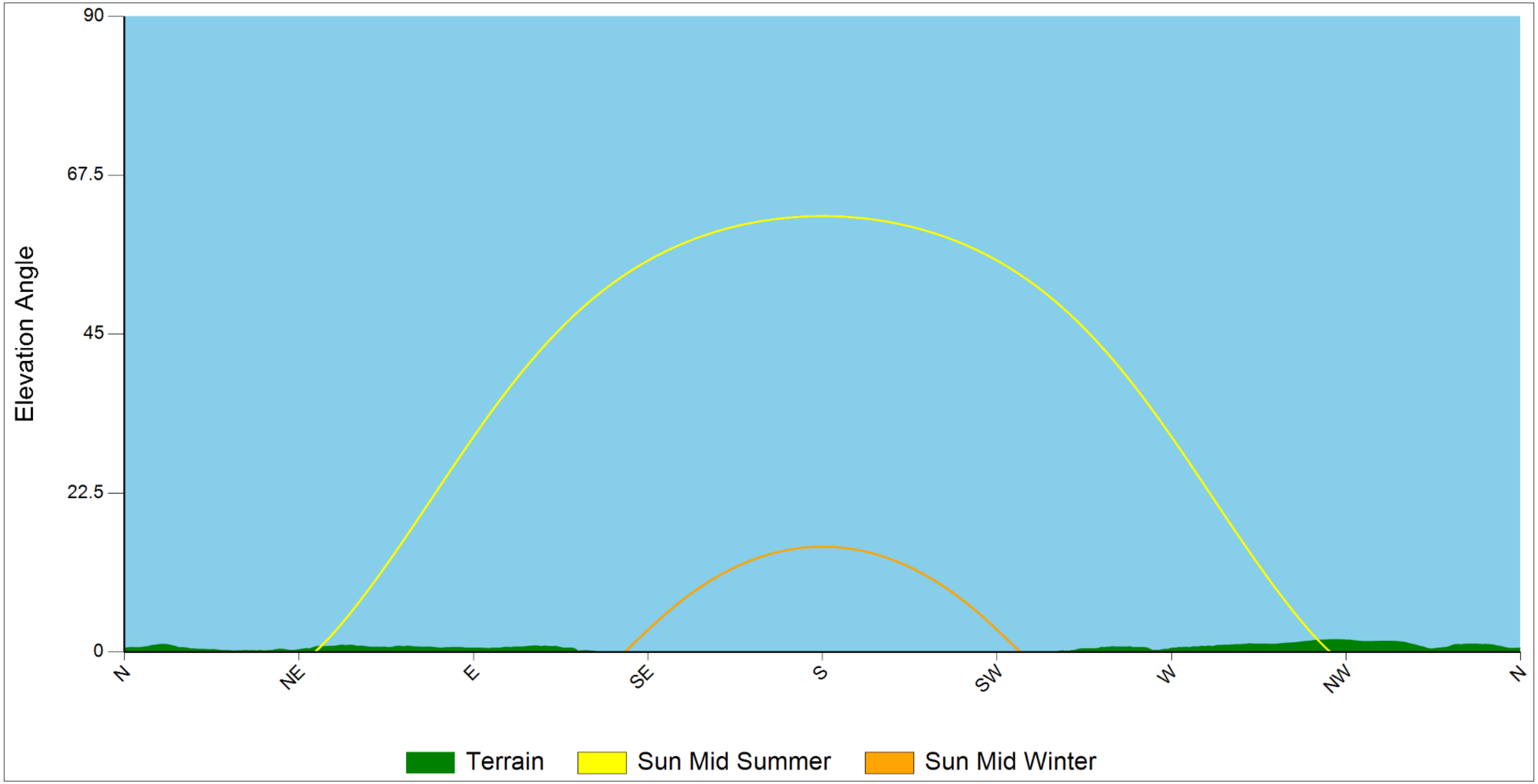
- Time;
- Date;
- Latitude;
- Longitude.

The following is true at the location of the solar development:

- The Sun is at its highest around midday and is to the south at this time;
- The Sun rises highest on 21 June reaching a maximum elevation of approximately 60-65 degrees (longest day);
- On 21 December, the maximum elevation reached by the Sun is approximately 10-15 degrees (shortest day).

The combination of the Sun's azimuth angle and vertical elevation will affect the direction and angle of the reflection from a reflector.

Terrain Sun Curve - From lon:-4.112938 lat: 51.729047



APPENDIX D – GLINT AND GLARE IMPACT SIGNIFICANCE

Overview

The significance of glint and glare will vary for different receptors. The following section presents a general overview of the significance criteria with respect to experiencing a solar reflection.

Impact Significance Definition

The table below presents the recommended definition of 'impact significance' in glint and glare terms and the requirement for mitigation under each.

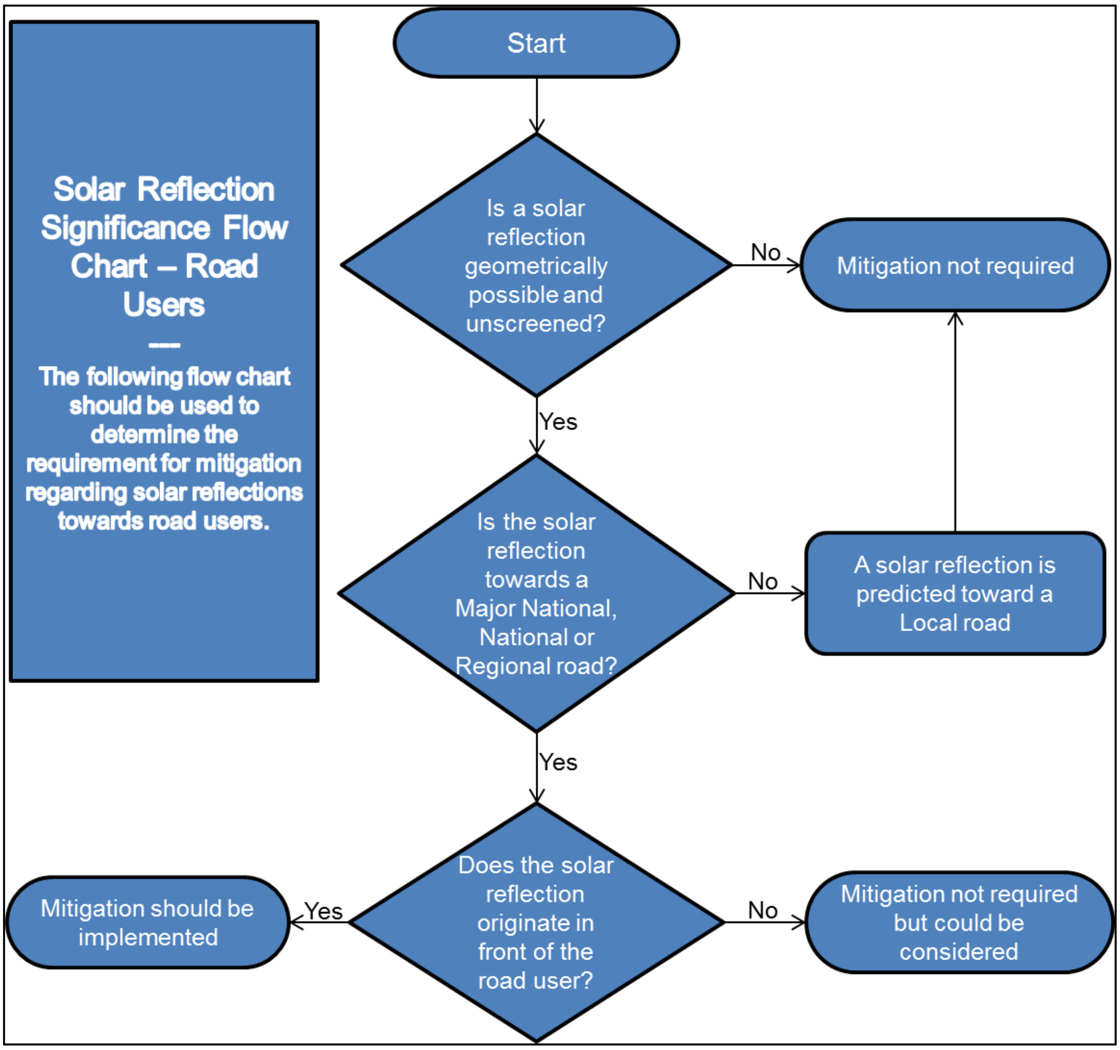
Impact Significance	Definition	Mitigation Requirement
No Impact	A solar reflection is not geometrically possible or will not be visible from the assessed receptor.	No mitigation required.
Low	A solar reflection is geometrically possible however any impact is considered to be small such that mitigation is not required e.g. intervening screening will limit the view of the reflecting solar panels.	No mitigation required.
Moderate	A solar reflection is geometrically possible and visible however it occurs under conditions that do not represent a worst-case.	Whilst the impact may be acceptable, consultation and/or further analysis should be undertaken to determine the requirement for mitigation.
Major	A solar reflection is geometrically possible and visible under conditions that will produce a significant impact. Mitigation and consultation is recommended.	Mitigation will be required if the proposed development is to proceed.

Impact significance definition

The flow charts presented in the following sub-sections have been followed when determining the mitigation requirement for receptors.

Assessment Process for Road Receptors

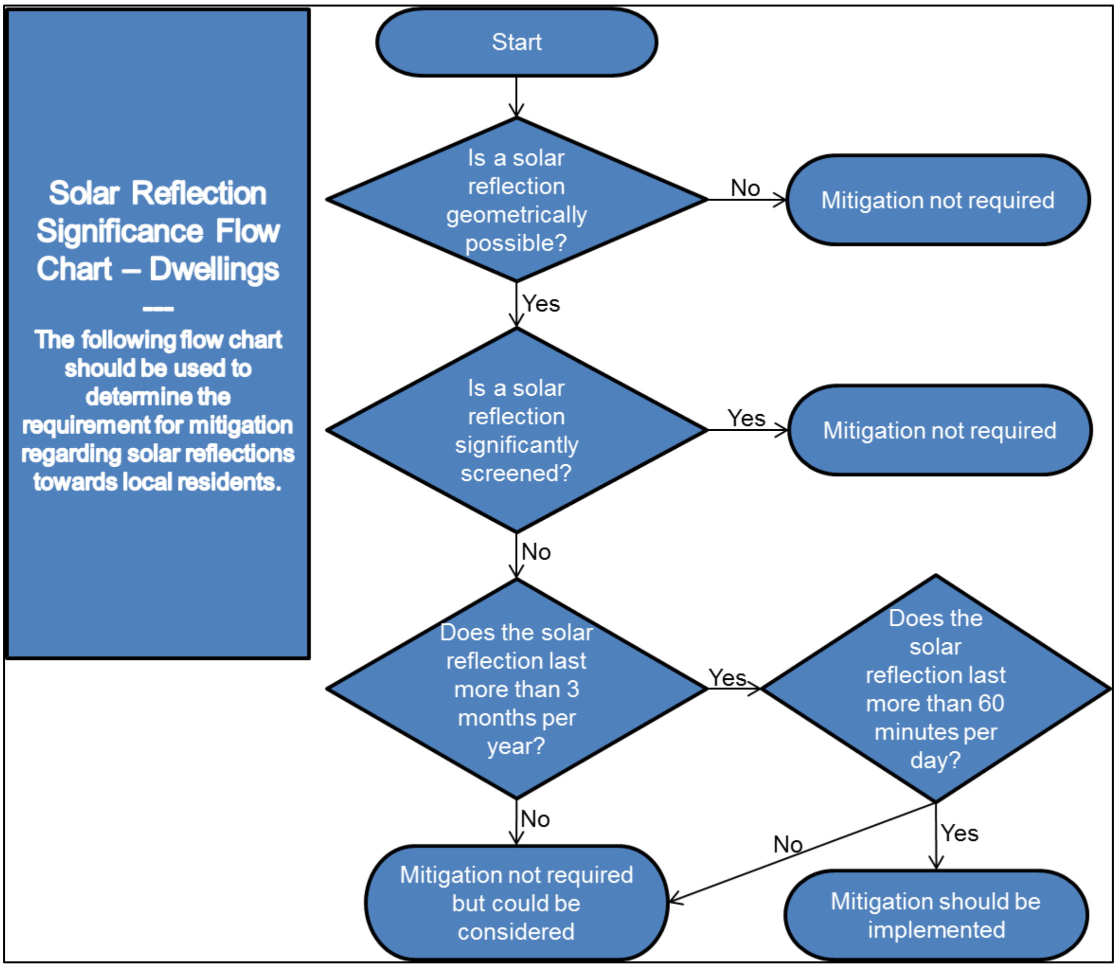
The flow chart presented below has been followed when determining the mitigation requirement for road receptors.



Road receptor mitigation requirement flow chart

Assessment Process for Dwelling Receptors

The flow chart presented below has been followed when determining the mitigation requirement for dwelling receptors.



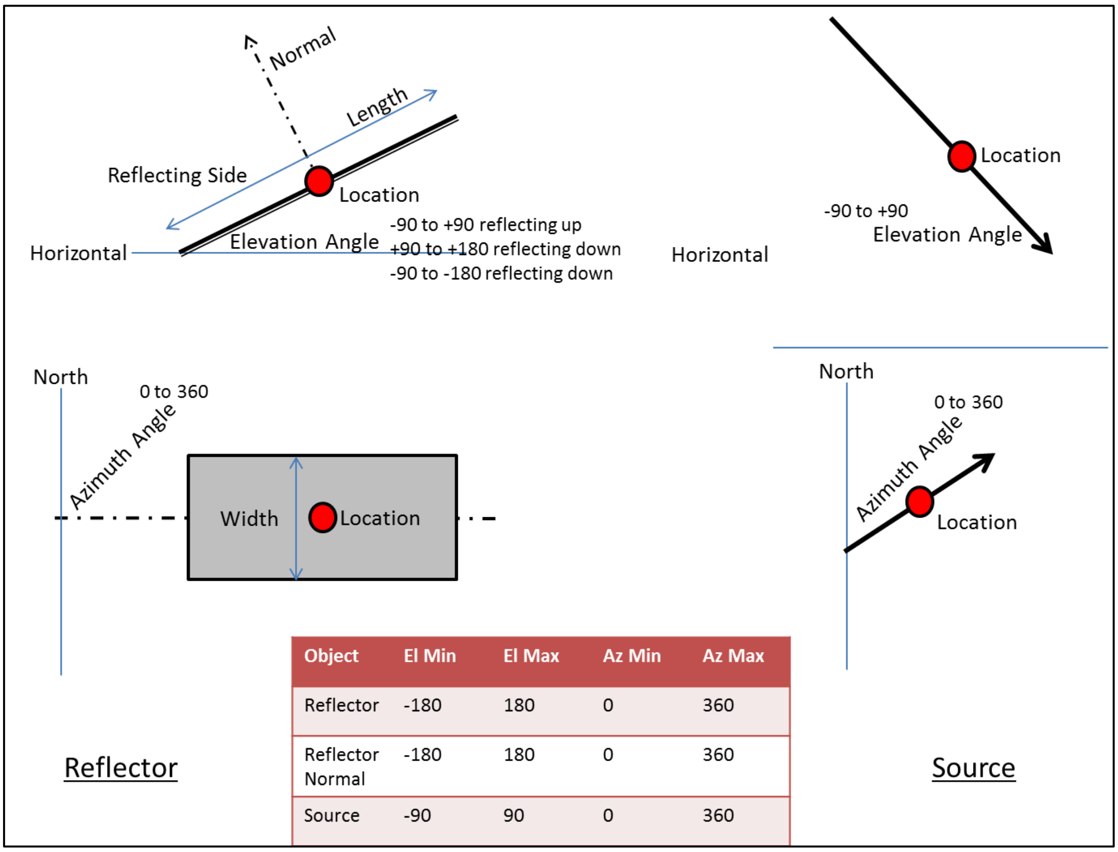
Dwelling receptor mitigation requirement flow chart

APPENDIX E – PAGER POWER'S REFLECTION CALCULATIONS METHODOLOGY

The calculations are three dimensional and complex, accounting for:

- The Earth's orbit around the Sun;
- The Earth's rotation;
- The Earth's orientation;
- The reflector's location;
- The reflector's 3D Orientation.

Reflections from a flat reflector are calculated by considering the normal which is an imaginary line that is perpendicular to the reflective surface and originates from it. The diagram below may be used to aid understanding of the reflection calculation process.



Object	El Min	El Max	Az Min	Az Max
Reflector	-180	180	0	360
Reflector Normal	-180	180	0	360
Source	-90	90	0	360

The following process is used to determine the 3D azimuth and elevation of a reflection:

- Use the Latitude and Longitude of reflector as the reference for calculation purposes;
- Calculate the Azimuth and Elevation of the normal to the reflector;
- Calculate the 3D angle between the source and the normal;

- If this angle is less than 90 degrees a reflection will occur. If it is greater than 90 degrees no reflection will occur because the source is behind the reflector;
- Calculate the Azimuth and Elevation of the reflection in accordance with the following:
    - The angle between source and normal is equal to angle between normal and reflection;
    - Source, Normal and Reflection are in the same plane.

APPENDIX F – ASSESSMENT LIMITATIONS AND ASSUMPTIONS

Pager Power's Model

It is assumed that the panel elevation angle provided by the developer represents the elevation angle for all of the panels within the solar development.

It is assumed that the panel azimuth angle provided by the developer represents the azimuth angle for all of the panels within the solar development.

Only a reflection from the face of the panel has been considered. The frame or the reverse of the solar panel has not been considered.

The model assumes that a receptor can view the face of every panel within the proposed development area whilst in reality this, in the majority of cases, will not occur. Therefore any predicted reflection from the face of a solar panel that is not visible to a receptor will not occur.

A finite number of points within the proposed development are chosen based on an assessment resolution so we can build a comprehensive understanding of the entire development. This will determine whether a reflection could ever occur at a chosen receptor. The calculations do not incorporate all of the possible panel locations within the development outline.

A single reflection point on the panel has been chosen for the geometric calculations. This will suitably determine whether a reflection can be experienced at a location and the general time of year and duration of this reflection. Increased accuracy could be achieved by increasing the number of heights assessed however this would only marginally change the results and is not considered significant.

Whilst line of sight to the development from receptors has been considered, only available street view imagery and satellite mapping has been used. In some cases this imagery may not be up to date and may not give the full perspective of the installation from the location of the assessed receptor.

Any screening in the form of trees, buildings etc. that may obstruct the Sun from view of the solar panels is not considered unless stated.

APPENDIX G – RECEPTOR AND REFLECTOR AREA DETAILS

Road Receptor Details

The details are presented in the table below.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
1	-4.126943	51.729946	145.82
2	-4.126431	51.729094	152.07
3	-4.126002	51.728271	157.17
4	-4.126007	51.727363	162.33
5	-4.126091	51.726471	164.95
6	-4.126525	51.725618	168.13
7	-4.126970	51.724761	169.50
8	-4.127248	51.723887	170.00
9	-4.127418	51.722991	166.39
10	-4.127440	51.722410	163.51

Assessed receptor (road) locations for A476

Dwelling Receptor Details

The details are presented in the table below.

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
1	-4.106910	51.736161	141.29
2	-4.103454	51.731806	117.44
3	-4.103626	51.731606	116.87
4	-4.110606	51.726585	115.89
5	-4.110221	51.726280	115.53
6	-4.110841	51.723269	121.74
7	-4.128524	51.723530	171.80
8	-4.126800	51.722584	164.76

No.	Longitude (°)	Latitude (°)	Assessed Altitude (m) (amsl)
9	-4.126680	51.722390	163.71
10	-4.127005	51.722091	162.27
11	-4.126889	51.721981	162.39
12	-4.126722	51.721822	161.96
13	-4.126542	51.721635	161.24
14	-4.126335	51.721398	159.32

Assessed receptor (dwellings) locations

Site 1

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.125740	51.727055	4	-4.125740	51.727055
2	-4.123921	51.726830	5	-4.123921	51.726830
3	-4.123934	51.726465	6	-4.123934	51.726465

Modelled reflector Site 1

Site 2

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.125944	51.725975	4	-4.125195	51.725324
2	-4.124375	51.725762	5	-4.125424	51.724687
3	-4.124644	51.725336	6	-4.126628	51.724847

Modelled reflector Site 2

Site 3

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.122980	51.726191	5	-4.121115	51.726230
2	-4.122814	51.726180	6	-4.121340	51.726230
3	-4.122832	51.726561	7	-4.121311	51.725622
4	-4.121078	51.726430	8	-4.122998	51.725758

Modelled reflector Site 3

Site 4

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.123439	51.725621	4	-4.122703	51.724222
2	-4.121600	51.725495	5	-4.123379	51.724486
3	-4.121493	51.724209			

Modelled reflector Site 4

Site 5

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.120631	51.725421	6	-4.117766	51.725792
2	-4.118899	51.725423	7	-4.118427	51.725783
3	-4.118930	51.725789	8	-4.118446	51.725489
4	-4.118612	51.726031	9	-4.120281	51.724258
5	-4.117776	51.726033	10	-4.120663	51.724266

Modelled reflector Site 5

Site 6

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.120669	51.724049	7	-4.118045	51.724038
2	-4.120409	51.724044	8	-4.118031	51.723624
3	-4.117984	51.725561	9	-4.119039	51.723627
4	-4.117333	51.725571	10	-4.118989	51.722809
5	-4.117364	51.724395	11	-4.120630	51.722837
6	-4.117808	51.724046			

Modelled reflector Site 6

Site 7

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.117598	51.726594	4	-4.118507	51.726354
2	-4.117594	51.726208	5	-4.118068	51.726359
3	-4.118509	51.726202	6	-4.118053	51.726601

Modelled reflector Site 7

Site 8

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.115467	51.727940	3	-4.117225	51.727318
2	-4.115460	51.727334	4	-4.117173	51.727934

Modelled reflector Site 8

Site 9

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.114154	51.735421	7	-4.114689	51.733856
2	-4.113362	51.735964	8	-4.115726	51.734239
3	-4.112964	51.735944	9	-4.116245	51.734723
4	-4.112575	51.735491	10	-4.116348	51.735100
5	-4.112669	51.735004	11	-4.115984	51.735421
6	-4.114049	51.733874			

Modelled reflector Site 9

Site 10

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.114241	51.733535	5	-4.113959	51.732872
2	-4.113004	51.734267	6	-4.114358	51.732870
3	-4.112606	51.734265	7	-4.114589	51.733535
4	-4.112425	51.734006			

Modelled reflector Site 9

Site 11

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.111546	51.735347	6	-4.109462	51.734012
2	-4.110765	51.735679	7	-4.111735	51.733987
3	-4.109823	51.735675	8	-4.111738	51.734193
4	-4.109389	51.735260	9	-4.112183	51.734196
5	-4.109948	51.734983	10	-4.112495	51.734541

Modelled reflector Site 11

Site 12

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.113645	51.732719	8	-4.110682	51.733687
2	-4.112537	51.733491	9	-4.111061	51.732980
3	-4.112262	51.733490	10	-4.111974	51.732979
4	-4.112262	51.733613	11	-4.112331	51.732571
5	-4.111820	51.733618	12	-4.112773	51.732567
6	-4.111809	51.733503	13	-4.112774	51.732213
7	-4.111156	51.733685	14	-4.113665	51.732222

Modelled reflector Site 12

Site 13

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.109936	51.733762	6	-4.109474	51.731679
2	-4.109388	51.733767	7	-4.109227	51.731679
3	-4.108861	51.733349	8	-4.109426	51.731188
4	-4.109067	51.732985	9	-4.109893	51.731175
5	-4.108761	51.732979	10	-4.111190	51.731618

Modelled reflector Site 13

Site 14

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.108852	51.731101	9	-4.107710	51.732452
2	-4.108813	51.731317	10	-4.107906	51.731960
3	-4.108353	51.731787	11	-4.108111	51.731692
4	-4.108245	51.732237	12	-4.107791	51.731697
5	-4.107560	51.733281	13	-4.108090	51.731183
6	-4.107105	51.733280	14	-4.108411	51.731175
7	-4.107384	51.732984	15	-4.108570	51.730941
8	-4.107447	51.732761	16	-4.109024	51.730932

Modelled reflector Site 14

Site 15

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.106149	51.733147	18	-4.105855	51.729730
2	-4.106131	51.732818	19	-4.106742	51.729729
3	-4.105973	51.732816	20	-4.106767	51.730195
4	-4.105955	51.732446	21	-4.106860	51.730197
5	-4.105801	51.732447	22	-4.106872	51.730440
6	-4.105795	51.731445	23	-4.107201	51.730438
7	-4.105579	51.731441	24	-4.107207	51.730671
8	-4.105573	51.731278	25	-4.107539	51.730671
9	-4.105685	51.731282	26	-4.107470	51.731259
10	-4.105751	51.730676	27	-4.107295	51.731453
11	-4.105887	51.730675	28	-4.107183	51.731456
12	-4.105874	51.730443	29	-4.107154	51.732554
13	-4.105972	51.730443	30	-4.106855	51.732554
14	-4.105967	51.730205	31	-4.106852	51.732788
15	-4.106270	51.730199	32	-4.106665	51.732791
16	-4.106264	51.730070	33	-4.106688	51.733145
17	-4.105870	51.730067			

Modelled reflector Site 15

Site 16

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.107925	51.730616	4	-4.107752	51.729929
2	-4.108133	51.730466	5	-4.108445	51.730478
3	-4.107416	51.729931	6	-4.108257	51.730615

Modelled reflector Site 16

Site 17

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.110946	51.722761	5	-4.108516	51.720609
2	-4.110470	51.722466	6	-4.109716	51.720044
3	-4.110426	51.721726	7	-4.113053	51.719891
4	-4.109856	51.721086	8	-4.113087	51.721916

Modelled reflector Site 17

Site 18

ID	Longitude (°)	Latitude (°)	ID	Longitude (°)	Latitude (°)
1	-4.109841	51.718742	7	-4.107928	51.720005
2	-4.109650	51.718917	8	-4.107883	51.719285
3	-4.109657	51.719801	9	-4.107527	51.719280
4	-4.108549	51.720353	10	-4.107480	51.718982
5	-4.108167	51.720354	11	-4.109228	51.718437
6	-4.108148	51.720009	12	-4.109840	51.718437

Modelled reflector Site 18

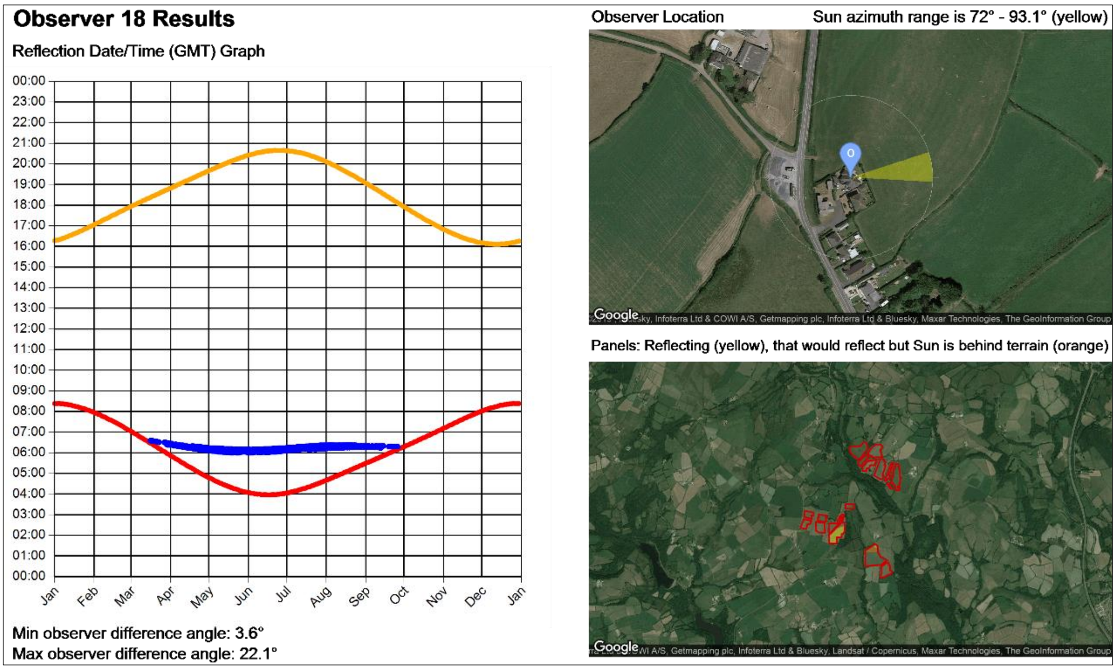
APPENDIX H – GEOMETRIC CALCULATION RESULTS- PAGER POWER RESULTS

The charts for the receptors are shown on the following pages. Each chart shows:

- The receptor (observer) location – top right image. This also shows the azimuth range of the Sun itself at times when reflections are possible. If sunlight is experienced from the same direction as the reflecting panels, the overall impact of the reflection is reduced as discussed within the body of the report;
- The reflecting panels – bottom right image. The reflecting area is shown in yellow. If the yellow panels are not visible from the observer location, no issues will occur in practice. Areas shown in orange are those where the Sun is obscured by terrain at the visible horizon and therefore no solar reflection could occur. Additional obstructions which may obscure the panels from view are considered separately within the analysis;
- The reflection date/time graph – left hand side of the page. The blue line indicates the dates and times at which geometric reflections are possible. This relates to reflections from the yellow areas only;
- The yellow and red lines show sunrise and sunset times respectively.

Dwellings Receptors

Only locations where the reflections are possible and unscreened are presented.



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