Siting Solar Photovoltaics at Airports

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ABSTRACT

Airports present a significant opportunity for hosting solar technologies due to their open land; based on a 2010 Federal Aviation Administration study[1], the US Department of Agriculture, and the US Fish and Wildlife Service, there's potential for 116,704 MW of solar photovoltaics (PV) on idle lands at US airports.[2] PV has a low profile and likely low to no impact on flight operations.

This paper outlines guidance for implementing solar technologies at airports and airfields, focusing largely on the Federal Aviation Administration's policies. The paper also details best practices for siting solar at airports, provides information on the Solar Glare Hazard Analysis Tool[3], and highlights a case study example where solar has been installed at an airport.

1. BACKGROUND

Airports and airfields present a significant opportunity for hosting solar technologies due to large amounts of open land. A study conducted by the Federal Aviation Administration (FAA), U.S. Department of Agriculture (USDA), and U.S. Fish and Wildlife Service (USFWS) stated that in 2010 there were approximately 15,000 airports in the United States.[4] Of those, 2,915 were considered significant to national air transportation and are included in the National Plan of Integrated Airport Systems. The authors estimated there are approximately 3,306 square kilometers (816,930 acres) of grassland within the 2,915 significant airport properties in the contiguous United States.[5] The authors contend that grasslands are representative of idle lands at airports. Assuming that 7 acres of grassland could host 1 MW of fixed-axis (non-tracking) photovoltaics (PV), there's potential for 116,704 MW of PV on idle lands at airports in the United States. These calculations exclude small and military airfields, and thus are conservative.

2. SOLAR PHOTOVOLTAICS

PV arrays convert sunlight to electricity. The systems require very little maintenance, make no noise, and operate without moving parts and without producing air pollution or greenhouse gases. Arrays can be mounted on buildings and structures (such as parking garages) or ground-mounted on supporting poles or racks. The arrays produce direct current (DC), which can be conditioned into grid-quality alternating current (AC) electricity or used to charge batteries. A typical PV cell converts approximately 14% of the solar energy striking its surface into usable electricity.[6]

The amount of electricity a system produces depends on the system type, orientation, and the available solar resource (the amount of the sun's energy reaching the earth's surface, which varies across the United States). A higher solar resource means more of the sun's energy is reaching the surface, which is optimal for PV system performance. Resources are highest in the Southwest, and fairly high in the western states, Texas, and Florida.

The cost of PV-generated electricity has dropped 15- to 20-fold in the last 40 years. Grid-connected PV systems sell for \$0.20/kWh–\$0.32/kWh in 2011, or about \$5/W_p \$8/W_p, including support structures and power conditioning equipment. Costs reported for PV projects are decreasing rapidly, so a local solar installer may be the best source of current cost information. Operation and maintenance costs are reported at \$0.008/kWh produced, or at 0.17% of capital cost without tracking and 0.35% with tracking.[7] The systems are very reliable and last 20 years or longer.[8]

PV system installations at airports cost marginally more than those for systems sited in other locations. Additional costs could be incurred for project planning and coordination with FAA and related glare/glint studies.

A variety of financing mechanisms help facilitate PV system installations. Third-party financing, in which an entity finances, owns, and operates the system, is a mechanism for installing a PV system for little or no capital and is most often utilized for commercial- or utility-scale systems. These include power purchase agreements, energy savings performance contracts, and utility energy services contracts.[9] The FAA also operates the Voluntary Airport Low Emissions (VALE) program, which helps airport sponsors meet their state-related air quality responsibilities under the Clean Air Act.[10] Through VALE, airport sponsors can be eligible for funds to help support the procurement and installation of PV systems.

3. GUIDANCE FOR INSTALLING PV AT AIRPORTS

The FAA regulates and oversees all aspects of American civil aviation.[11] Generally, solar projects are reviewed at the regional level; FAA Headquarters becomes involved only if a project requires additional resources or presents a complex problem.[12]

The FAA has an interest in solar energy for many reasons. It supports modernization and improved efficiency, and as such, supports appropriate solar projects. The FAA is sometimes a PV operator, generally at remote or off-grid facilities. It ensures solar projects are sited properly and do not cause safety problems for aviation or interfere with aeronautical and airport activities. Specifically, the FAA wants to ensure solar systems do not create glint (a momentary flash of bright light) or glare (a continuous source of bright light). The FAA has determined that glint and glare from typical ground-mounted solar energy systems could have an ocular impact to pilots and/or air traffic control facilities and compromise the safety of the air transportation system.[13]

3.1 Technical Guidance for Evaluating Selected Solar Technologies on Airports

In November 2010, the FAA released a document titled *Technical Guidance for Evaluating Selected Solar Technologies on Airports*.[14] The FAA created this document to provide a readily usable reference for FAA technical staff who review proposed airport solar projects and for airport sponsors that may be considering solar installations. It addresses solar technology, electricity grid infrastructure, FAA safety regulations, financing alternatives, incentives, case studies, etc.[15]

This is currently the only publically available and federally issued guidance for installing solar technologies at airports; it is a good reference for all relevant stakeholders. It includes a checklist of FAA procedures to ensure the systems are safe and pose no risk to pilots, air traffic controllers, or airport operations.

A note on the initial page of the report reads:

> As of October 23, 2013, the FAA is reviewing multiple sections of the *Technical Guidance for Evaluating Selected Solar Technologies on Airports* based on new information and field experience, particularly with respect to compatibility and glare. All users of this guidance are hereby notified that significant content in this document may be subject to change, and the FAA cautions users against relying solely on this document at this time. Users should refer instead to the interim policy (http://federalregister.gov/a/2013-24729).

The interim policy is detailed below; however, it states that in late 2013 the FAA planned to publish an update to the November 2010 *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. This update will include the standards for measuring glint and glare outlined in the interim policy. It will also provide enhanced criteria to ensure the proper siting of a solar energy installation to eliminate the potential for harmful glare to pilots or air traffic control facilities.[16] As of May 27, 2014, the FAA has not yet issued an update to the technical guidance.

3.2 Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports

On Oct. 23, 2013, the FAA posted a notice on the Federal Register, titled *Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports*. The notice states that in 2012, the FAA partnered with the US Department of Energy "to establish a standard for measuring glint and glare, and clear thresholds for when glint and glare would impact aviation safety. The standards that this working group developed are set forth in this notice."[17] The notice also reads:

> The FAA is adopting an interim policy because it is in the public interest to enhance safety by clarifying and adding standards for measuring ocular impact of proposed solar energy systems. FAA will consider comments and make

appropriate modifications before issuing a final policy in a future Federal Register Notice. The policy applies to any proposed solar energy system that has not received unconditional airport layout plan (ALP) approval or a "no objection" from the FAA on a filed 7460-1, Notice of Proposed Construction or Alteration. The FAA expects to continue to update these policies and procedures as part of an iterative process as new information and technologies become available.[18]

A solar energy system located on an airport that is not federally obligated or located outside the property of a federally obligated airport is not subject to this policy. Proponents of solar energy systems located off airport property or on nonfederally obligated airports are strongly encouraged to consider the requirements of this policy when siting such systems.

Considerations outlined in the notice include sponsor requirements to:

- Notify the FAA of its intent to construct *any* solar installation, including the intent to permit airport tenants, such as federal agencies, to build such installations.[19]
    - Request FAA review and approval to depict proposed solar installations that will either be ground-based installations or that are not ground-based but substantially change the footprint of a colocated building or structure (i.e., a roof-mounted system that increases the footprint of an existing building or structure) on its ALP, before construction begins.
    - Comply with the policies and procedures outlined in the Interim Policy to demonstrate to the FAA that a proposed solar energy system will not have an ocular impact that compromises the safety of the air transportation system.[20]
    - When siting a proposed solar energy system, limit the potential for inference with communication, navigation, and surveillance (CNS) facilities by ensuring that solar energy systems remain clear of the critical areas surrounding CNS facilities.

3.2.1 Standards for Measuring Ocular Impact

The FAA prescribes the solar glare hazard analysis plot as the standard for measuring the potential ocular impact of any proposed solar energy system on a federally obligated airport. The airport sponsor must reference Solar Glare Ocular Hazard Plot and utilize the associated Solar Glare Hazard Analysis Tool (SGHAT)[21] to demonstrate the potential for glare and glint resulting from a proposed solar project. Nonfederally obligated airports or solar systems adjacent to airports are also encouraged (but not required) to utilize this tool. The FAA will consider the use of alternative tools or methods case-by-case. [22]

For an airport sponsor to obtain FAA approval to revise an ALP to depict a solar installation and/or a "no objection" to a Notice of Proposed Construction Form 7460-1, the sponsor must demonstrate the proposed solar energy system meets the following standards:[23]

- No potential for glint or glare in the existing or planned airport traffic control tower (ATCT) cab
- No potential for glare or "low potential for after-image" along the final approach path for any existing or future landing thresholds (including any planned interim phases), as shown on the current FAA-approved ALP. The final approach path is defined as 2 miles from 50 feet above the landing threshold using a standard 3° glide path.

As part of the analysis, ocular impact must be examined over the entire calendar year in 1-minute intervals, from when the sun rises above the horizon until the sun sets below the horizon.[24]

SGHAT was designed to determine whether a proposed solar energy project would have the potential for ocular impact. The tool was developed by the FAA and Sandia National Laboratories (SNL) to provide a quantified assessment of (1) when and where glare will occur throughout the year for a prescribed solar installation and (2) potential effects on the human eye at locations where glare occurs.[25] This free, web-based tool uses a Google map interface and requires a user to register.

The user inputs the location of the proposed site, draws an outline of the proposed solar array, and provides additional information about the solar system, including height and reflectance. The user specifies observer locations (usually the ATCT) or flight paths. A screenshot of the input page is shown in Fig. 1.

If the tool finds glare, it calculates the retinal irradiance and subtended angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a plot that specifies when glare will occur throughout the year; color codes indicate the potential ocular hazard. The tool can also predict relative energy production and evaluate alternative designs, layouts, and locations to identify configurations that maximize energy production and mitigate glare impacts.[26]

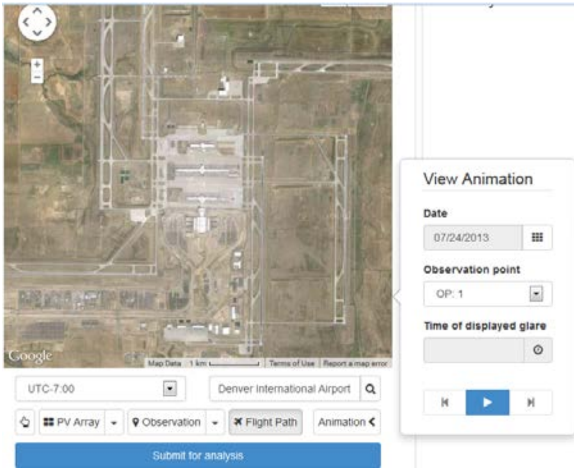

Fig. 1: Input page of SGHAT. Source: SGHAT

The SGHAT user's manual provides detailed information about the needed inputs, assumptions used in calculations, and interpreting outputs. A few important assumptions and limitations are outlined here:

- The software is applicable to flat reflective surfaces only. Focused mirrors, such as parabolic troughs or dishes, cannot be simulated in SGHAT.
- SGHAT simulates fixed systems only; it does not currently apply to tracking systems.
- The software assumes the PV array is aligned with a plane defined by the total heights of the coordinates outlined in the Google map.
- SGHAT does not consider manmade or natural obstacles such as trees, hills, and buildings between the observation points and the prescribed solar installation that may obstruct observed glare.
- The software currently uses a user-prescribed constant reflectance for the solar modules. The reflectance increases with increasing incidence angle.[27]

3.3 Siting Considerations for Airports

In addition to the aforementioned requirements, other considerations need to be taken into account when siting solar systems at or near airports. Systems should also be placed an appropriate distance from the runway and adhere to relevant safety and fire measures.

3.3.1 System Performance

An ideal solar installation would be situated in an unshaded, south-facing location with an optimum tilt angle (generally equal to latitude; see third bullet for more information). Not all sites are suitable for solar technologies. A few rules of thumb are helpful in determining when solar technologies are appropriate.

- Identify an unshaded area for solar PV installation, particularly during the peak sun hours of 9 a.m.–3 p.m. Shade caused by trees, nearby buildings, and roof equipment or features such as chimneys will reduce the output of a solar panel.
- It is best to orient fixed-mount panels due south in the northern hemisphere. Siting panels so they face east or west of due south will decrease energy production. However, that effect varies by location and could be minimal.
- In the area of Boulder, Colorado, for example, the losses due to orientation are about 4% for a panel facing 45° east of south and about 10% for one facing 45° west of south (due to the mountains to the west).[28] Such an orientation is not ideal because it reduces energy production; however, it may be necessary due to land availability constraints or to minimize or alleviate glint or glare.
- For locations in latitudes less than 20º, the optimal tilt angle for achieving the highest performance from a fixed-mount PV panel is equal to the latitude of a location. At higher latitudes, the correlation is not valid. A previous study analyzed the annual solar resource data for different latitudes.[29] At a location of 40° north latitude, an optimal tilt varies from 30° to 35° to maximize the annual energy production. Fixed-mount solar panels can be flush- or tilt-mounted on roofs, pole mounted on the ground, or integrated into building materials, such as roofs, windows, and awnings. However, a tilt angle equal to latitude is not always feasible because of factors such as roof pitch, wind or snow loading, or a need to minimize or alleviate glint and glare. The impact of a nonideal tilt angle varies by location and could be minimal. The energy production of PV systems at various orientation and tilt angles can be calculated by tools such as PVWatts.[30]

3.3.2 Minimizing Glare and Glint

Aside from these strategies, physical methods may reduce reflection from panels and the associated glare and glint. These include the application of antireflective coatings[31] and/or texturing[32] to the panels. Neither has discernable effects on system performance but could help minimize reflection.

3.3.3 Wildlife Impact

Very little information is available quantifying the potential impact of solar systems on wildlife, or of wildlife on solar system installations, at airports. The previously referenced study conducted by the FAA, USDA, and USFWS states "airports offer one of the few land uses where reductions in wildlife, abundance, and habitat quality are necessary and socially acceptable, due to risk of wildlife collisions with aircraft."[33] However, when siting solar systems at airports, it is important to mitigate wildlife attractants, such as perches or shade. A study by the USDA National Wildlife Research Center (NWRC) aimed to evaluate the hazard level posed by PV facilities to aircraft, compare bird and mammal use of the two land cover types (PV and open land), and provides findings and guidance to the FAA.[34] FAA guidance does not yet touch on wildlife impact or mitigation strategies.

The NWRC study compared open land with PV-covered land at airports in five US locations. The results indicated most observations at PV arrays were of perched birds. Birds do not present risk to aircraft when they are perched, either on or under panels. However, it is unclear if the PV arrays are drawing birds from outside the airport or if the observations were simply local birds that would be present regardless of the PV. Very little information is available on the effects of solar energy development on wildlife, which are generally assumed to be negative due to habitat destruction and modification. This is in contrast to the FAA, USDA, and USFWS study, which indicated solar system development is compatible with airports due to the need to reduce wildlife abundance and habitat quality. The USDA NWRC study noted that the observed low use of PV arrays by birds for perching or sheltering should facilitate solar development at airports, especially in regions where solar development is most promising. Furthermore, the study stated that "establishment of PV arrays could play a major role in efforts to design and operate "greener" airports."[35]

Strategies can be used to minimize the potential for birds being drawn to the solar system for perching or sheltering. These could include spikes or other such systems on top of each panel to limit birds' ability to perch, and potential closures or barriers behind panels to decrease the ability of birds or wildlife to shelter there.

4 INSTALLATIONS

Airport lands are a relatively new application of solar PV; however, PV has been implemented successfully in dozens of airports worldwide; for example:

- **Denver International Airport (DIA):** DIA, located in Denver, Colorado, has installed approximately 8 MW of solar PV on its property. In 2012, DIA was the 11th busiest airport in the world as designated by passenger traffic. The solar PV installed on the airport land meets approximately 6% of the annual electricity consumption of the airport overall.

- **Indianapolis International Airport in Indianapolis, Indiana:**[36] Operating as of 2013, the 12.5-MW system sits at the main airport exit.

- **Fresno Yosemite Airport in Fresno, California:**[37] The 2-MW system was constructed in 2008, and energy production meets approximately 60% of the airport's energy demand.
- **Gatwick Airport in London, England:**[38] The 50-kW system was installed in 2012 just 150 meters from the main runway. The installation company spent about six months negotiating the siting with the United Kingdom National Air Traffic Service and the Civil Aviation Authority to ensure the solar panels were not disruptive to the airport.
- **Birmingham Airport in Birmingham, England:**[39] Installed in 2011, the 50-kW system was installed on the roof of the terminal.
- **Athens International in Athens, Greece:**[40] In October 2012, the Athens airport completed installation of an 8-MW system on site. To ensure safe operation, a pilot PV unit was installed at the airport's train station in 2004 to provide data for the newest installation.
- **Ancona Falconara Airport in Falconara Marittima, Italy:**[41] The buildings surrounding the airport control tower have 45 kW of solar PV installed. Prior to the project, an analytic study was completed that looked at the sun and landing aircraft positions to ensure comfort of pilots and staff in the control tower.

4.1 Case Study Example

The Manchester-Boston Regional Airport in Manchester, New Hampshire, installed a solar 530 kW DC PV system on the roof of an existing six-story parking garage in August 2012. The system was designed to save about $100,000 in electric utility costs annually and more than $2,000,000 over the 25-year life of the project.[42] The $3.5-million project was funded under the FAA's VALE program, which covered 95% of the costs.[43,44]

Within the first month of installation, air traffic controllers started complaining about glare from the system (Fig. 2). The glare occurred for approximately 45 minutes each morning, as seen from the tower, which was located just west of the parking garage.[45] Neither aircraft pilots nor any airlines commented on glare issues. While the airport, contractor, FAA, and others sought a solution, approximately 25% of the system was covered with tarps.

Fig. 2: Solar PV at MHT. Source: SNL

Clifford K. Ho, Cianan A. Sims, and Julius E. Yellowhair from SNL used the SGHAT tool in 2012 to investigate possible solutions, and the results were published in the *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 2.0.*[46] The study recommended a less reflective PV panel to create a perceptible glare decrease. The report also recommended the panels be rotated 90° to the east, which would point away from the air traffic control tower. Additional possible solutions investigated for the south-facing problem panels included:

- Moving panels
- Altering the tilt
- Adding blinds to the tower.

Based on recommendations from SNL and a separate study by the Massachusetts Institute of Technology and the Volpe Center, the array is currently being reconstructed at 90° rotation from the current position, facing the east, to eliminate the glare problems. The rotation solution was verified with the SGHAT tool. Completion of the solar PV array facing east is expected in summer 2014 with an estimated decrease of efficiency by 10% for the new orientation.

4.2 Unique Airport Applications

Solar has several unique applications at airports; for example:

- **PV for runway deicing**: The University of Arkansas is developing a system that utilizes PV as the energy source for deicing runways instead of plowing or applying chemicals. The solar panels convert the sunlight into energy, which is then stored in a battery bank. Energy is then sent to electrodes imbedded in the cement to melt the ice to keep the slab above freezing temperatures. Because snow and ice removal requires expensive equipment, large quantities of energy, and a high number of personnel, the economics of solar PV for ice melt are promising.[47]
- **PV in building façades**: The Geneva airport recently installed solar PV in the balustrade in the main terminal. The panels are dye-sensitized solar cells encapsulated in glass, which were incorporated into the façade of the terminal. This unique application generates electricity, and the new windows can improve the energy efficiency of the space without sacrificing daylighting to the interior space.[48]
- **PV for airport lighting**: The US Department of Defense is utilizing solar-powered obstruction lights at forward-operating bases. The installation of these lights is fast and easy; trenching, wiring, and disruptions in aviation operations are unnecessary. Solar-powered lights can be used for approach, runway, and taxiway lights; wind cones; precision approach path indicators; approach lights; and elevated runway guard lights.[49]

5. CONCLUSIONS

Airports present a significant opportunity for hosting solar technologies due to large amounts of open land. In particular, solar PV has a low profile and the potential to have low to no impact on flight operations.

Solar systems have successfully been implemented at dozens of airports worldwide. There have also been less successful installations where inadequate planning and analysis led to insurmountable glint and glare issues. It is clear successful implementation of solar systems depends on detailed planning and siting studies, including considerations for glint and glare potential, wildlife impacts, system performance, and safety. With sufficient analysis in the planning stages, solar systems should continue to be synergistic with airport operations.

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(19) The sponsor must notify FAA by filing FAA Form 7460-1, "Notice of Proposed Construction or Alteration," under 14 CFR Part 77 for a nonrulemaking case

(20) This process enables the FAA to approve amendment of the ALP to depict certain solar energy projects or issue a "no objection" finding to a filed 7460-1 form

(21) The Solar Glare Hazard Analysis Tool is available at: https://share.sandia.gov/phlux

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