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Aviation Analysis, Renewables Development & Visualisation, and Radio Communications

Annex to

RAF St Athan, Cardiff Airport

Glint & Glare Assessment for the proposed

Rosedew Farm Solar Park

(dated 25 February 2015):

Garrad Hassan and Partners Ltd:
Caddington PV Solar Farm – Review of the PV Reflection Studies in the Public Domain

(dated 22 December 2010)

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CADDINGTON PV SOLAR FARM - REVIEW OF THE PV REFLECTION STUDIES IN THE PUBLIC DOMAIN

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INTRODUCTION

Emsrayne Ltd. (the Client) requested that GL Garrad Hassan (GLGH) provide the outline design and related methodological descriptions needed for input to the planning application for the proposed Caddington Solar Photovoltaic (or PV) Farm near Luton Airport. Pegasus Environmental (Pegasus) are providing the Client with planning and environmental expertise and are responsible for submitting the planning application. As part of this work GLGH visited the site on two occasions (8 and 21 October 2010) to collect pertinent site information.

The Client has requested that GLGH provide a review of the PV reflection studies that are available in the public domain. The purpose of the study is to summarize the relevant conclusions contained in other studies with regard to the impact of the glint and glare to offsite viewers, its intensity and eventual mitigation measures. GLGH has also investigated the presence of PV systems at or near airports and the findings of the corresponding environmental assessments, provided this information is publicly available.

DEFINITIONS

The following definitions are key to understanding the results of the review:

Glint – Also known as a specular reflection, produced as a direct reflection of the sun in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction (Figure 1).

Glare – A continuous source of brightness, relative to diffuse lightning. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun. Glare is significant less intense than glint (Figure 2).

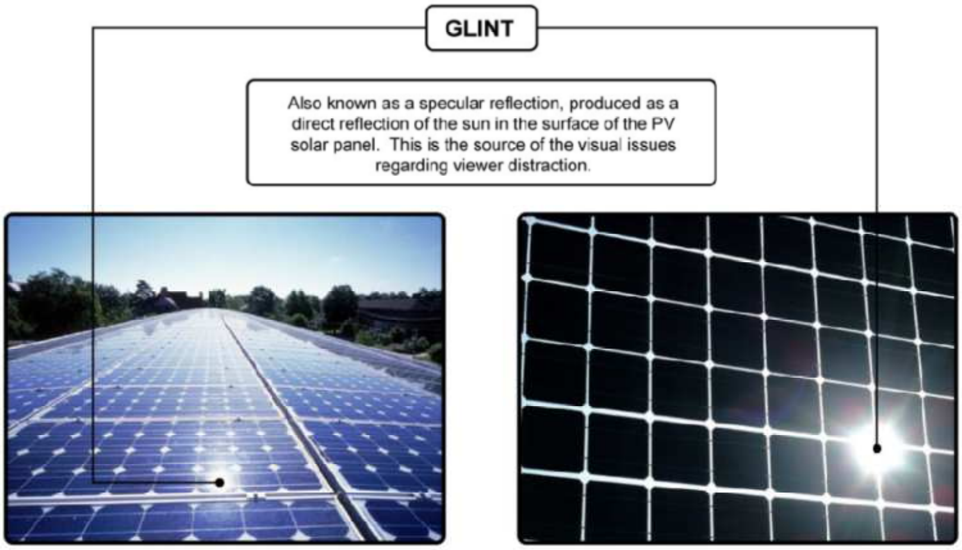

Figure 1: PV panel – glint (source: [1]).

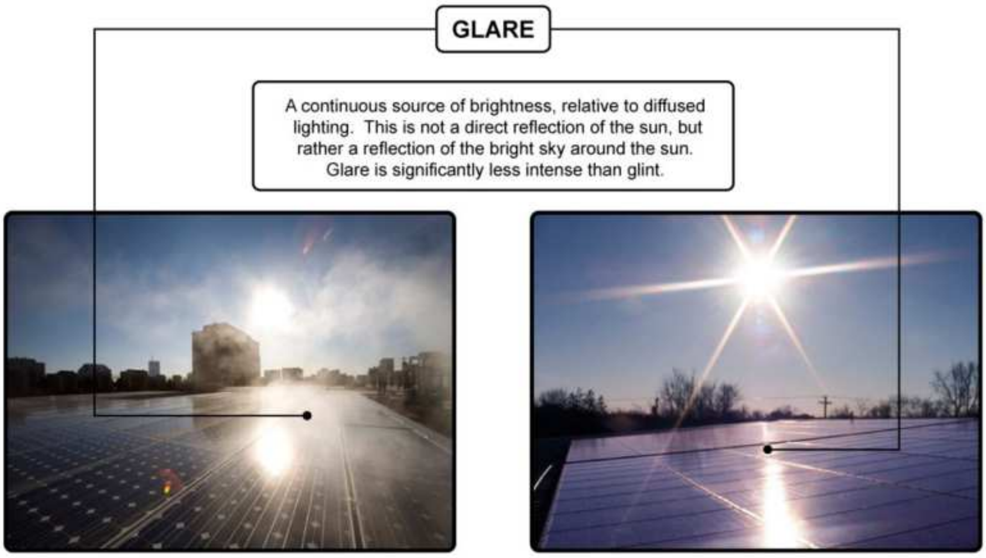

Figure 2: PV panel – glare (source: [1]).

Glint is defined as a momentary flash of light, while glare is defined as a more continuous source of excessive brightness relative to the ambient lighting.

RESULTS OF THE ANALYSIS

1.1 Reflectance of PV Panels

Solar PV panels are specifically designed to absorb light, rather than reflect it, as reflected light results in the loss of energy output. Modules are dark in colour and have coatings that enable the panel to absorb as much of the available light as possible, which directly increases energy production.

According to a recent study, completed by the PV module manufacturer SunPower Corporation [2], “The glare and reflectance levels from a given PV system are decisively lower than the glare and reflectance by standard glass and other common reflective surfaces in the environments surrounding the given PV system.”

The US patent #6359212 [3] explains the differences in the refraction and reflection of solar module glass versus standard window glass. Solar modules use high transmission, low iron glass which absorbs more light, producing small amounts of glare and reflectance than normal glass. Figure 3 shows the reflected energy percentages of sunlight of some common residential and commercial surfaces. Figure 4 is a zoom in Figure 3 which shows the reflection of the transparent surfaces only, including standard glass and two types of solar glass – high light transmission glass and glass with antireflective coating. It should be noted that the reflected energy percentage of solar glass is far below that of standard glass and more on the level of smooth water. It is also pointed out that, as light physics resolves, the least amount of light is reflected when the beam is perpendicular to the collecting surface. In other words, the least amount of energy is reflected when the beam is at 0 degrees to the normal. This limits the effect of eventual glint and glare issues related to PV panels to certain hours during a day – i.e. early in the morning and late in the afternoon, where the sun height angles are lower.

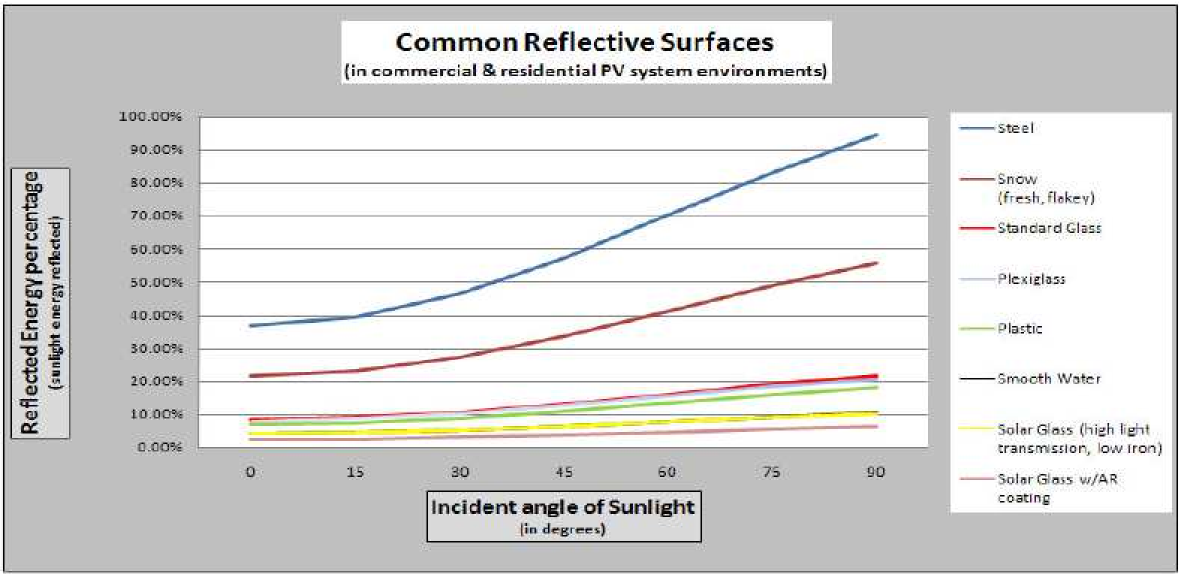

Figure 3: Reflection of common surfaces (source: SunPower [2])

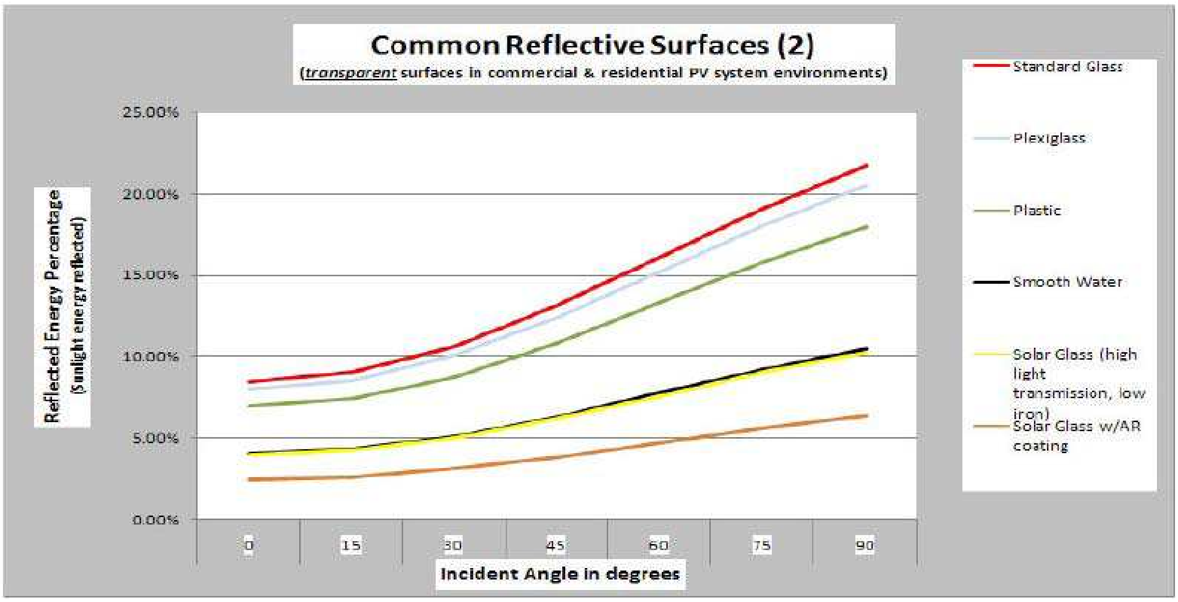

Figure 4: Reflection of common surfaces (source: SunPower [2])

The reflection curves for the surfaces analysed by Sunpower show a change in trend between 20 and 30 degrees of deviation from normal incidence. This change is less marked for solar glass as shown in the figures above.

The thin film PV module manufacturer First Solar hit on the same ideas regarding PV module reflectivity [4] and potential hazard to air traffic, concluding that "PV panels near airports present no greater hazard due to reflected sunlight than parking lots filled with cars. In general, light is specularly reflected from any smooth surface where the index of refraction is different from that of air. The intensity of the reflection will be dependent on the angle between the sun and the solar panel, and the index of refraction of the panel. The index of refraction of air is 1 and un-treated soda lime glass is ~1.5. Multiple reflections from the front and back surface of the glass are not apparent in solar panels since they are designed to absorb light and convert it into electricity. At normal incident First Solar panels reflect about 4 percent of incoming light, following Fresnel Equations. Car windows, on the other hand, reflect from the front and back surface of the glass increasing the intensity; causing about 7.7 percent of the light to be reflected at near normal incident." This result is in line with Sunpower's findings above.

Reflectivity of the metal stands and frames is possible and can be subdued, if necessary, by painting the frames with a colour with low reflective properties and/or by using frameless PV panels.

It is further noted that when surfaces are wet, reflective properties can clearly alter. However, as solar farm components are tilted, there is little risk of pooling of water and therefore these conditions are not expected to alter the reflective properties of the panels.

1.2 Glint and Glare from PV Systems

There is a perceived issue of glint and glare surrounding the reflectivity of a PV solar panel. As a result of the perceived reflection levels, there is a concern of possible distractions to motorists, aircraft and the hazard of eye damage. However, the following case studies have been found to demonstrate that the impact is minor and can be mitigated.

a) Case Study: Panoche Valley

> A glint and glare study on the Panoche Valley Solar Farm Project, US [1] was conducted early this year, including 3D simulations of the glint and glare effect on nearby key view points. The PV plant under study is an open-field ground-mounted system at fix tilt like the one proposed at Caddington, UK. The review of the simulations determined that glint and glare will be visible to motorists but limited to those with east and northeastern views in the morning, and west and northwestern views in the evening, for a brief period of time in the early morning or late evening during summer months only.
>
> In the case of Caddington this effect is expected to be reduced to a minimum on account of the hedgerows around the site (at a minimum height of 3 meters) and the different patches of more mature woods surrounding the site.
>
> Regarding air traffic, the same study explains that private aircraft may cross the project area and potentially experience glint and glare from solar operations and that these occurrences were dependent on altitude, relationship to the project area and panel position. They concluded, however, that glint and glare to aircraft should not be an issue as several large scale solar projects have been completed and constructed at or near major airports without incident as it is commented in a further paragraph.

b) Case Study: Nellis PV plant and other airports

> The largest PV system (14.2 MW peak, see Appendix) constructed on the grounds of an airport facility is Nellis (Nevada), where the PV solar panels are located just south of active US Air Force runways. Nellis and NV Energy completed a study of solar refraction from flat plate PV modules [5]. The purpose of the study was to quantify glare from a flat plate solar PV system (SPVS). The study utilized a worst case scenario approach based upon information available at Nellis, including using recorded Nellis data for intensity; calculating

glare experienced by pilots if reflected angle was directly into a pilot's eyes for every hour of the year; comparing the SPVS to known ocular safety metrics. Comparison of the proposed SPVS was made with known data points such as the reflectivity of other common surfaces pilots may see upon approach, Federal Aviation Administration (FAA) regulations and published reports, and example flat plate panel SPVS installed at other airports.

The results of the study indicated that under the worst case scenario, there would be a slight potential for an after image or flash glare resulting from reflected direct sunlight. This after image or flash glare is similar to the potential for flash glare due to water and less than that due to weathered, white concrete and snow. Since this represented the worst case scenario, it would be expected that pilots would typically mitigate glare using glare shields and sunglasses; these typically reduce radiation by approximately 80 percent and would make any reflected sunlight from solar panels insignificant.

In fact, Solar PV arrays have been approved and constructed on the grounds of airport facilities, which are exceptionally sensitive to reflectivity. Eventual PV module reflectivity can be mitigated with appropriate sitting. GLGH has found a large number of examples of PV systems having been built at or near airport facilities worldwide. Ten of such systems are shown in the Appendix section, where basic data of each installation are given.

1.3 Applicable Regulations

The most developed regulation regarding glint and glare issues from solar systems at airport areas is that from the US Federal Aviation Administration (FAA). A brief outline of the FAA's guidelines and requirements is set out below.

The FAA Regulations, Part 77 [6] provides the FAA with broad authority for protecting the US airspace. The requirements under Part 77 include the triggers for FAA review of solar projects at or in the vicinity of an airport.

The evaluation of a project's consistency with aviation and airport activities is best conducted in partnership with the FAA, using the Airport Layout Plan (ALP) as a starting point.

All solar projects at airports must then submit to FAA a Notice of Proposed Construction Form 7460 under Part 77 to ensure the project does not penetrate the imaginary surfaces around the airport or cause radar interference or glare. Even if a project will be roof mounted and the height will be below an existing structure such as a building or light fixture, the sponsor must still submit a case for analysis to ensure that the project does not cause glare or interfere with radar installations. The FAA will conduct an aeronautical study of the project and will issue a determination of hazard or no hazard. The timeline for these approvals is typically 30-45 days.

Once the FAA completes the aeronautical study, a determination will be made regarding the impact to air navigation. The determination will be one of the following: a No Hazard Determination, a Conditional Hazard Determination, or a Final Hazard Determination. Airport sponsors for currently operating solar PV projects in the US that have submitted Form 7460 to the FAA for an airspace review have obtained a "No Hazard Determination."

For off-airport projects, local governments, solar developers, and other stakeholders in the vicinity of an airport have the responsibility to inform the FAA about proposed projects so that the agency can determine if the project, especially if large, presents any safety or navigational problems. GLGH understands that this would be the case for the Caddington PV plant in the UK.

Like other development projects, solar facilities are also subject to the national and local environmental laws like the Town and Country Planning (Environmental Impact Assessment) regulations in the UK or the National Environmental Policy Act (NEPA) in the US.

1.4 Conclusion

From the findings of this review it is considered reasonable to conclude that the proposed PV system will not cause a substantial increase in the solar radiation reflectivity compared to other grass, soils, roads and pathways present in and around the site.

Unlike Concentrating Solar Power (CSP) systems, where sunlight is collected in mirrors, focused and redirected to an engine, PV panels are designed to absorb solar energy and convert it directly to electricity. It is noted that Caddington will use PV panels only and thus potential reflectivity issues particular to CSP systems will be non-existent. For reference, potential glint and glare hazards from CSP systems are further analysed in [7].

APPENDIX – PV SYSTEMS AT OR NEAR AIRPORTS

Nellis Air Force Base

Location: Nellis Air Force Base, Nevada, US
Installed Power: 14.2 MWp
Completion: December 2007
System type: Ground-mounted, single-axis polar trackers
(Source: [8],[9])

Source: Nellis US AFB website [10].

Figure A.1: Bird's eye view of the PV system at Nellis.

Source: Sunpower Co. website [8].

Figure A.2: Detail of the trackers installed at Nellis.

Denver International Airport

Location: Denver International Airport, Colorado, US
Installed Power, completion date and system type:

Phase 1	2 MW	August 2008	Single-axis tracker
Phase 2	1.5 MW	December 2009	Ground-mounted fix tilt
Phase 3	4.4 MW	2011 (expected)	Ground-mounted fix tilt

(Source: [11])

Source: Quanta Renewable Energy website [12].

Figure A.3: Bird's eye view of the PV system at Denver International Airport.

Source: Quanta Renewable Energy website [12].

Figure A.4: Detail of the trackers at Denver International Airport (phase 1).

San Francisco International Airport

Location: San Francisco International Airport, California, US
Installed Power: 600 kWp
Completion: 2007
System type: Rooftop-mounted system
(Source: [13])

Source: Blue Oak Energy website [13].

Figure A.5: Bird's eye view of the rooftop-mounted PV system at San Francisco International Airport.

Fresno Yosemite International Airport

Location: Fresno, California, US
Installed Power: 2.4 MWp
Completion: September 2008
System type: Single-axis trackers
(Source: [14])

Source: Airport technology [15].

Figure A.6: Bird's eye view of the PV system at Fresno Yosemite International Airport.

Source: Airport technology [15].

Figure A.7: Detail of the trackers at Fresno Yosemite International Airport.

Oakland International Airport

Location: FedEx Hub, Oakland International Airport, California, US
Installed Power: 904 kWp
Completion: Summer 2005
System type: Rooftop-mounted system
(Source: [16])

Source: Sharp [16].

Figure A.8: Bird's eye view of the FedEx hub at Oakland International Airport.

Source: Fedex website [17]

Figure A.9: Close up view of the rooftop mounted system at FedEx hub.

Munich Airport

Location: Access road to Munich Airport, Freising, Germany
Installed Power: 500 kWp
Completion: Summer 2005
System type: Sound barrier
(Source: [18])

Source: Isofoton [19].

Figure A.10: Sound barrier along the access road to Munich Airport (E53 highway).

Zurich Airport

Location: Zurich Airport, Zurich, Switzerland
Installed Power: 290 kWp
Completion: 2003
System type: BIPV system
(Source: [19])

Source: Isofotón [19].

Figure A.11: BIPV system at Zurich Airport.

Changi Airport

Location: Budget Terminal, Changi Airport, Singapore
Installed Power: 250 kWp
Completion: February 2010
System type: Rooftop-mounted system
(Source: [20])

Source: Phoenix Solar [20].

Figure A.12: Rooftop-mounted system at Changi Airport, Singapore.

Boston Logan Airport

Location: Terminal B, Logan Airport, Boston, Massachusetts, US
Installed Power: 197 kWp
Completion: June 2009
System type: BIPV, Solar Parking Lots
(Source: [21])

Source: Massport [22]

Figure A.13: Solar trees on parking garage at Boston's Logan Airport.

Stuttgart Trade Fair Centre

Location: Neuen Messe Stuttgart, Germany
Installed Power: 3.8 MWp
Completion: February 2009
System type: Rooftop-mounted system
(Source: [23])

Source: Planet Energy [23]

Figure A.14: Detail of the rooftop PV system at the New Trade Fair Centre in Stuttgart.

Source: Sunstrom [24]

Figure A.15: Aerial view of Stuttgart Airport – the Trade Fair Centre is located on the left hand side.

REFERENCES

[1] Pfaff J., "Solargen Energy – Panoche Valley Solar Farm Project – Glint and Glare Study", Power Engineers Inc., May 21, 2010.

[2] SunPower Co. Technical Support, "Technical Notification: SunPower Solar Module Glare and Reflectance", September 29, 2009.

[3] Hall J.T. and Cottrell F.D., "Method for testing solar cell assemblies and second surface mirrors by ultraviolet reflectometry for susceptibility to ultraviolet degradation", Patent 6359212, March 19, 2002.

[4] First Solar, "Solar Panel Installations at Airports", September 10, 2009.

[5] U.S. Air Force, "Draft Environmental Assessment – Outgrant for Construction and Operation of a Solar Photovoltaic System in Area I, Nellis Air Force Base, Clark County, Nevada", October 2010.

[6] Federal Aviation Regulations, Part 77, Objections Affecting Navigable Airspace, March 1993. Available at https://oeaaa.faa.gov/oeaaa/external/content/FAR_Part77.pdf, last accessed November 30, 2010.

[7] Ho C.K., Cheryl M.G. and Diver R.B., "Hazard Analysis of Glint and Glare from Concentrating Solar Power Plants", SolarPaces 2009, Berlin Germany. Ph.D., Sandia National Laboratories, Solar Technologies Department, P.O. Box 5800, Albuquerque, NM 87185-1127, USA.

[8] SunPower Co., "Nellis Air Force Base builds largest solar PV power plant in North America with SunPower – Case Study", www.sunpowercorp.com, last accessed November 29 2010.

[9] "World's largest photovoltaic PV plants", www.pvresources.com, last accessed November 29 2010.

[10] Nellis US Air Force Base website, http://www.nellis.af.mil, last accessed November 29 2010.

[11] Powergen website, http://www.powergenworldwide.com, last accessed November 29, 2010.

[12] Quanta Renewable Energy website, http://www.quantarenewable.com, last accessed November 29, 2010.

[13] Blue Oak Energy website, http://www.blueoakenergy.com/, last accessed November 29, 2010.

[14] "Fresno Airport Case Study", Solar Power Partners, Inc, 2008. Available at www.solarpowerpartners.com.

[15] Airport technology website, http://www.blueoakenergy.com/, last accessed November 29, 2010.

[16] "Sharp Solar Power System Installed on Fedex's Oakland International Airport", Sharp Electronics Corporation, 2008.

[17] FedEx website, http://mediacenter.fedex.designcdt.com/node/216, last accessed November 29, 2010.

[18] Grottke M. et al "PV Soundless – World Record along the Highway – A PV Sound Barrier with 500 kWp and Ceramic-based PV Modules", Paris, 2004.

[19] Isofoton website, www.isofoton.com, last accessed November 29, 2010.

[20] Technical Brochure, Phoenix Solar, available at www.phoenixsolar.de, last accessed November 29, 2010.

[21] Broadway Electrical Co., Inc. "Logan Solar Project Article – Boston Globe", available at http://broadelec.com/projects/logan.html, last accessed November 30, 2010.

[22] Massport, Independent Public Authority which develops, promotes and manages airports, the seaport and transportation infrastructure in the Massachussets State, US, www.massport.com, last accessed November 30, 2010.

[23] Planet Energy website, www.planet-energy.de/presse_fotos.php, last accessed November 30, 2010.

[24] Sunstrom website, www.sunstrom.de, last accessed December 1, 2010.