Airport Solar PV Implementation Guidance Document

for Asia-Pacific & Middle East Airports

Contents

Figures

Disclaimer

Unit 13, 2/F, HKIA Commercial Building, 1 Sky Plaza Road,

Hong Kong International Airport, Hong Kong

Tel: (852) 2180 9449

Email: communications@aci-asiapac.aero | Website: www.aci-asiapac.aero

Acknowledgement

This guidance document builds on airport operators' understanding of the key elements of solar PV implementation at airports.

ACI Asia-Pacific would like to express its gratitude to the ACI **Asia-Pacific Regional Environment Committee**, for their time and efforts in drafting the guidance document amid their busy daily work schedule at their respective airports.

Special thanks to **Delhi International Airport Ltd** and **Malaysia Airports Holdings Berhad** for leading and steering the development of this guidance document.

Executive Summary

Solar is one of the most convenient source of renewable energy for Airports. The plain topography, presence of flat building roofs and nature of Airport operational requirements favors solar Photovoltaic (PV) as compared to other sources of renewable energy. Solar PV projects are also a visible means to demonstrate the implementation of environmental policies.

PV systems are one of the top applicable renewable energy opportunities for Airports, which have been installed at well over 100 airports worldwide and are well-suited for many existing airports designs due to the vast horizontal surfaces on which they can be installed. They can be mounted on terminal buildings or placed on unused or otherwise unproductive airport properties and lands. For many airports, PV systems constitute an economically and technically feasible way to increase the share of renewables in the energy supply and save costs.

However, for many airports, developing solar PV also leads to challenges in terms of planning and implementation due to lack of adequate knowledge and guidance. Developing PV systems in airports also requires special considerations and studies to be carried out to address some of the unique aviation challenges such as solar glare, compliance to operational requirements, safety implications etc. This guidance document intends to help airports in the region to determine technical & economic feasibility and smooth implementation of solar PV projects within their airport.

This guidance document lays out the project development process as a series of tasks namely; demand estimation, site selection, technology evaluation and plant design, financial viability assessment, selection of developer/supplier, plant construction, plant commissioning and operation & maintenance. Some project development activities may happen in parallel. It is up to the individual airports to oversee the activities and ensure they are coordinated and synchronised appropriately to achieve the desired outcome.

Few examples of airports solar installation case studies and parameters are featured at the end chapters.

Preface/Foreword

Use of renewable energies is one of the long-term objectives of natural resource sustainability and climate change mitigations across the world. Renewable energy projects are known to provide multiple benefits for an individual airport in addition to the environmental benefits stretching beyond the airport site itself. Issues related to renewable energy projects will include some, if not all of the following (1):

- Operational reliability and risk mitigation
- Price volatility management
- Legislative and regulatory compliance
- Greenhouse gas (GHG) emissions reduction objectives
- Corporate Social Responsibility (CSR) reporting and stakeholder communications
- Opportunities for additional revenue generation

Photovoltaic (PV) systems are one of the top applicable renewable energy opportunities for Airports. PV systems have been installed at well over 100 airports worldwide and are well-suited for many existing airports designs due to the vast horizontal surfaces on which they can be installed (1). They can be mounted on terminal buildings or placed on unused or otherwise unproductive airport properties and lands. For many airports, PV systems constitute an economically and technically feasible way to increase the share of renewables in the energy supply and save costs.

However, for many airports, developing solar PV also leads to challenges in terms of planning and implementation due to lack of adequate knowledge and guidance. Developing PV systems in airports also requires special considerations and studies to be carried out to address some of the unique aviation challenges such as solar glare, compliance to operational requirements, safety implications etc. (3). It is recommended that airports approach the operational and safety aspects of such a project in line with their change management processes.

This guidance document intends to help airports in the region to determine technical & economic feasibility and smooth implementation of solar PV projects within their airport.

Background

In 2010, energy supply sectors (including electricity and other energy) contributed about 35% of total anthropogenic Greenhouse Gas (GHG) emissions (2). With the rapid economic and development growth, the energy demand rises by 1.3% each year (Figure 1) and almost tripling to 2040. As highlighted in the Intergovernmental Panel on Climate Change (5) Special report published in October 2018, the world should take urgency and scale of actions in response to the limit the Global warming to 1.5 °C in align with the Paris Agreement. The latest IPCC report published in August 2021 reaffirmed that climate change is already affecting every region on Earth, in multiple ways. The changes we experience will increase with further warming. There is an urgent demand on shifting the traditional energy generation method to any sustainable energy source for climate change mitigation.

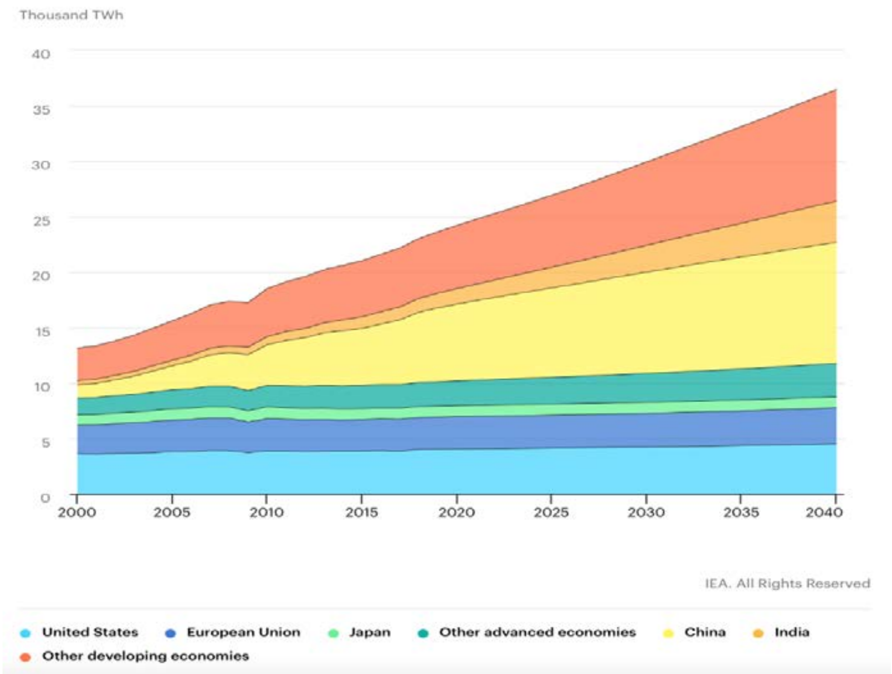


Figure 1: Global electricity demand by region in the Stated Policies Scenario, 2000-2040 (IEA, 2019) (4)

On airports decarbonisation journey, ACI Asia-Pacific has been promoting the use of renewable energy to airports since 2017. Results from ACI Asia-Pacific Environment Survey 2021 showed that 33% of the respondents implemented onsite solar energy, ranked 3rd in GHG / carbon reduction measures, for those airports with onsite solar energy measures. However, for majority of these airports, the solar energy generated only contributed to less than 10% of their total energy consumption.

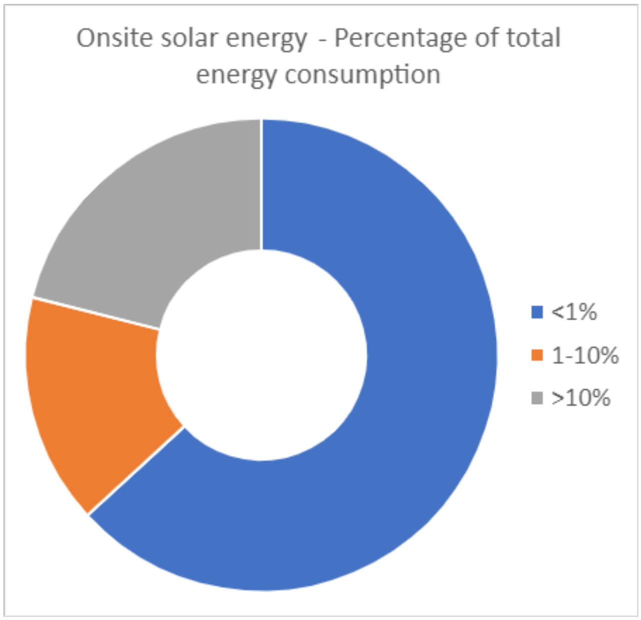


Figure 2: Onsite solar energy % of total energy consumption of respondents to ACI Asia-Pacific Environment Survey 2021

ACI Asia-Pacific Green Airports Recognition 2017 – Energy Management publication contains numerous best practices sharing in renewable energy utilisation applicable to other airports in the region and six of them were solar energy projects. At the Thirteenth Assembly of the ACI Asia-Pacific Regional Assembly, 24 April 2018, in Narita, Japan, airports resolve to:

- Consider using renewable energy to save costs and strive to achieve carbon neutrality in a cost-effective manner;
- Include waste management and renewable energy in the design of future expansions of existing terminal buildings and the construction of new buildings;
- Share innovative best practices in waste management and the use of renewable energy at airports; and
- Make use of relevant ACI and ICAO guidance materials on waste management and renewable energy.

At the 17th Assembly of the ACI Asia-Pacific Regional Assembly, 18 May 2022, in Singapore, airports resolve to urge Governments support to decarbonise electricity grid and facilitate renewable energy at airports.

Simple Tool to Determine Feasibility of Solar at Airports

In consultation with airports colleagues worldwide, Zurich Airport has developed a simple tool (6) for airports to determine feasibility of Solar PV at their airport, which provides first indication on the feasibility of a photovoltaic plant at airports with minimal information required such as available surface, some location specific information and local electricity costs.

Zurich Airport's tool considers feasibility mainly from investment aspects but not those related to the links with Airport Carbon Accreditation the promotion of environmental policies.

Introduction to Solar PV

Solar Photo Voltaic (PV) are best known as a method for generating electric power by using solar cells to convert energy from the sun radiation into a flow of electrons by the photovoltaic effect. Solar cells produce Direct Current (DC) electricity from sunlight which can be used to power equipment or to recharge a battery. Figure 2 (17) illustrates a typical solar PV system.

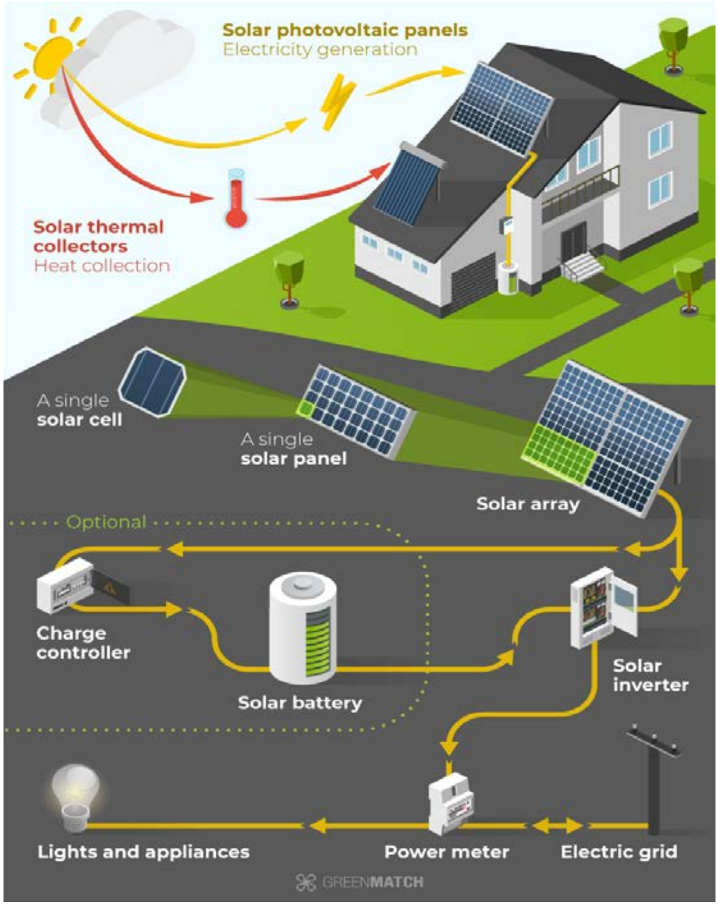


Figure 3: Solar PV system

Solar PV systems offer a number of significant benefits, including

- ✓ Solar is available everywhere in the world;
- ✓ Solar PV technologies are relatively simple, modular, easy to install and dismantle and scale up, and are having higher mobility than other RE;

- ✓ Solar can be installed on the roofs of buildings affording double usage of real estate;
- ✓ Compare to traditional conventional power plants using coal, oil and gas for power generation, solar power has no direct fuel costs to supply sustainable energy resources;
- ✓ An affordable energy source for decarbonisation.

Solar PV systems operate in the presence of direct or diffuse solar irradiation, it is possible to build solar PV systems anywhere, the greatest return is afforded in areas with high solar irradiation. To review the estimated solar energy available for power generation and other energy applications, the solar resource maps with indicative photovoltaic power potential (how many kWh of electricity can be produced from a 1 kWp free-standing c-Si modules, optimally inclined towards the Equator) are commonly used.

Figures 3 and 4 showed the solar resource maps for the Asia-Pacific Region. These figures indicated the average annual sum of PV electricity generation (PVOUT) varies between 1,400 to 2,000 kWh/kWp, which is relatively high and the region should take advantage of this solar resource to support sustainable airport development. Photovoltaic Electricity Potential – Asia is shown in Figure 4 ().

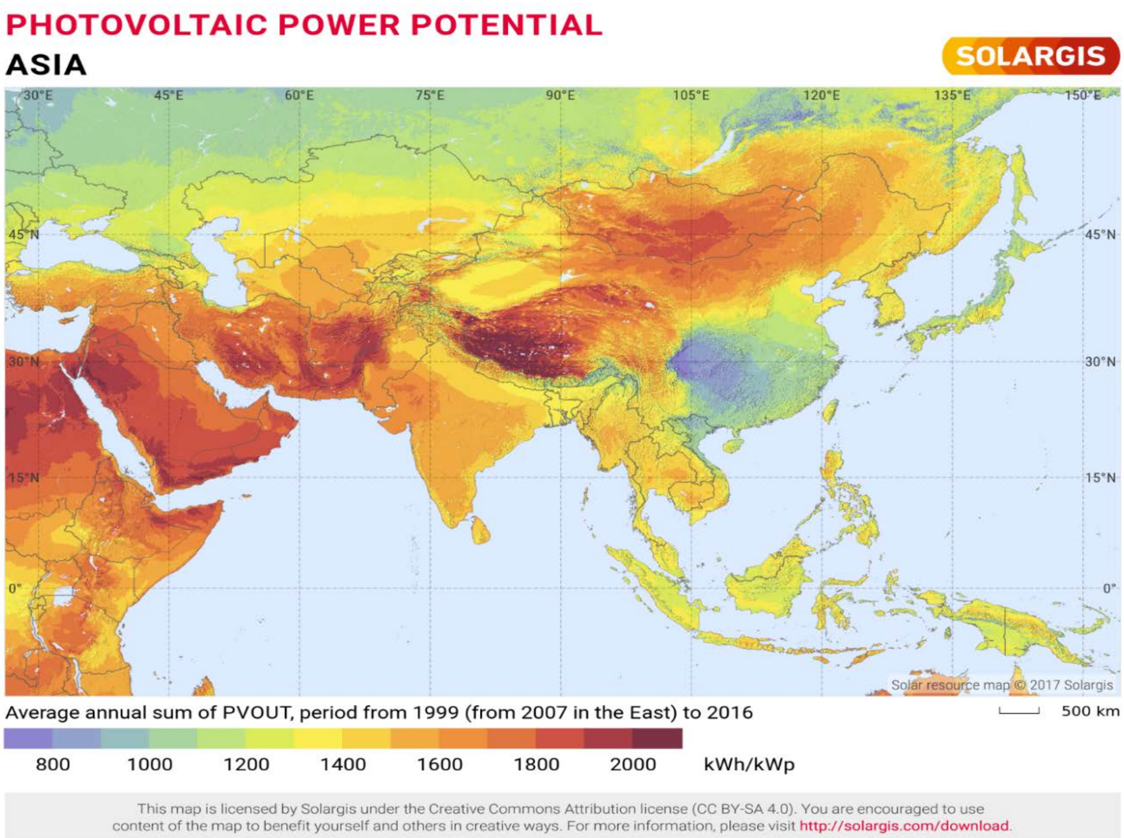


Figure 4: Photovoltaic Electricity Potential – Asia (Solargis, 2019) (18)

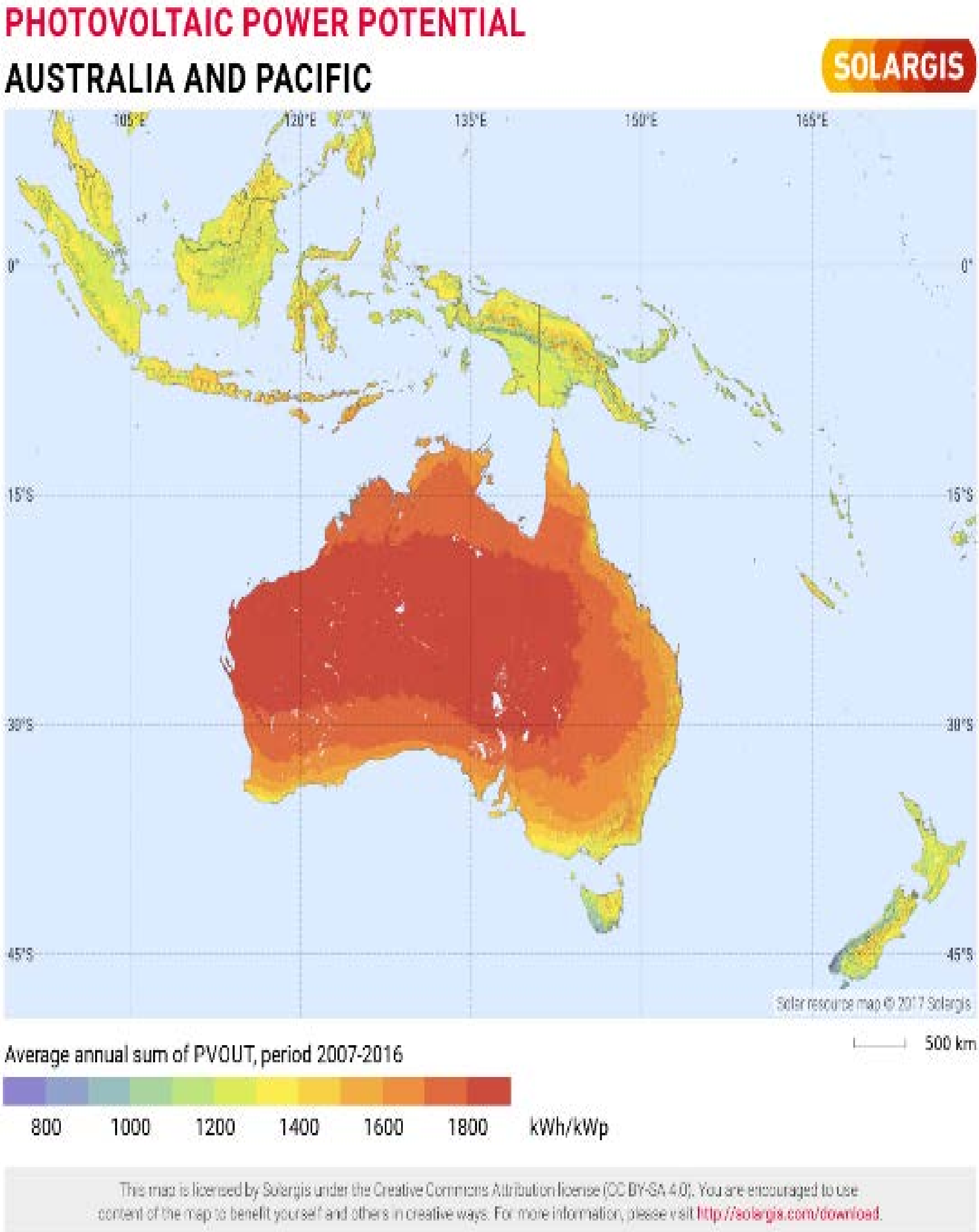


Figure 5: Photovoltaic Electricity Potential – Australia and Pacific (Solargis, 2019)

With the maturing solar PV system and technology, the 3rd generation of commercial PV module efficiency at AM (Air Mass coefficient) 1.5 had been highly improved from 15 to 41 percent nowadays. The solar PV Module costs had also decreased from $3.5 USD/W to $0.5 USD/W on average in the past 10 years (7).the decline in the cost of electricity from utility-scale solar photovoltaic (PV) projects since 2010 has been remarkable. Between 2010 and 2019, the global weighted average levelised cost of electricity (LCOE)[1] from solar PV fell **82%**, reaching USD 68.4 per megawatt-hour (MWh) (8).

Developing Solar Project in Airports

Solar is one of the most convenient source of renewable energy for Airports. The plain topography, presence of flat building roofs and nature of Airport operational requirements favors solar PV as compared to other sources of renewable energy. Solar PV projects are also a visible means to demonstrate the implementation of environmental policies. However, developing solar PV project within Airports are different from that of developing it elsewhere as it requires certain additional planning and design strategies, various studies and a multidisciplinary team of experts.

This guidance document, lays out the project development process as a series of tasks. Some project development activities may happen in parallel as well. It is up to the individual airports to oversee the activities and ensure they are coordinated and synchronised appropriately to achieve the desired outcome.

[1] The levelized cost of electricity, is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered.

Airport Solar project development process - Standard Task for implementation

Task 1: Demand estimation

- Assess required solar capacity by analysing/reviewing current and future electricity demand and supply at the airport to.

Task 2: Site selection

- Site selection considering site environmental & climatic condition, and compatibility with aviation specific requirements such as ICAO/FAA guidelines, government regulations etc.

Task 3: Technology evaluation and plant design

- Carry out an assessment to identify latest & suitable technology, plant components, plant design and layout, annual solar yield and site development requirements.

Task 4: Financial viability assessment

- Carry out Financial viability assessment of the PV plant and finalisation of business model to develop the plant.

Task 5: Selection of developer/supplier

- Selection of developer/supplier (vendor) for setting up the solar PV plant

Task 6: Plant Construction

- Plan, execute and complete Solar PV installation by the selected developer/supplier.

Task 7: Plant commissioning

- Ensure proper commissioning taking account of system specification, power evacuation facility requirement, legal compliance and safety requirements covering occupational safety, airport safety and aircraft safety etc.

Task 8: Operation & Maintenance

- Ensure operation and maintenance requirements are fulfilled as per Original Equipment Manufacturers (OEM) recommendations.

Task 1- Demand estimation

Intent: Assess required solar capacity by analysing and reviewing electricity demand and supply at the airport

Solar PV works best where the electricity can be generated and consumed within nearby proximity. This is one of the central reasons why airports are good locations for solar PV as airports are high energy consumption facilities. However, Airports need to evaluate the need the demand, supply opportunities before deciding to develop solar PV project.

1.1. Carry out electricity demand & supply gap assessment

1.1.1. Review Overall Electricity Demand

Airports need to review the overall airport infrastructure and identify the major energy consumption areas. Airports also need to review overall electricity load and seasonal variations in demand to understand the electricity requirements during different seasons of the year. Based on airport operational schedule, the load varies throughout the 24 hours' period as well and hence it is key to review the demand variations throughout the day for better planning of solar PV at the Airport.

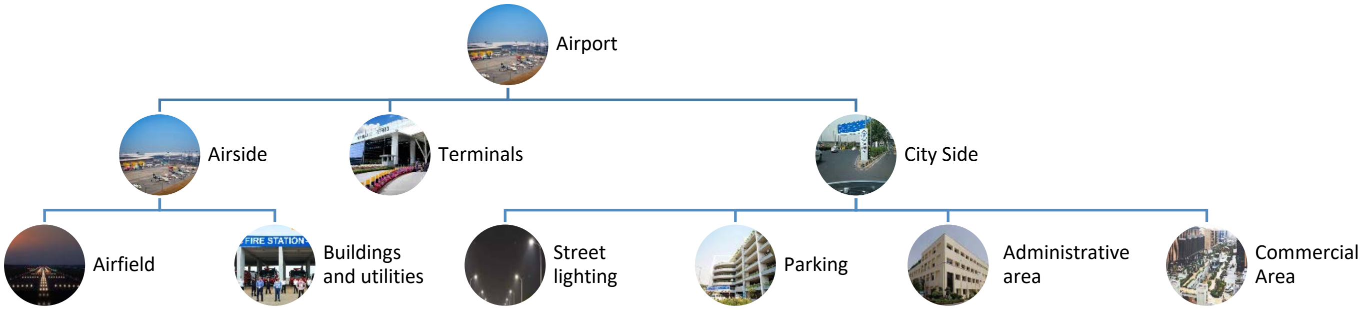


Figure 6: Major energy consumption area within the Airport

Airports may also look at spatial distribution of load to understand the utilisation of produced electricity, in order to set site preferences closer to utilisation facilities (site selection is being covered in Task 2 of this Guidance Document).

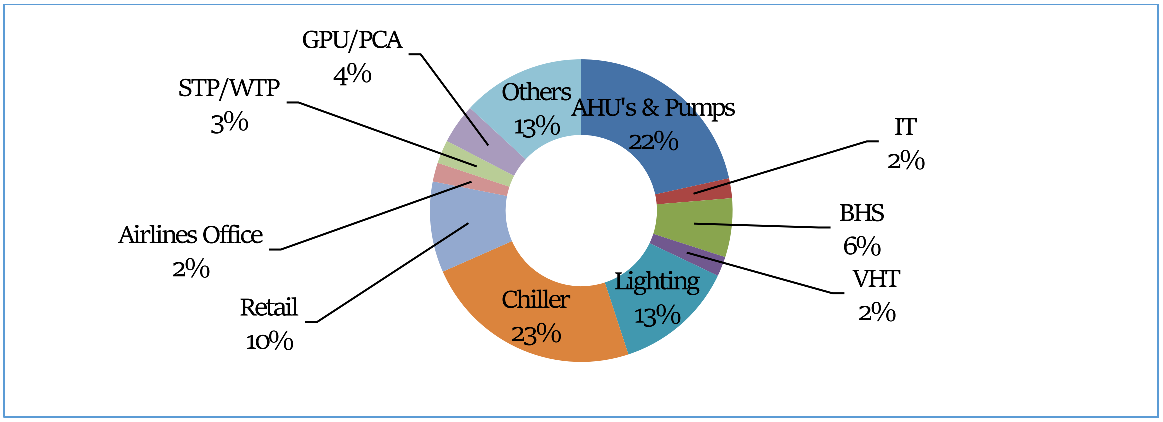


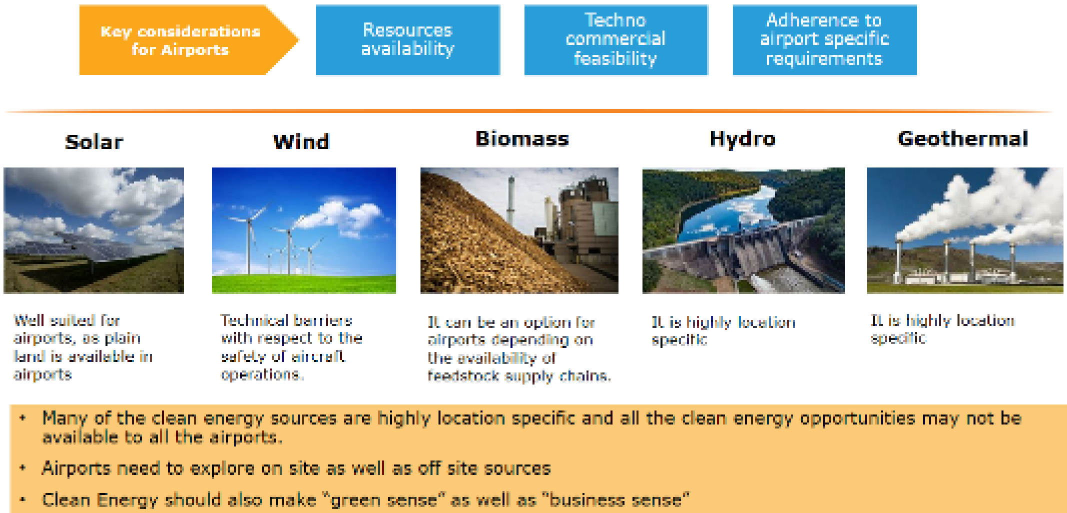
Figure 7: Distribution of electricity consumption within a typical Airport

1.1.2. Carry out future electricity demand projections

In addition to review of current demand, airports also need to review future electricity demand projections, based on passenger growth, infrastructure additions as per approved master plan. This will enable phase wise planning of capacity upgradation of the solar plant to meet future electricity demand of the Airport.

1.1.3. Identify the various supply opportunities

Identify the various electricity supply opportunities currently available to the airport. This may include grid electricity, use of green electricity through market-based measures such as open access or signing of long-term power purchase agreements etc. Airports may use their own selection criteria for selecting electricity supply options. This will provide flexibility in planning renewable energy share through not only on site but also through off site



routes as well. However, this Guidance Document focuses only on onsite solar PV development.

1.2. Review supply to the grid and electricity storage options

While planning for solar plants, Airports also need to take into consideration, the opportunities available with respect to supplying of excess electricity to grid and also review the possibilities of storage of electricity. This will enable airport to right sizing of solar plants and in many cases also improve financial viability of the plant.

1.3. Estimate the required capacity of solar PV

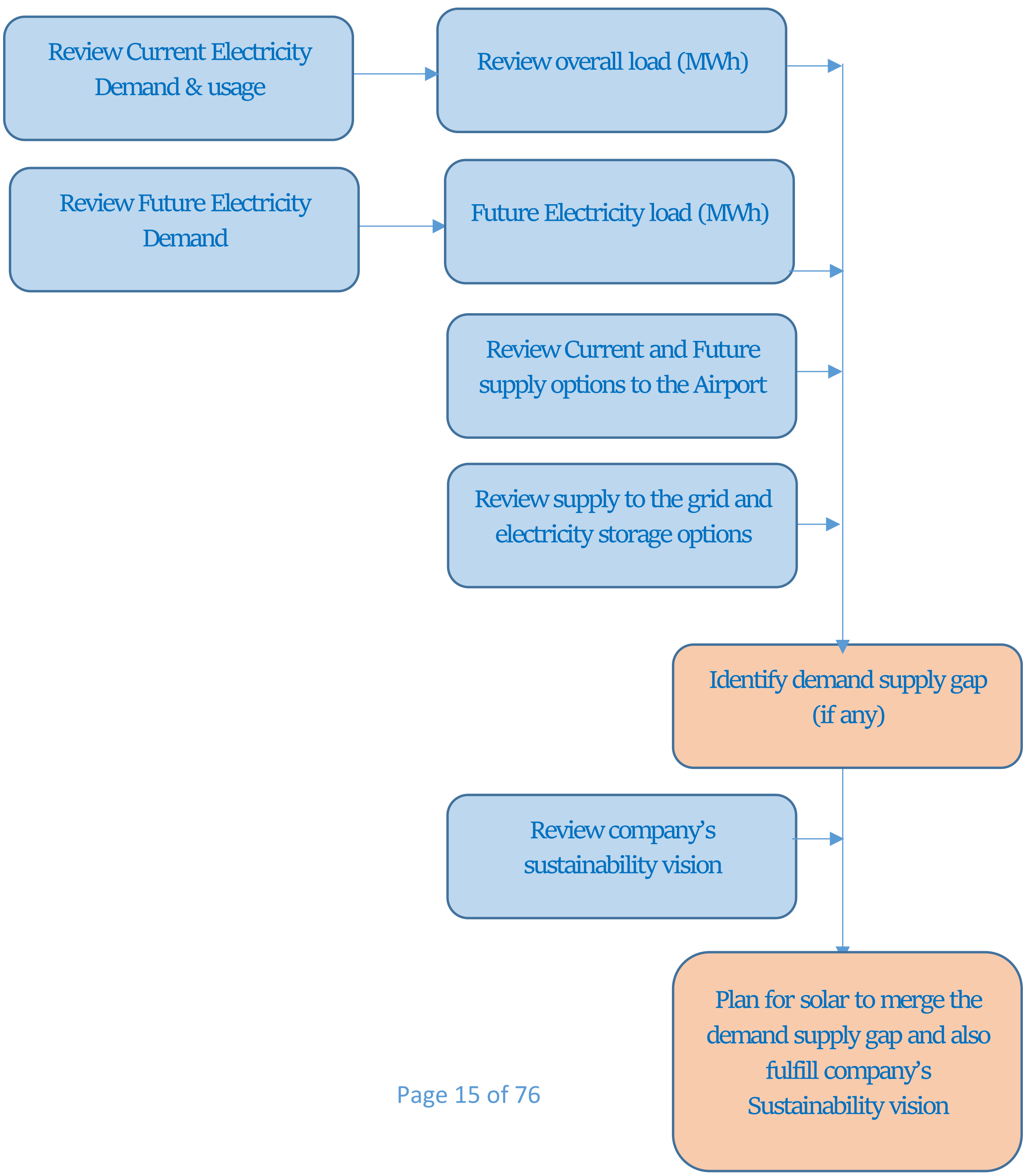
In addition to current electricity demand assessment, future airport growth, provisions of master plan, possible supply opportunities available to meet current and future electricity demands, Airports also need to consider their sustainability vision in terms of achieving renewable energy and/or climate change related goal. Airports may also review local & regional requirements with respect to renewable energy generation and also align towards country specific targets and commitments before finalising the onsite solar plant capacity. The ability of the Airport to supply power to the local energy grid and/or store energy will also be a factor when considering what solar PV capacity is required.

It is important to note the relationship between electricity demand, supply opportunities and area availability in assessing the capacity of solar projects. For example, urban airports (airports in bigger cities), tend to be space constrained but have a high demand for electricity on-site. Rural airports (Airports in smaller or remote locations), on the other hand, likely have plenty of space to site a solar project, but not much on-site electricity demand and a grid connection may be required to supply excess electricity generated from the onsite solar plant. Due to these siting and economic factors, solar projects should be designed to balance electricity demand, grid distribution vs storage possibilities and available space.

1.4. Outcome of Task 1

At the end of Task 1 the airport will be able to assess the capacity of solar plant needed to be set up at the Airport. However, the actual capacity of the plant will be finalised at the end of Task 4, after completion of Task 2, 3 and 4.

1.5. Process flow of Task 1



Task 2- Site selection

Intent: Site selection considering general requirements and aviation specific requirements

Selecting a suitable site is a crucial step of developing a successful solar PV project at Airports. While selecting a site, the aim is to maximise output, minimise the cost and also avoid any disturbances to Airport operations. Some of the basic studies/assessments airports need to consider while selecting a site for the solar PV plant are-

- Availability of space
- Availability of solar resource & climatic condition of the site
- Site's ability to comply with aviation specific requirements etc.

2.1. Assessment of available sites based on general requirements

2.1.1. Climatic Conditions

The amount of solar radiation available for solar energy generation is dependent upon its geographic location. Key climatic conditions important for setting up a solar PV plant are: availability of solar radiation, flooding, high winds, snow and extreme temperatures etc. This information may be collected from Government databases and reports. This can also be referred from the global solar atlas (https://globalsolaratlas.info/map) that provides quick and easy access to solar resource and photovoltaic power potential data globally. This website provides various useful information related to solar PV, which will enable airport operators to take a decision on initiating more in-depth and site specific studies.

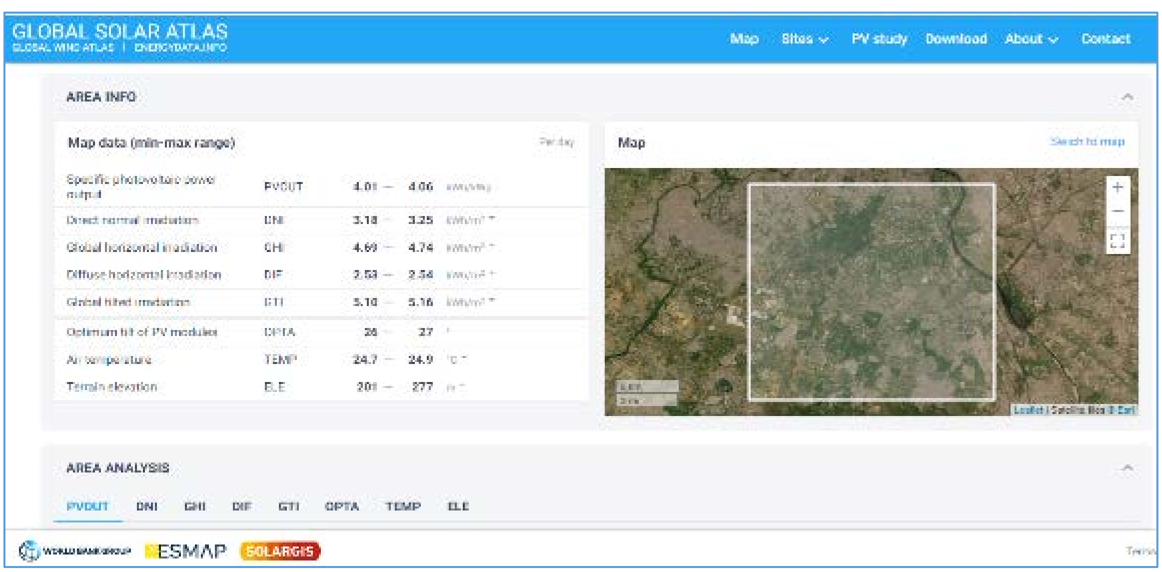


Figure 8: Snapshot of Global Solar Atlas

- **Topographical study**: Study the land topography to assess the **shading effect** on the site from nearby buildings, vegetation and other structures etc. Flat or slightly south facing slopes are preferable for projects in the northern hemisphere whereas north facing slopes are preferable for projects in the southern hemisphere. This is also important for sites considered for setting up of rooftop solar plant.

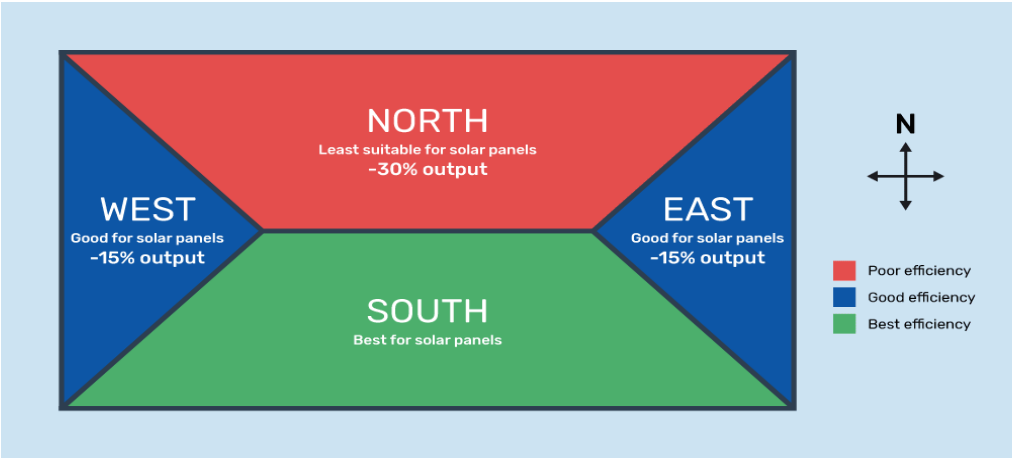


Figure 9: Suitable position of solar panels in Northern Hemisphere

- **Additional Studies:** Apart from the above studies, the Airports should also review: availability of utilities and associated facilities such as proximity to existing roads, extent of new roads required, availability of grid connection, water availability and supply provisions etc. as these facilities will ensure easy implementation and operation of the solar project

For ground mounted solar PV projects, geotechnical study also needs to be carried out apart from the above studies.

- **Geotechnical study**: Ground-mounted systems require geotechnical studies to enable airport operators to assess requirements for module support structure and its foundation. Geotechnical study should cover evaluation of groundwater, resistivity, load bearing properties, soil pH levels and seismic risk etc.

For rooftop solar PV, below mentioned points needs to be looked into, in addition to the above assessment (except for geotechnical studies).

An analysis of the existing roof loading capacity must be conducted to determine if structural reinforcement is required which will impact project cost. Special mountings need to be considered in areas prone to hurricanes and other seasonal weather events. Airports also need to refer to local building codes to identify key design parameters such as wind loadings of buildings etc.

Key focus points for rooftop solar are-

- ✓ Rooftop space availability for setting up the solar PV plant

- ✓ Nearest injection point for supply of generated electricity in the electrical network
- ✓ Roof shading
- ✓ Roof structure strength

After taking account of above general requirements, eliminate the sites that do not meet general requirements of Solar PV for installation.

2.2. Assessment of available sites based on aviation specific requirements

The below points should be taken into consideration while selecting a site out of all the sites that meet the general requirements as mentioned in Section 2.1.

- Consider the requirements of ICAO's Annex 14 (14), Volume I – Aerodrome Design & Operations, to identify solar sites consistent with design guidance
- Consider guidance provided by ICAO Doc 9184 (15), Airport Planning Manual, Part 2 – Land Use and Environmental Control, to assess the compatibility of project sites.
- Ensure the project is not located in a Runway Object Free Area, Obstacle Free Zone, Runway Safety Area, Taxiway Object Free Area or a Taxiway Safety Area
- Ensure project height does not penetrate the imaginary surfaces that define the lower limits of airspace including the clearway
- Ensure that the project does not interfere with the aeronautical Radar system
- Ensure compliance to Obstacle Limitation Surface and comply with the NOC requirements from Airport Authority.
- Airports may also refer to FAA Document on Solar PV

2.3. Assessment of available site for glare / reflection (16)

A solar PV-plant close to an airport or within the operational area of an airport may produce reflection which may impact Airport/Aircraft operation. Glare /reflection can influence the vision of pilots, ATCOs and the drivers of ground vehicles during arrival and departure procedures. Currently, there are only limited standards on potential glare for airport solar facilities. However, Airports need to conduct special glare/ reflectivity study on the selected site(s) to find out the impact of glare or reflection on airport operation and how to avoid or minimise its impact on airspace safety.

Airports should approach the evaluation of the operational and safety aspects in line with their change management processes. This should ensure that aviation authorities feel confident in the airport's plans. This is especially useful in States with few or no specific regulations for solar farms on or near the airport.

In the glare study, the sun rays reflected by the PV modules are analysed in details. It establishes the orientation and tilt angle of the solar panels that will produce minimum or no impact of on airport and aircraft operation.

Depending on site specifics (e.g., existing land uses, location and size of the project) an acceptable glare evaluation may involve one or more of the following levels of assessment:

- A qualitative analysis of potential impact in consultation with the Control Tower, pilots, and airport officials
- Airports may also plan for a small pilot plant with a smaller capacity to review plant performance and also verify if there is any impact on Airport operation. Such type of demonstration field test with solar panels at the proposed site can be carried out in coordination with ATC Tower personnel. However, computer simulations and analysis also gives robust inputs for airport to make useful decisions regarding the plant set up by optimising its impacts.
- A geometric analysis to determine days and times when an impact is predicted.

The amount of light reflected off of a solar panel surface depends on the amount of sunlight hitting the surface as well as the surface reflectivity. The amount of sunlight interacting with the solar panel will vary based on geographic location, time of year, cloud cover, and solar panel orientation & tilt angle. Often 1000W/m^2 is used in calculations as an estimate of the solar energy interacting with a panel when no other information is available.

To minimise reflection, solar PV panels are constructed as dark, light-absorbing materials and covered with an anti-reflective coating. These panels reflects less than 2% of the incoming sunlight depending on the angle of the sun. Using the previously mentioned value for solar irradiance (1000W/m^2), this would mean roughly 20 W/m^2 are reflected off of a typical PV panel.

The glare study will help Airports in-

- Identify the feasible location of solar PV installation area that will have minimum or no impact on airport operation
- Identify the potential orientation and tilt angle of PV arrays on land and rooftops
- Exploring feasibility of having a sun tracking mechanism with the panels (rotating panels) as it may increase overall output provided it doesn't impact airport and aircraft operation.

2.4. Carry out stakeholder consultation

After the glare analysis is done, the airport operator, may discuss the solar project details with key stakeholders of the airport, such as Airlines and Pilot community, air navigation service providers, regulators etc. for taking their inputs. The selected site/sites may be presented in a stakeholder consultation meeting for their inputs. All the relevant inputs shared by the stakeholders needs to be taken into consideration before finalising the location.

2.5. Outcome of Task 2

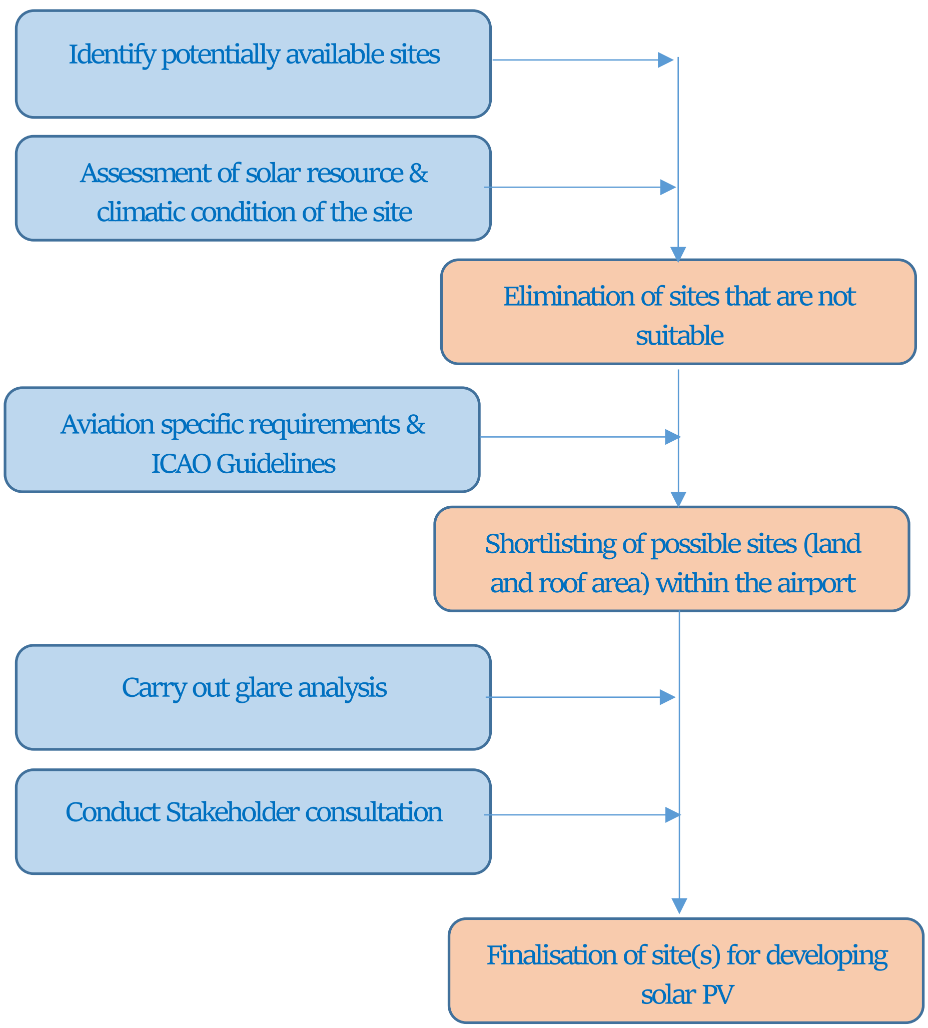
Based on site selection process as described in section 2.1 to 2.4 of this report, identify sites that are most suitable for setting up of solar plants.

2.6. Checklist for Site selection

A basic checklist for ensuring completion of site selection task is presented below-

- Suitable land area identified for the scale of development proposed.
- Land use plan checked with Airport Master Plan
- Climatic conditions such as solar resource, wind, temperature, precipitation, snow, hail, lightning, hurricane and dust etc. assessed
- Topographic characteristics obtained
- Geotechnical survey completed, if required
- Potential access routes to site (both normal and emergency) assessed
- Grid connection assessed (capacity, proximity, right-of-way, stability and availability).
- Soiling risks assessed, if required
- Availability of water supply/ground water determined
- Requirements with respect to any national requirements (e.g. Annex 14, ICAO Doc 9184, EASA and FAA guidelines) are reviewed
- Glare analysis of site conducted
- Stakeholder consultation carried out
- Site finalisation is completed

Process flow of Task 2



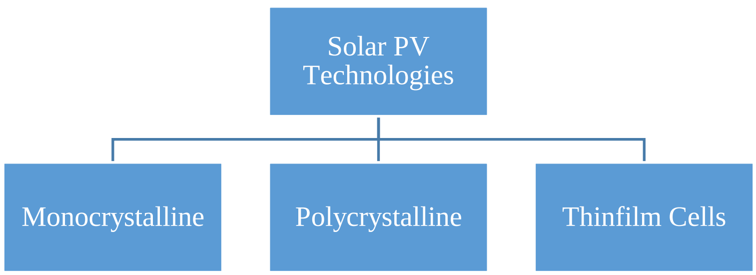
Task 3- Technology evaluation and plant design

Intent: Carry out an assessment to identify suitable technology, plant components, plant design and layout, annual solar yield and site development requirements.

Currently there are multiple Solar PV technologies available for generating electricity. The Airport operator need to conduct a detailed assessment to arrive at the best suited technology for the airport, considering the key concerns such as glare effect, radar interference and physical penetration of airspace. Hence PV module type selection and plant designs is crucial in order to eliminate or minimise the safety related risks. While selecting panel technology and type, the outcome of section 2.3 of this document may also be taken into consideration.

3.1. Assessment of suitable PV technologies

Technologically, PV modules are broadly divided into three main categories:



Monocrystalline: They are made from pure silicon crystal, which has continuous lattice and almost no defects. Its properties provide for high efficiency of light conversion. Manufacturing of the Si crystals is rather complicated, which is responsible for high cost of this type of photovoltaics. Recent developments have decreased the total thickness of Si material used in monocrystalline cells to reduce cost. The monocrystalline silicon cells have a typical black or iridescent blue color. The monocrystalline silicon cells are highly durable and last over 25 years. However, their efficiency decrease gradually (about 0.5% per year), so replacement of operating modules might be needed at certain point of time. The main disadvantages of the monocrystalline silicon panels are high initial cost and mechanical vulnerability.

Polycrystalline: Polycrystalline cells are made by assembling multiple grains and plates of silicon crystals into thin wafers. Smaller pieces of silicon are easier and cheaper to produce, so the manufacturing cost of this type of PV is less than that of monocrystalline silicon cells. The polycrystalline cells are slightly less efficient (~12%). These cells can be recognised by their mosaic-like appearance. Polycrystalline cells are also very durable and may have a service life of more than 25 years. The energy conversion efficiency of these type of panels are lesser than that of monocrystalline.

Amorphous silicon (Thin-film): Thin film photovoltaic cells are produced by depositing silicon film onto substrate glass. In this process, less silicon is used for manufacturing compared to mono- or polycrystalline cells, but this economy comes at the expense of conversion efficiency. Thin-film PV have efficiency of ~6% versus ~15% for single crystal Si cells. The main advantage of the thin-film PV technology is that the amorphous silicon can be deposited on a variety of substrates, which can be made flexible and come in different shapes and therefore can be used in many applications. These are further subdivided into more categories based on the material used.

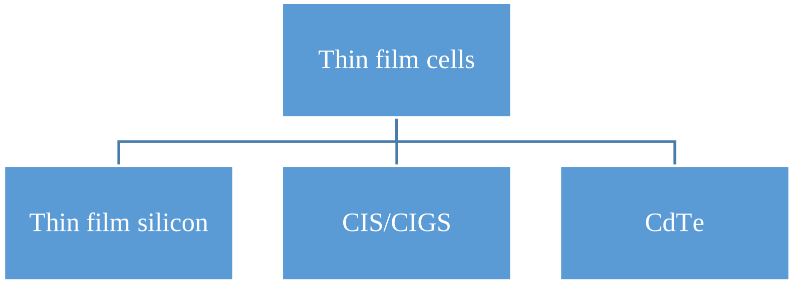


Table 1: Comparison of some of the PV technologies (9)

Technology	**Crystalline Silicon**	**Amorphous Silicon**	**Cadmium Telluride**	**Copper Indium Gallium Di-Selenide**
Abbreviation	c-Si	a-Si	CdTe	CIGS or CIS
Current commercial module efficiency	11-19%	4-9%	10-11%	7-12%
Area/kW (m2/kW)	7-8	15	10	10

3.2. Technical evaluation & consideration of plant components

3.2.1. Solar PV module selection by the Airports

Technology options: When choosing between module technologies, it should be realised that each technology has examples of high quality and low-quality products from different manufacturers. Also, different technologies have a differing spectral response and so certain technologies will be better suited for use in certain locations, depending on the local solar light conditions. Many of them show a better response in low light levels. For carrying out technology review, Airports may conduct a comparative analysis via energy yield estimation.

Estimate energy yield: The energy yield exercise provides fair idea of technological options and allow a comparative analysis among the available options. Airports may use simulation software to compare the impact of different module or inverter technologies and different plant layouts on the predicted energy yield.

Simulation software such as PVWatts, PVGIS, PV-Online, PV*Sol Online, PVsyst, SAM etc. are commonly used for estimating energy yield. The energy yield estimation also requires: Basic plant design, indicative layout and proposed components identified for the project. Below steps may be used for estimating annual energy yield:

- Identify average monthly horizontal irradiation, wind speed and temperature data from available sources including satellite image derived data and data from land based meteorological stations.
- Calculate the global incident radiation on the tilted collector plane
- Calculate the losses, using details of the inverter specifications, PV module specifications, PV module characteristics, on-site conditions and plot layout.
- Apply downtime losses, ohmic losses, module degradation and transformer losses to obtain an energy yield that reflects a twenty-five-year plant life.

A detailed plant design and component sizing may be carried out after this exercise. Some software for simulating Solar PV System and also estimating its energy yield are presented in Table 2:

Table 2: Useful software for simulating Solar PV

Software	Manufacturer / Developing Institution	Website
HOMER	National Renewable Energy Laboratory, USA	https://www.homerenergy.com/
PVWatts	National Renewable Energy Laboratory, USA	https://pvwatts.nrel.gov/pvwatts.php
System Advisor Model (SAM)	National Renewable Energy Laboratory, USA	https://sam.nrel.gov/
PVsyst	Institute of Environmental Sciences (ISE), University of Geneva, Switzerland	https://www.pvsyst.com/
PVGIS	European Commission	https://re.jrc.ec.europa.eu/pvg_tools/en/
PV*SOL Online	Valentin Software	https://pvsol-online.valentin-software.com/#/

1. **Hybrid Optimisation Model for Electric Renewable**
HOMER models for distributed generation systems - both on and off-grid. HOMER's algorithms for optimisation and sensitivity analysis, accounts for variations in

technology costs and energy resource availability and also evaluates the economic and technical feasibility of a large number of technology options.

2. **PVWatts**

PVWatts is a useful map-based free online software for US and international photovoltaic sites analysis. It helps in estimating the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential PV installations.

3. **The System Advisor Model**

It is a free techno-economic software model that facilitates decision-making in case of solar PV projects. SAM makes performance predictions and cost-of-energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that is specified as inputs to the model.

4. **Photo Voltaic systems**

PVsyst is appropriate for grid-connected, stand-alone, pumping and DC-grid systems. It is a PC software package for the study, sizing, simulation and data analysis, directed for architects, engineers and researchers, enduring quite beneficial tools for academia. The new PVsyst Version 6.84 introducing new Solar Anywhere files available in TMY and timeseries (hourly and 30 minutes).

5. **Photovoltaic Geographical Information System (PVGIS)**

The Photovoltaic Geographical Information System (PVGIS) is a web application for the estimation of the performance of photovoltaic (PV) systems. PVGIS provides information about solar radiation and photovoltaic (PV) system performance for any location in Europe and Africa, as well as a large part of Asia and America. This application calculates the monthly and yearly potential electricity generation [kWh] of a Photovoltaic system with defined modules tilt and orientation.

6. **PV*SOL Online**

This is an online free tool for calculation of PV systems. Made by the developers of the full featured market leading PV simulation software PV*SOL, this online tool lets the user input basic data like

- Location of your system
- Load profile and annual energy consumption
- PV module data (manufacturer, model, orientation, quantity etc.)
- Inverter manufacturer

After the simulation of the system, the results are presented as Annual PV energy, Performance ratio, Own power consumption, Solar fraction etc.

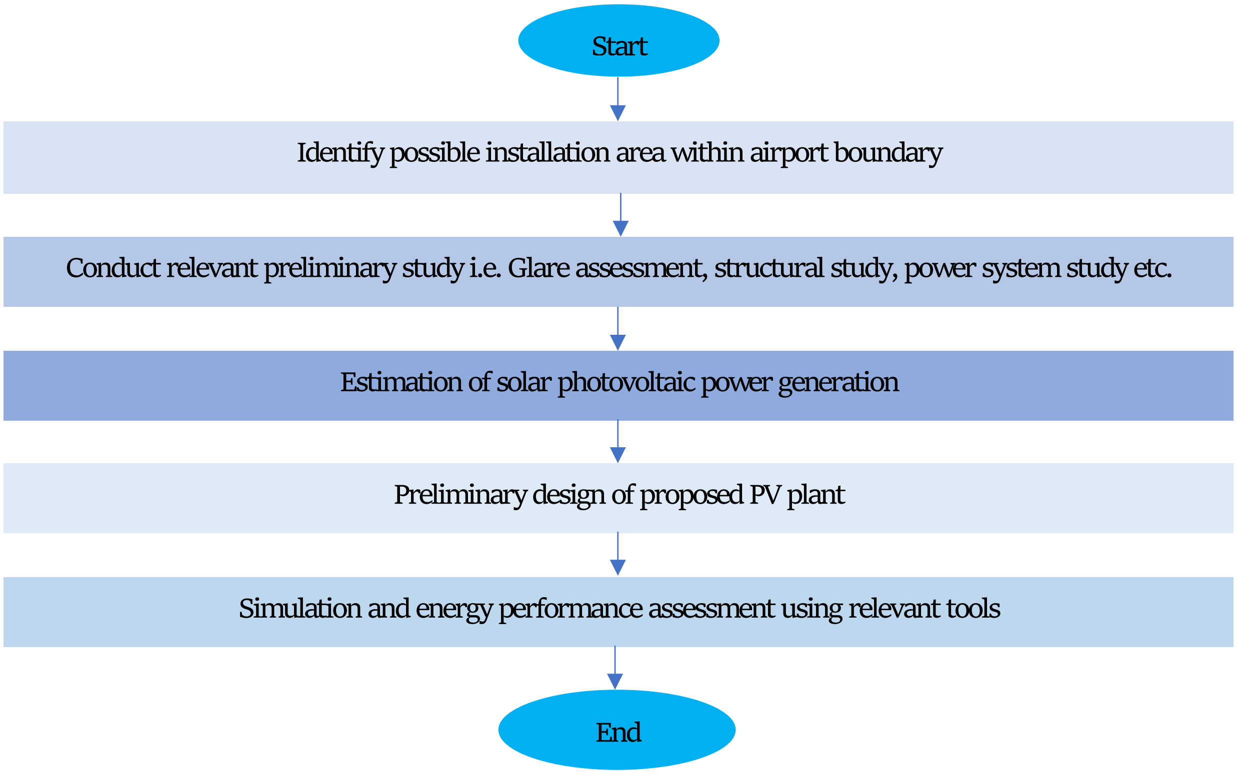


Figure 10: Process flow on the simulation of solar PV system

Other key factors to be considered for selecting suitable solar PV technology are (10)-

Minimum LOCE: The aim is to keep the levelised cost of electricity (LCOE) at a minimum. When choosing between high efficiency-high cost modules and low efficiency low cost modules, the cost and requirements of land and plant components will have an impact. High efficiency modules require significantly less land, cabling and support structures per MWp installed than low efficiency modules.

Module properties: Temperature coefficient of power will be an important consideration for modules installed in hot climates. The degradation properties and long-term stability of modules should be understood well before selecting panel technology. Airports may also review the results of independent testing of modules from scientific journals or research papers.

Warranty: The manufacturers' warranty period is a useful parameter for distinguishing between modules but care should be taken with the power warranty.

Other parameters: Other parameters important for selection of modules include: compliance to relevant IEC/CE/UL certifications, lifetime and maximum system voltage.

3.2.2. Inverter selection

The inverters convert DC power generated by solar panels into AC power system. Some of the common type of inverters used in solar PV projects are-

- **String Inverter:** In a string inverter solar panels are installed in rows, each on a "string" in a series. The string is connected to one string inverter. Strings inverters are based on a modular concept, in which PV string arrays are connected to inverters to feed into the AC grid in parallel configuration.

- **Central Inverter**: Central inverters are similar to string inverters but they are much larger and can support more strings of panels. Instead of strings running directly to the inverter, as with string models, the strings are connected together in a common combiner box that runs the DC power to the central inverter where it is converted to AC power.

While central inverters are usually preferred for most utility-scale PV projects, both configurations have their pros and cons. Central inverters offer high reliability and ease of installation. String inverters, on the other hand, are cheaper, simpler to maintain and can give enhanced power plant performance on some sites.

Some of the key considerations for inverter selection are listed below-

Performance: Airports should explore high efficiency inverters as the additional electricity yield usually compensates for the higher initial cost of inverters. It is to be noted that efficiency changes with DC input voltage, percentage of load, and several other factors.

Compatibility with Modules: The module type also defines the type of inverter needs to be installed. The compatibility of certain type of inverters with the selected module needs to be confirmed from the manufacturers. If modules of different specifications are to be used, then string or multi-string inverters are recommended, in order to minimise mismatch losses.

Project size: Size influences the inverter connection concept. Central inverters are commonly used in large solar PV plants.

Grid code: The grid code affects inverter sizing and technology. The national grid code might recommend or mandate certain type of inverters.

Product reliability: High inverter reliability ensures low downtime and maintenance and repair costs. If available, inverter mean time between failures (MTBF) figures and track record should be assessed by the Airport.

Modularity: Ease of expanding the system capacity and flexibility of design should be considered when selecting inverters.

Shading conditions: For sites with different shading conditions or orientations, string inverters or micro inverters might be more suitable.

Other condition: Product warranty needs to be reviewed and compared for all the available options. In addition, the inverters shall be compliant to most recent standards (and latest amendments if any) developed by the International Electrotechnical Commission (IEC) and European Standards (EN). It should be noted that electro-magnetic compatibility standards (EN 16000-4) permit some non-compliant emissions. When this occurs, it is often in the 100 to 200 MHz range. Inverters should be sourced that are fully compliant or are located so that any emissions do not interfere with CNS-equipment. Ease of access to qualified service and maintenance personnel and availability of parts is an important dimension to consider during inverter selection.

3.2.3. Transformer selection

Transformers helps in stepping up voltage levels for transmission of electricity across the site and for export to the grid. If the plant is connected to the distribution network, power can then be exported to the grid directly. If the plant is connected to the transmission grid, grid transformers are used to step up the voltage even further.

The selection of an appropriate transformer should consider several basic issues. These include the required size of the transformer, its position within the electrical system, and the physical location of installation etc. The size of the transformer, which will depend on the projected maximum power exported from the solar array, should be specified in MVA. At a minimum, transformers should be built according to the following standards:

- BS EN 50464-1:2007+A1:2012
- IEC 60076

3.2.4. Mounting structures

Mounting structures may be either fixed or tracking. Fixed tilt mounting systems are simpler, cheaper and have lower maintenance requirements than tracking systems. Although tracking systems are more expensive and more complex, they can be cost-effective in locations with a high proportion of direct irradiation. Tracking systems tend to concentrate reflections, making the solution a possible mitigation for unfavorable reflections.

3.3. Design layout

3.3.1. General layout design

The design of each plant should be considered on a case-by-case basis, as each site conditions are different. While general guidelines and best practices can be formulated, there are no "one-size-fits all" solutions. International standards and country-specific electrical codes should be followed in order to ensure that the design will lead to safe and compliant PV plant.

In designing the site layout, the following aspects are important:

- Choosing row spacing to reduce inter-row shading and associated shading losses.
- Choosing the layout to minimise cable runs and associated electrical losses.
- Allowing sufficient distance between rows to allow access for maintenance purposes and, as required, RFF-vehicles
- Choosing a tilt angle that optimises the annual energy yield according to the latitude of the site and reduces glare.
- Orientating the modules to face a direction that yields the maximum electricity.

3.3.2. Electrical design

The electrical design of a PV project can be split into the DC and AC systems. Some of the key components of the DC systems are:

- **Array(s) of PV modules**: The solar array consists of one or more PV modules which convert sunlight into electric energy. The modules are connected in series or parallel to provide the voltage and current levels to fulfil electrical load requirement.
-

<u>From Cell to Array</u>

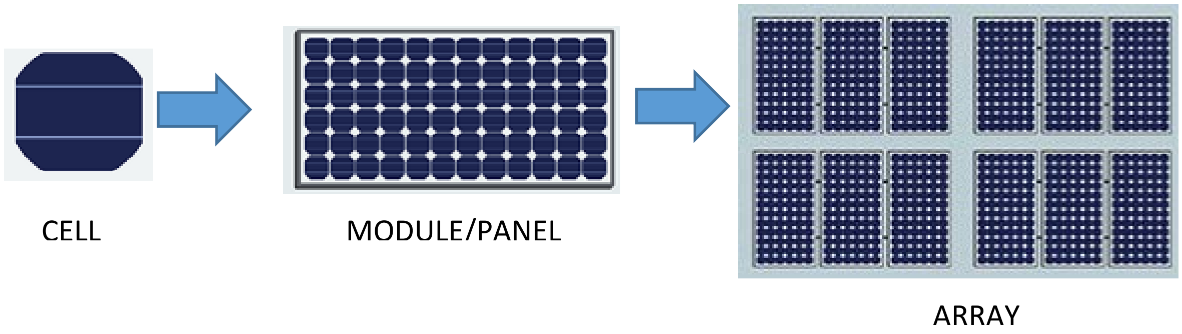


Figure 11: Cell to Array- key components of solar PV

The design of a PV array will depend on the inverter specifications and the chosen system architecture. Using many modules in series in high voltage (HV) arrays minimises ohmic losses. However, safety requirements, inverter voltage limits and national regulations also need to be considered.

- **Inverter sizing:** The optimal sizing depends on the specifics of the plant design. Following the detailed mentioned in Section 3.2.2 will enable Airports to select right type of inverter and after that Inverter and PV array sizing can be obtained from the inverter manufacturers, who offer system-sizing software. Such tools also provide an indication of the total number of inverters required.

- **Cable selection and sizing:** The selection and sizing of DC cables for solar PV power plants should be in line with national codes and regulations applicable to each country. Specifically designed cables for solar PV installations ("solar" cables) are available and may be considered by the Airports. The below criteria should be considered when sizing cables:
  - The cable voltage rating
  - The current carrying capacity of the cable
  - The minimisation of cable losses

- **DC cabling (module, string and main cable)**: Single-conductor, double-insulation cables are preferable for module connections. Using such cables helps protect against short circuits. When sizing string cables, the number of modules and the number of strings per array need to be considered. The number of modules defines the voltage at which the cable should be rated. The number of strings is used to calculate the maximum reverse current that can flow through a string.

  The cables should be rated to the highest temperature they may experience (for instance, 80°C). Appropriate de-rating factors for temperature, installation method and cable configuration should also be applied.

- **DC connectors (plugs and sockets)**: Specialised plug and socket connections are normally pre-installed on module cables to facilitate assembly. These plug connectors provide secure and touch-proof connections.

- **String Fuses/Miniature Circuit Breakers (MCBs):** String fuses or miniature circuit breakers (MCBs) are required for over-current protection. They must be rated for DC operation. Airports may follow National codes and regulations when selecting and sizing fuses and MCBs.

Some of the key components of the AC systems are:

- **AC Cabling:** Cabling for AC systems should be designed to provide a safe and cost-effective means of transmitting power from the inverters to the transformers and beyond. Cables should be rated for the correct voltage and have conductors sized, taking into account the operating currents and short-circuit currents (I_{SC}).

- **AC Switchgear**: Appropriately rated switchgear and protection systems should be included to provide disconnection, isolation, earthing and protection. On the output side of the inverters, provision of a switch disconnector is recommended as a means to isolate the PV array.

- **Transformer:** The capacity of the transformer (specified in MVA) will depend on the projected maximum power exported from the solar array. The transformer solution should comply with national and international standards including IEC 60076. The below points should be considered while sizing transformer-
  - **Losses**: Minimising the iron losses and also copper losses in a transformer is a key requirement, as this will increase the energy supplied to the grid and thereby enhance the revenue of a solar PV power plant.
  - **Test Requirements**: Transformers should be subjected to a number of routine and type tests performed on each model manufactured; these tests are set out in IEC 60076. The manufacturer also can be requested to undertake special tests mentioned in IEC 60076.

- **Earthing and Surge Protection**: Earthing should be provided as a means to protect against electric shock, fire hazard and lightning. By connecting to the earth, charge accumulation in the system during an electrical storm is prevented. The earthing of a solar PV power plant encompasses the following:
  - Array frame earthing.
  - System earthing (DC conductor earthing).
  - Inverter earthing.
  - Lightning and surge protection.

  National codes and regulations and the specific characteristics of each site location should be taken into account when designing the earthing solution.

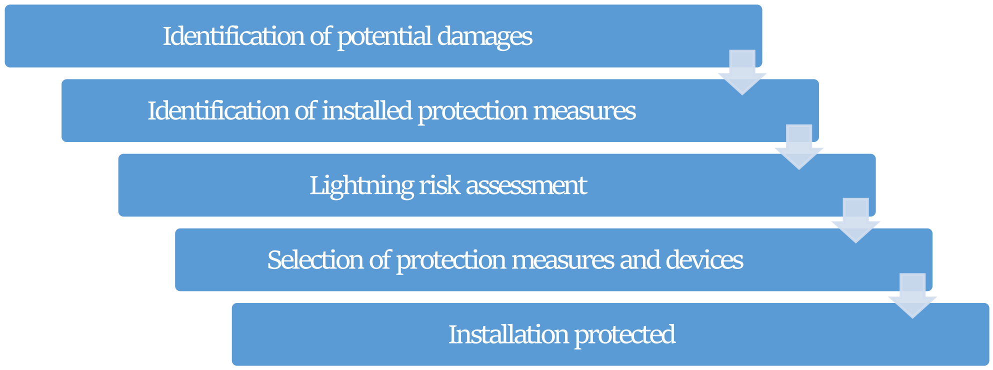
- **Earthing system** (11)**:** The aim of earthing in electrical installations and circuits is to enhance the safety of the installation by reducing the level of danger inherent to fault currents. Fault currents may be caused by different factors. Therefore, it is very important to design an earthing system according to the installation's characteristics.

  Purpose of an earthing system:
  - Provides safety for persons and animals
  - Protects the installation and equipment
  - Enhances quality of signal (reduced electromagnetic distortion)
  - Provides a fixed reference voltage for equipotentialisation

  Factors to consider at the design stage of an earthing system:
  - Soil humidity (reduces earthing resistance)
  - Earthing enhancing devices reduce soil resistance
  - Buried electricity and gas installations require security distances
  - Buried pipes and water tanks shall be bonded equipotentially with earth termination
  - Fault currents can be transmitted to persons and animals, presenting a high risk through both direct and indirect contact.

- **Lightning protection**: The entire PV plant and the electrical room needs to be protected from lightning. The protection system should be based on early streamer emission lightning conductor air terminals. The air terminal will be capable of handling multiple strikes of lightning current and should be maintenance free after installation. These air terminals will be connected to respective earthing stations, and an earthing grid will be formed connecting all the earthing stations through the required galvanised iron tapes.

Steps of the lightning protections assessment process:



3.3.3. Fire protection

The solar PV plant needs to be equipped with suitable fire protection and fighting systems for entire PV array area, inverter stations, main control room and switchyard as per the country specific fire safety standards and local fire authority requirements. Some of the fire protection provisions are-

- Automatic fire detection system
- Fire Extinguishers
- Fire buckets

3.3.4. Remote monitoring and data acquisition system

The plant need to incorporate a communication system to monitor the output of each string and inverter so that system faults can be detected and rectified before they have an appreciable effect on production. The monitoring system ideally should be a web-based internet portal solution. A local display can be provided showing performance parameters such as instantaneous and cumulative energy produced, tons of CO_2 saved, etc. For large solar plants, a variety of components can be assembled to create a customised monitoring solution. A well-coordinated system benefits both the airport operator and local grid operator.

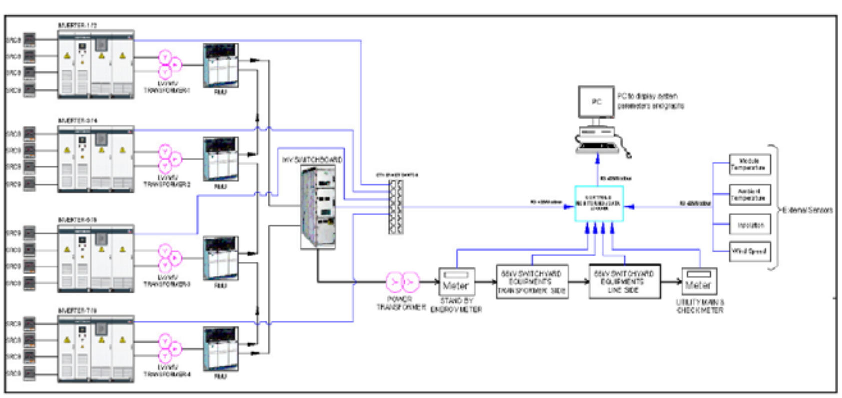


Figure 12: Indicative schematic of data monitoring

3.3.5. Identify site development requirement for setting up PV plant:

Identify site development requirement for setting up PV plant and assess site readiness (leveling, road accessibility, site clearance etc.). Review and plan for facilities (material storage, loading & unloading, site office etc.) required during project development stage.

3.4. Outcome of Task 3

The outcome of Task 3 will be selection of solar PV technology and its components. Based on these Airport will be able to ensure preliminary design of solar PV plant and assess the site development requirements. The outcome of Task 3 will enable Airports to take up Task 4- Financial viability assessment.

3.5. Checklist for assessment to identify suitable technology, plant components, plant design and layout, annual solar yield and site development requirements

A basic checklist for identifying PV module technology -

- List of solar PV technologies/modules identified
- Energy yield estimation is carried out to compare the performances of the solar PV modules
- A brief cost comparison in terms of LCOE is carried out based on standard market prices
- Properties of various modules are reviewed and compared
- Warranty and other properties of PV modules are reviewed and compared
- Explore electricity storage options for the excess generation which can be utilised when electricity generation is low

A basic checklist for inverter selection

- Suitable capacity for project size.
- Compatible with national grid code
- Product warranty terms and conditions in line with the market standards
- Suitable for the environmental conditions of the project site.
- Efficiency should be in line with the current market standards

A basic checklist for transformer selection

- Suitable capacity for project size
- Compatibility with the national grid regulations
- Product warranty terms and conditions in line with the current market standards
- Suitable for the environmental conditions of the project site.
- Efficiency in line with the market standards
- Load/no-load losses in line with market standards

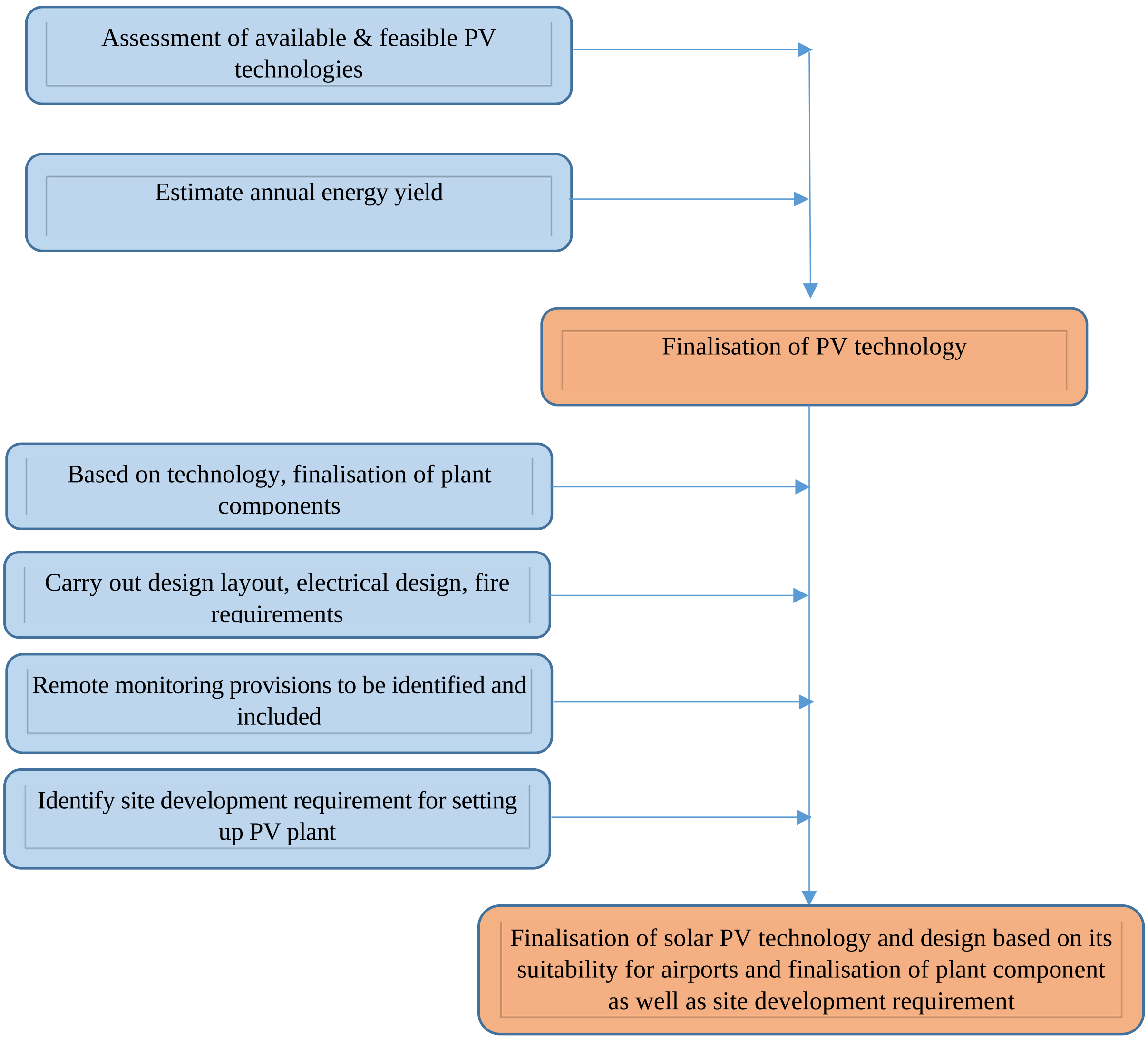
A basic checklist for mounting structure selection

- Product warranty terms and conditions in line with market standards
- Suitable for the environmental conditions of the project site.

A basic checklist for design layout

- Tilt angle and orientation of the PV array suitable for the location
- Inter-row distance suitable for the site
- Shading from nearby objects considered and suitable buffer zone included accordingly
- PV string size suitable for the inverter type selected
- Combiner boxes suitable for the environmental conditions.
- DC and AC cables are sized correctly as per the plant requirements
- Low Voltage and High Voltage protection equipment are correctly sized.
- Suitable earthing and lightning protection designed for site specific conditions
- Civil works are suitable for environmental conditions.
- Monitoring system in line with the current market standards
- Fire protection in line with market standards and meets the requirements of insurance provider

3.6. Process flow of Task 3



Task 4- Financial viability assessment

Carry out financial feasibility assessment of the PV plant and finalisation of business model to develop the plant

Financial viability assessment will help airports to decide whether to invest or not in a solar project or which model may be more preferred etc. This is usually done by calculating financial indicators such as Pay Back Period (PP), Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (RoI) or Levelized Cost of Electricity (LOCE) generation. For this, the Airport needs to have actual or estimated/assumed values for key inputs such as: capital expense, operating expense, government benefits, other revenue sources such as carbon credits or renewable energy certificates etc. For conducting commercial feasibility of the solar project, airports may follow the below steps-

4.1. Review cost estimates

4.1.1. Estimate capital expenses

Capital costs are fixed, one-time expenses incurred on the purchase of land, buildings, construction, and equipment used for setting up the solar PV plant. Capital cost covers (12)-

- Cost associated with consulting services such as various studies, glare analysis, cost of design etc.
- the cost of solar panels;
- electrical line and substation costs;
- battery storage cost
- cost of IT and automation tool such as energy management system and SCADA
- other associated costs and project administration costs;
- Physical contingencies and
- Any tax/charges directly associated with the purchased equipment and services etc.

4.1.2. Estimate Operation and maintenance expenses

Operation and maintenance (O&M) costs are associated with the maintenance and administration of the solar PV plant. These include minor and major maintenance costs necessary to ensure reliable electricity supply. Among the specific technical issues that can influence the O&M cost are-

- Spares cost
- Man power cost
- Insurance cost
- Cost of monitoring and reporting activities
- Cost associated with preventive and corrective maintenance operations etc.

4.1.3. Review current electricity cost

The current electricity cost incurred by the Airport operator is important in determining the viability and financial attractiveness of the project as the electricity purchased at this cost will be replaced by the electricity generated by the solar plant. This can be referred from the electricity purchase invoice raised by the electricity supplier.

4.2. Review Government benefits / incentives

Federal, state, and local incentives can greatly affect the financial viability of a PV installation. Examples of various incentives are capital subsidy, tax rebates, accelerated depreciation, generation-based incentives etc. Identifying such schemes at the project conceptualisation stage helps in better project evaluation and also helps in enhancing financial viability of projects.

4.3. Review available market based mechanism for renewable energy projects and emission reduction projects

Solar PV are eligible to be developed as emission reduction under various market-based mechanisms to generate carbon credits. In many countries these projects can also be developed as project which can earn Renewable Energy Certificate (REC)/ International Renewable Energy Certificate (iREC) etc. Early consideration of such schemes in the overall planning process enhances the probabilities of getting such accreditations. This also ensures additional revenue from the project.

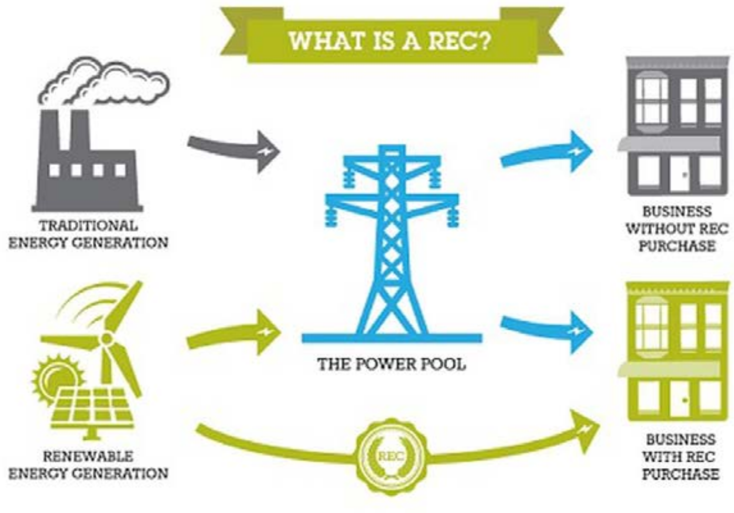


Figure 13: The REC process

4.4. Carry out detailed Economic Evaluation

Airports may select one or multiple financial indicators such as Simple Payback Period, NPV, IRR, RoI, LCOE etc. to review the financial viability of the solar project.

4.4.1. Simple Payback Period

Simple payback determines the number of years required for the energy savings from the PV system to offset the initial cost of the investment. To calculate it, most commercial installers take the net cost of the solar system after incentives have been applied (initial cost) and divide it by the projected annual electric bill savings, after adjusting for annual O&M expenses.

$$Payback\ (years) = \frac{Initial\ Cost\ (\$)}{Annual\ Production\ \left(\frac{kWh}{year}\right)\ X\ Values\ \left(\frac{\$}{kWh}\right) - O\&M\ \left(\frac{\$}{year}\right)}$$

Simple payback is an attractive calculation because the calculation is straightforward and easy to understand. Airports can assess how quickly an investment might pay back (the smaller the simple payback, the better the investment) and whether the investment might pay back within the expected lifetime of the project.

However, because of the simplicity of the simple payback calculation, there are limitations when assessing the economic feasibility of PV projects. The simple payback calculation ignores several critical investment characteristics, including the time value of money, energy price escalation, variable rate electricity pricing, alternative investment options, and what happens after payback etc.

4.4.2. Net Present Value (NPV)

Net present value (NPV) is the difference between the present value of cash inflows (savings) and the present value of cash outflows (cost) over a period of time. The savings and costs are also discounted. A positive NPV reveals an economically feasible project. The greater the NPV, the better, but a positive NPV does not necessarily mean the investment should be made. Airports may also review opportunity cost of the capital as an additional calculation and review.

Using NPV formula, it can be shown how the 25 to 30-year lifetime cash flow of a solar project compares in today's dollars, factoring in for inflation, interest, and other lost opportunity costs. The NPV formula is shown below:

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(I+r)^t} - I_o$$

Where:

C_t = the net cash receipt at the end of year t
I_o = the initial investment
r = the discount rate/the required minimum rate of return on investment
n = the project/investment's duration in years

4.4.3. The internal rate of return (IRR)

The IRR is the discount rate at which the NPV for a project equals zero. Whereas NPV can show the project's net present value in dollars, the IRR reveals the rate of return from NPV cash flows received from an investment. This rate means that the present value of the cash inflows for the project would equal the present value of its outflows.

The IRR is the break-even discount rate. The IRR is found by trial and error.

$$\sum_{t=1}^{n} \frac{C_t}{(I+r)^t} - I_0 = 0$$

Where, r = IRR

IRR of an annuity that describes the annualised return rate of the investment:

$$Q\,(n,r) = \frac{I_o}{C}$$

Where:

Q (n,r) is the discount factor
I_o is the initial outlay
C is the uniform annual receipt (C_1 = C_2 =....= C_n).

4.4.4. Return on Investment (ROI)

RoI is a metric used to denote how much profit has been generated from an investment. When a project yields a positive return on investment, it can be considered profitable, because it yielded more in revenue than it cost to pursue. If the project yields a negative return on investment, it means the project cost more to pursue than it generated in revenue. If the project breaks even, then it means the total revenue generated by the project matched the expenses.

ROI (%) = Net Income/Investment

4.4.5. Levelised cost of energy (LCOE)

LCOE expresses the cost of the energy produced from a PV system. The measure includes construction and operation costs of projects. The principal advantage of LCOE is that comparisons are possible between different electricity sources, such as utility-provided electricity and roof-mounted PV. Comparisons can also be made across different system lifespans.

$$\frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t= Investment expenditure in year t (including financing)

M_t = Operations and maintenance expenditures in year t
F_t = Fuel expenditures in year t
E_t = Electricity generation in year t
r = Discount rate
n = Life of the system

While conducting the financial viability assessment, it is important to do a sensitivity analysis as well, by changing the key parameters such as project size, overall cost, electricity prices, cost and price escalation etc.

The sensitivity analysis may also include commercial arrangement such as electricity banking, net metering and supply opportunities to other users. By using the sensitivity analysis the airports can test the financial viability of the projects under various scenarios and this will help Airport finalise the actual capacity of the solar plant to be set up with optimum financial benefits.

4.5. Finalise business model

Based on the financial indicator as described in section 4.4, airport can carry out financial viability of the solar plants. Apart from reviewing the financial viability, the Airports also need to finalise a business models to develop the project-

- Concession model: The solar facility is owned by a private company
- Investment mode: The solar facility owned by the airport

Regardless of who owns the solar facility, the airport plays a leading role in project development with support from other stakeholders. Based on the ownership model the airport selects, different financial incentives can be availed. The business model followed also determines who owns the environmental attributes of the project.

4.5.1. Concession Model – Airport as Host

The concession model offers a good approach for airports to develop solar especially in places with attractive tax credits. In the concession model, the airport leases property to a private developer granting them the right to construct, own, and operate a solar facility. The basic contract is a land (or roof) lease with a rental fee, annual escalation and terms of lease. For ensuring feasibility of the project, the developer usually seeks a long-term lease that may range from 10-30 years. The land lease agreement may include options for the airport to buy the facility back from the developer and terms and conditions of such an option.

The developer owns the solar facility, the electricity it produces, and the green benefits associated with it. The airport usually executes a PPA with the developer to purchase the electricity produced by the solar facility for a specific price over a long-term period.

Table 3: Advantages and disadvantages of Concession Model

Advantages	Disadvantages
• The concession model is fundamentally a simpler proposition	• The primary disadvantage to the concession model is that the sponsor releases control of the project.

for the airport if not more economical in the long-term. • It requires no capital investment from the airport. • It requires no specialised expertise on solar energy from the airport. • The Airport is seen as being proactive on environmental and energy issues and responding to the concerns of the community without taking on the risks associated with owning and operating the solar facility.	• A secondary drawback is that the airport will not achieve a payback point and begin receiving free electricity. • Instead, the Airport is locked into paying for the electricity (assuming a lower than market rate) for the life of the contract unless it exercises an option.

Investment Model– Airport as Owner

In the investment model, the airport owns the solar facility and utilises the electricity and associated "green" benefits on-site. The Airport contracts with a design-build firm to construct and commission the project. It may execute a separate contract for operations and maintenance.

Table 4: Advantages and disadvantages of Investment Model

Advantage	Disadvantage
• The Airport holds all rights to its property. • Assuming all factors are equal, the cost of the project is less over the life of the project (e.g., 25 years) than private ownership where long-term airport electricity payments also pay for the private company's return on investment. • This leads to a point in the future where the solar facility is entirely paid off and is providing free electricity to the airport for the cost of maintenance.	• Owning a solar project could also mean owning additional responsibilities associated with the project management. • While these issues are no different (or riskier) than any other construction project on airport land, the technical issues associated with solar energy development may present some challenges beyond those associated with typical building systems and airport support structure. • It requires funding the capital investment.

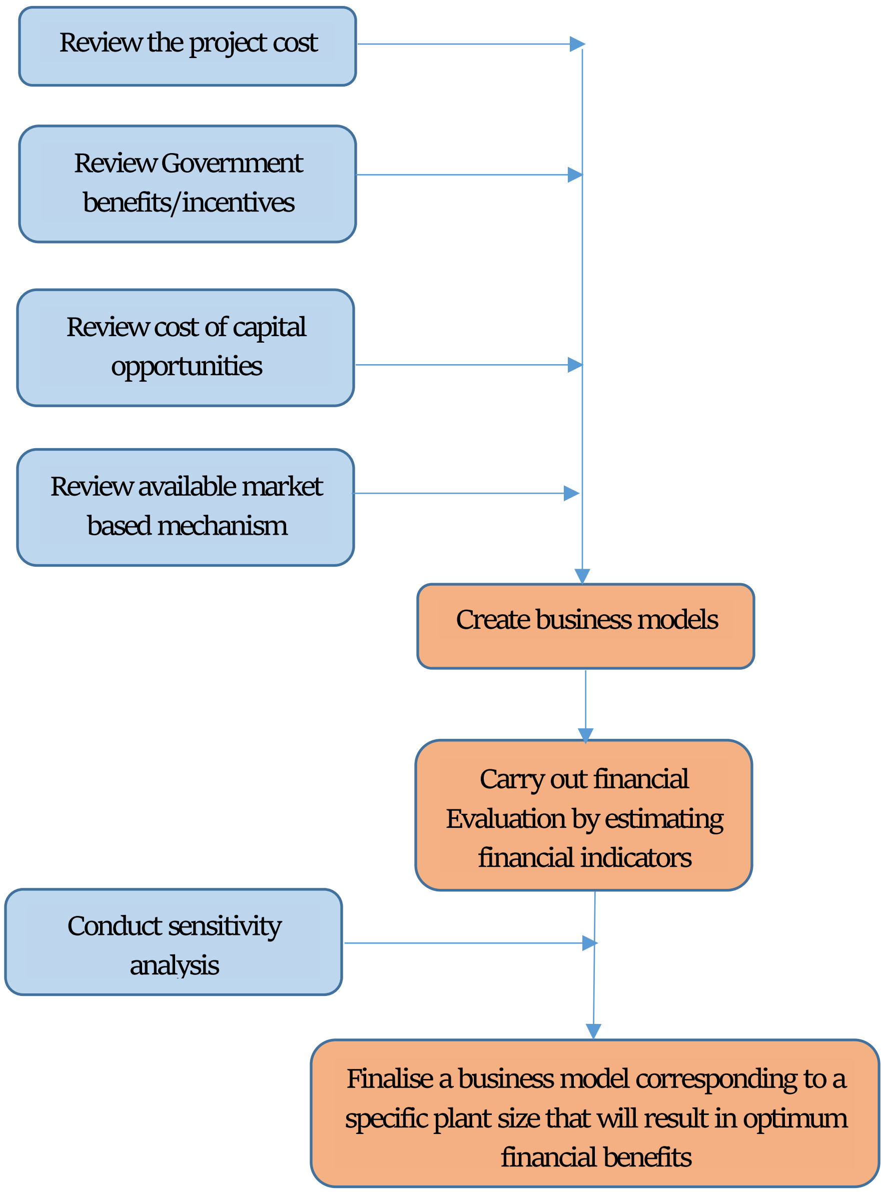
4.6. Outcome of Task 4

At the end of Task 4, the Airport will complete the assessment of financial viability of the solar project. The Airport can also compare the feasibility of the plant by changing project capacity based on electricity banking, net metering and supply opportunities to other users. The outcome of Task 4 will help Airports finalise the solar PV plant capacity and ensure its financial viability.

4.7. Checklist for carrying out financial feasibility assessment of the PV plant and finalisation of business model

- All capital expenses are estimated
- All operation and maintenance expenses of the plant is estimated
- The current electricity cost is assessed
- Identify any government benefits
- Review monetary benefits of market-based market based mechanism for renewable energy projects and emission reduction projects
- Cost benefit estimation is carried out
- Sensitivity analysis is carried out to arrive at final solar PV capacity with optimum financial benefits
- Business model is evaluated and finalized

4.8. Process flow of Task 4



Task 5- Selection of developer/supplier

Intent: Selection of developer/supplier (vendor) for setting up the solar PV plant

The selection of the developer/supplier will be based on the business model selected by the Airport in the previous section. The selection of developer/supplier by the Airport is only required in case the Airport opts for investment model as described in the previous section.

Under investment model the Airport operator may opt for any one of the project development strategy:

- A full turnkey Engineering, Procurement and Construction (EPC) contract or
- A multi-contract approach wherein different agencies will be contracted by the Airport to carry out specific task related to solar PV project development

From an Airports perspective, a full turnkey EPC contract is less tedious than a multi-contract approach. However, a multi-contract approach gives the Airport operator greater control over the final plant configuration. Regardless of the strategy selected by the Airport, there are a certainaspects as mentioned in section 5.1 to 5.3 that are important for developer/supplier selection for setting up the solar PV plant.

For selecting the developer/supplier for setting up the solar PV plant Airports may initiate a bidding process by issuing a bid document, including, scope of work, technical specifications, certification requirements, eligibility criteria, evaluation criteria for supplier/developer selection, timeline for the project implementation, roles and responsibilities of the developer/supplier, business model, supports to be provided by the airport operator, man power requirements and other operational terms and conditions. Some of the key requirements which need to be included in the bid documents are-

5.1. Define the general scope of project for the developer/supplier

5.1.1. Define the scope of work (SoW)

Airports need to clearly define the SoW for prospective developer/suppliers to understand and submit the correct proposal. The SoW may include the services required by the Airport, including designing, planning, scheduling, permitting and constructing, interconnection etc. while ensuring all the terms and conditions set by the Airport. A detailed and accurate the scope of work lowers the risk of disputes and work rectification requirements during execution or construction phase.

The bid document should also clearly define terminal points or points that designate where the contractor's scope of work ends. It should include all supervision, management, labour, plant equipment, temporary works and materials required to complete the project, including (13):

- Develop detailed Plant design (civil, mechanical, electrical, IT, automation etc.)

- Purchasing and installing all plant components such as- PV modules, Inverters, mounting structures, including piled or ballasted foundations, DC cabling, AC cabling, Switchgear, Transformers, Grid connection interface, Earthing and lightning protection, Metering equipment, Monitoring equipment
- Design and execute civil works such as- develop substation building, permanent security fencing, Permanent access tracks (both internal and external) and site drainage etc.
- Security system (during construction and operation)
- Temporary and permanent site works, including provision of water and power
- Plant commissioning and synchronisation with the electricity distribution network
- Handover documentation (including as-built drawings, O&M manual and commissioning certificates)
- Spare parts package etc.

5.1.2. Define eligibility criteria

Airports need to define the eligibility criteria for the interested suppliers/developers to participate in the bidding process. Some of the key points that may be considered are-

- Experience of the interested suppliers
- Available capital and financial stability
- Team strength, qualification and competency of the team
- Reputation, customer feedback and market presence and feedback
- Any other factors which the management wish to consider as a part of company policy

Along with the eligibility criteria, the bid document can also include evaluation criteria for the interested suppliers/developers. The Airport may give some indication of scoring weightage for technical and financial criteria. Some of the technical criteria – such as development risk, supplier capabilities and track record, and customer service and relationships – may carry greater weightage. Clarity in the evaluation criteria will help interested suppliers/developers prepare a relevant proposal for the Airport operator.

5.1.3. Define quality, safety and environmental requirements for the PV plant

Airports may define all desired quality, safety and environmental requirements and certifications requirements for the project from the interested supplier/developer. The responsibility of securing all permits necessary to install the solar plant can be assigned to the interested supplier/developer.

The developer/supplier shall design the plant by taking inputs from relevant studies already conducted by the airport. If needed will carry out additional studies if deemed needed. It is the responsibility of the contractor to assess site topography and geotechnical attributes to estimate costs related to project installation.

For Ground-Mounted Solar

- Mounting system design needs to meet applicable local building code requirements with respect to snow, wind, and earthquake factors.
- Mounting system can either be fixed tilt or single axis tracker.
- Ground cover and vegetation management shall be included in the proposal.
- Storm water management and erosion control management plan shall be included in the proposal.
- All lines interconnecting solar arrays to point of interconnection shall be underground.

For Rooftop Solar

It is the responsibility of the contractor to assess the building structural integrity, roof condition and shading limitations.

- Mounting system shall limit roof penetrations or be fully ballasted. Mounting system design needs to meet applicable local building code requirements with respect to snow, wind, and earthquake factors. Solar system installation should not void the roof warranty.
- Conduit penetrations shall be minimised.
- System layout shall meet local fire department, code and ordinance requirements for roof access.

5.1.4. Define timeline of the bid process

The Airport while preparing the bid document should define the timelines of bid process and steps to be followed for selection of the supplier/developer. It should include proposed project schedule with milestones, clearly defining the timelines of the project start and completions as expected/planned by the Airport.

5.2. Issue tender / bidding document to hire supplier / developer of solar PV

Issue bidding document covering all relevant requirements to the potential supplier/developer. After issuing the bid provide sufficient time and opportunity for clarification of doubts to the potential supplier/developer. Such provisions should be transparently mentioned in the bid document.

5.3. Selection of supplier / developer of solar PV and contract finalisation

The supplier/ developer of solar PV need to be evaluated based on the selection criteria set in the bid document. The Airport may form an evaluation panel of experts for evaluating the proposal. The panel can be a cross functional team from different but relevant departments of the airport such as- engineering team, operations team, environment & sustainability team, finance team, Procurement team etc. Members from Legal team may also be a part of the panel for advice and to negotiate on terms. For this exercise, apart from in house experts, advice of external experts may also be sought (if needed).

After the supplier/ developer is finalised, the next step is to issue a contract to the selected supplier/ developer. While finalising the contract/purchase order, the airport need to ensure that:

- All legal compliances are reviewed and adequately considered
- All the requirements set in the bid documents form a part of the contract
- Management and Business requirements are included
- Timeline of the project is clearly mentioned
- Technical Specifications are in line with global/National standards and codes as applicable to the airport
- Team strength, competency and qualification criteria is mentioned
- All Certification required with respect to all parts and components of the plant is included
- A reviews mechanism is highlighted
- Penalties related to any kind of non-compliances are included

5.4. Outcome of Task 5

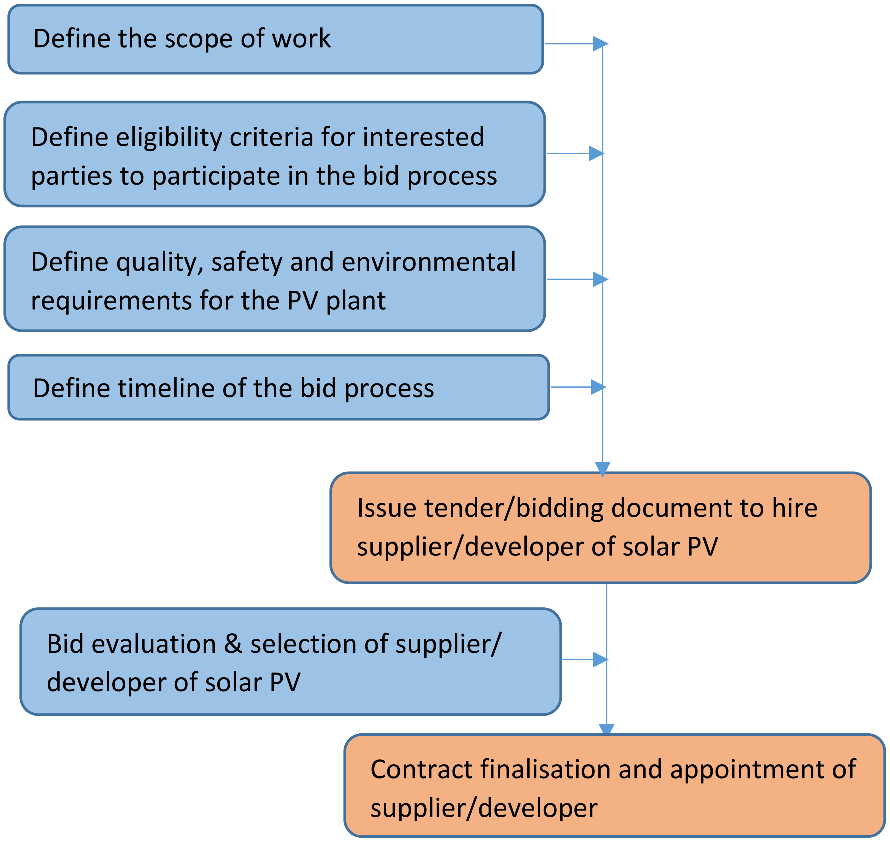
At the end of Task 5, the airport will have developer/supplier on board for setting up the solar PV plant. The outcome of Task 5 will be section of developer/supplier to set up the solar plant and finalisation of contract agreement.

5.5. Checklist for selection of developer/supplier (vendor) for setting up the solar PV plant

A basic checklist for selection of developer/supplier (vendor) for setting up the solar PV plant is presented below

- ☐ Finalisation of project development strategy- EPC or multi contract
- ☐ Finalisation of scope of work
- ☐ Define eligibility criteria of interested suppliers/developers to participate in the bidding process
- ☐ Define bid evaluation criteria
- ☐ Define quality, safety and environmental requirements for the PV plant
- ☐ Define project time schedule with milestones, Gantt chart
- ☐ Issue tender/bidding document to hire supplier/developer of solar PV
- ☐ Formation of an bid evaluation panel
- ☐ Selection of developer/supplier (vendor) for setting up the solar PV plant and contract finalisation

5.6. Process flow of Task 5



Task 6- Plant Construction

Intent: Plan and execute Solar PV installation by the selected developer/supplier

The planning and construction of solar projects depends upon project size, installation platform- building or ground mounted and locations within the Airport. One of the key objective of solar PV plant planning and construction is to attain the required standards of quality as specified by the Airport within the set timeline and budget. There are a number of key activities that needs to be carried out, either by the Airport operator or any other party appointed by the Airport operator (such as concessionaire, EPC contractor or task specific individual contractor) to execute the solar project. These activities are described in the following sections.

6.1. Formulate project execution team

- Identify a "Project Manager (PM)" for executing the project. The PM will ensure the project is completed as designed on time, on budget with accepted level of quality standards.
- Gather a team of electrical, mechanical, civil and environment & sustainability experts having good understanding of solar PV and its implementation requirements.
- Assign the delegation of power and roles and responsibility to the PM and team member.
- Conduct training for all the members to align themselves to the project objectives and requirements such as timelines, quality criteria, deliverables, check lists, commissioning requirements etc.

6.2. Environment, Health and Safety (EHS) Management

6.2.1. Construction EHS plan:

- Develop a construction EHS plan and electrical safety plan before any field work is taken up as per global best practices.
- The environmental, health and safety impact assessment undertaken for each project should result in an EHS Management Plan, which sets out key environmental, health and safety impacts identified for the project and addresses how these will be mitigated.

6.2.2. Obtain all the permissions/site clearances

- Obtain all the permissions/site clearances for setting up the project on rooftop/ground. Some of the licenses are- environmental permits, land use permits, and generator licenses etc.
- As a minimum standard, compliance with local H&S legislation should be documented and rigorously enforced. Some of the common health and safety concerns of solar projects are (13) falls from height, electrocution, incidents involving heavy lifting machinery (i.e., cranes) and traffic accidents are the most common causes of serious worker injuries or fatalities in solar projects.

6.3. Develop and implement construction management plan

The management of the construction phase of a solar PV project should be in accordance with general construction-project management best practices. Airports may develop a comprehensive construction management plan that will integrate all planning and management activities of solar PV projects.

The construction management plan should have the following details-

- **Milestones and timelines**: All project milestones and the expected timescales for completion should be identified. The broader milestones may be subdivided into multiple smaller activities for quick completion and progress tracking.

- **Risk and contingency:** Identify any risk or contingency related to the project. Risk items may include delays, weather risk, staff and equipment availability, transportation, ground conditions and environmental or health and safety incidents.

  Many of these risks can be mitigated during the initial conceptualisation and design stage by conducting studies and addressing through modified plant design. Some risks will remain until the equipment is on site such as lost equipment or equipment damaged in transport and this needs to be addressed through site planning. All the key risk and contingencies need to be assessed and managed throughout the construction process.

- **Restrictions placed on any task**: Restrictions placed on any task should be clearly highlighted in the plan. If there is a possibility of any task interfering airport operation, same shall be mentioned in the plan.

- **Interdependencies & linkages between tasks**: Interdependencies between tasks needs to be identified to schedule implementation of tasks. A project scheduling plan can be developed to indicate the start date of dependent tasks and highlight the critical path.

- **Project critical path identification**: The critical path analysis will enable airports to identify task which may impact project progress either positively or negatively.

- **Task Scheduling**: The plan should include task scheduling based on resource availability and external support and dependencies required. Appropriate sequencing of tasks is a vital part of the planning process. The overall sequence of works is generally site access, site clearance, security, foundation construction, cable trenches and ducts, substation construction, mounting frame construction, module installation, electrical site works, communications, site grid works and finally, testing and commissioning.

- **Quality management:** Controlling construction quality is essential for the success of the project. The quality criteria should be defined clearly in the contract agreements issued to the developer/supplier. An quality management plan can be developed to ensure the stated quality requirements are adhered to during construction of the project. A quality plan should contain details of works, material requirements, standards to be followed, quality certifications to be obtained, tests to be completed within the project, acceptance criteria, details of any records to be kept (for example, photographs or test results), quality audit details etc.

- **Responsibility matrix for tasks**: The plan will also define responsibility matrix for different aspects of the project for smooth co-ordination and completion of the tasks.

- **Progress review:** Review the plant installation as per contract requirements, on project progress, milestones achieved, EHS and quality requirements as well as other requirements to be followed by the solar project developer/supplier. Ensure the project development pre-requirements check sheet (if any) are addressed as per the contract within the timeline by the developer/supplier.

6.4. **Execution of Construction Work**

6.4.1. Civil works

The primary civil works involved in solar projects are- setting up of boundary walls, development of road network and construction of panel foundation in some cases. The design and construction of civil structure should be as per the geotechnical, topographical and other environmental studies carried out as discussed in Section 3 of this document.

Civil works in brown field Airport projects needs to be installed very carefully. Due to the nature of the excavation works digging or pile driving for foundations, it is important to carry out Ground Penetrating Radar (GPR) survey as well.

6.4.2. Mechanical Work

The mechanical construction phase usually involves the installation and assembly of mounting structures on the site. Some of the key points to be focused on are- correct orientation as per design and proper alignment of structures. If a tracking system is being used then- clearance for rotation of modules, proper installation of actuator etc.

6.4.3. Electrical Works

Airports need to ensure installation of solar panels, invertor, storage (battery bank) if any, transformer are connected and necessary testing is done and confirmed by the electrical in charge of the project as appointed/nominated by the Airport.

The Airport operator, while executing electrical works should ensure that-

- Cables are installed in line with the manufacturer's requirements and recommendations.
- The appropriate pulling tensions and bending radii should be adhered to prevent damage to the cable.
- Cables attached to the mounting structure require the correct protection, attachment and strain relief to make sure that they are not damaged.
- Underground cables should be buried at a suitable depth as per the best industry practices.
- Comprehensive tests should be undertaken prior to energisation to ensure that there has been no damage to the cables.

6.5. Construction supervision

It important for the Airport operator keep a track of project developments during construction. For this construction supervision may be carried out by the Airport by deploying in-house resources or by hiring external experts. The role of the construction supervisor is to ensure contractors adhere to the agreed terms and project requirements. The construction supervisor will also review the proposed designs, witness key tests and report to the Airport.

6.6. Outcome of Task 6

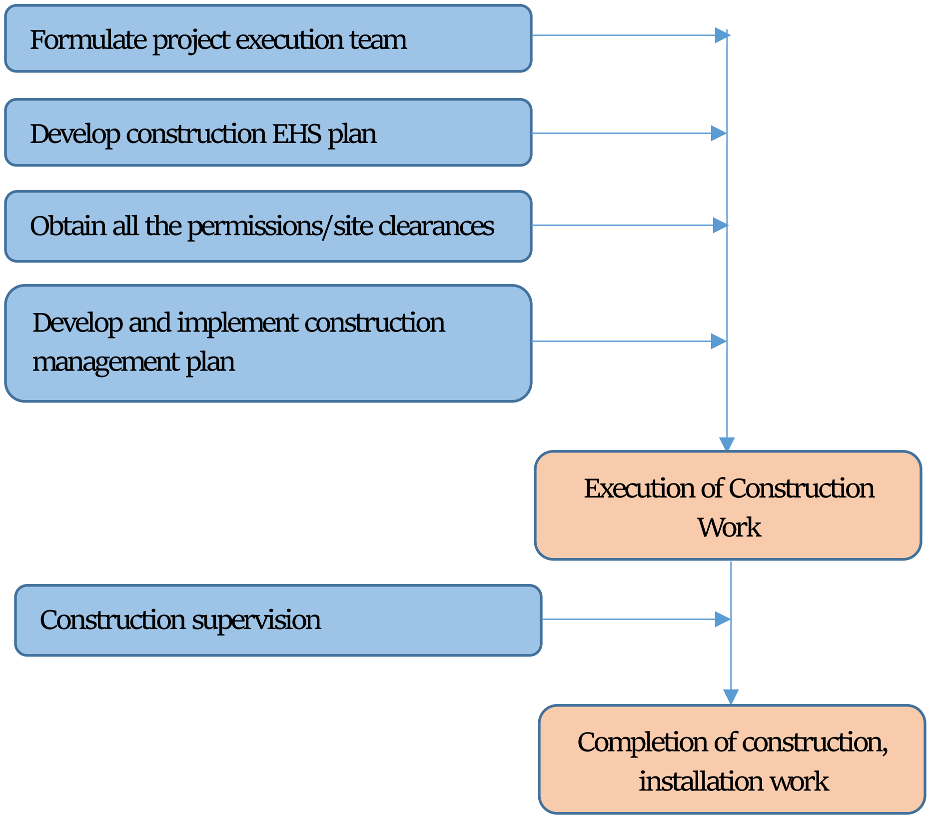
At the end of Task 6, the construction and installation of the solar project will be completed. This includes all civil, mechanical, electrical, fire, IT and automation related work as per industry standard, following all rules and regulation.

6.7. Checklist for planning and execution of solar PV installation

A basic checklist for planning and execution of solar PV installation is-

- [ ] Formulation of project team
- [ ] Development of construction of EHS plan
- [ ] Obtain all the permission and site clearance to initiate construction
- [ ] Design documentation completed
- [ ] Develop construction management plan covering all the key aspects of the project
- [ ] Execution of civil, mechanical and electrical works
- [ ] Carry out construction supervision and ensure
- [ ] Work completion as per construction management plan

6.8. **Process flow of Task 6**:



Task 7- Plant commissioning

Intent: Carry out commissioning of the solar PV plant, set up grid connection and perform plant acceptance testing.

7.1. Initiate commissioning activities

The commissioning process certifies that the Airport operator's requirements have been met, the PV plant installation is completed, the plant complies with grid and safety requirements and the plant is ready for generating electricity. Successful completion of the commissioning process is often considered to be part of the provisional or final acceptance of the PV plant.

Commissioning activities should commence following mechanical completion of the plant's various subcomponents or, where appropriate, sequentially as module strings are connected. For power plants employing modules which require a settling-in period, for example, thin film amorphous silicon modules, performance testing should begin once the settling in period has been completed.

Ideally, commissioning should be carried out by an independent specialist third party selected by the Airport. The third party should develop a commissioning plan highlighting task to be performed, testings to be done, documents to be prepared and incorporate any requirements set by the Airport operator. The commissioning plan needs to be approved by the Airport operator.

The commissioning process should include both visual and electrical testing. In particular, visual testing should be carried out before any system is energised. A useful reference for commissioning of PV systems can be found in IEC standard 62446:2009 Grid connected photovoltaic systems—Minimum requirements for system documentation, commissioning tests and inspection (13).

Commissioning should follow three main objectives (10):

- The power plant is structurally and electrically safe.
- The power plant is sufficiently robust (structurally and electrically) to operate for the specified lifetime of a project.
- The power plant operates as designed and its performance is as expected.

Critical elements of a PV power plant that require commissioning include (10): Module strings, Inverters and Transformers, Switchgear, Lightning protection systems, Earthing and electrical protection systems, Grid connection compliance protection and disconnection systems, Monitoring systems (including irradiation sensors), Support structure and tracking systems (where installed).

7.2. Commissioning test

Prior to connecting the plant to the grid, electrical continuity and conductivity should be checked by the electrical contractor. Once completed, pre-connection acceptance testing should be carried out on the DC side of the inverters. These tests include:

7.2.1. Polarity Check

The polarity of all DC cables should be checked. This is one of the simplest and most important safety commissioning tests. Several rooftop fires involving PV systems have been traced back to reverse polarity.

7.2.2. Open Circuit Voltage Test

This test checks whether all strings are properly connected (module and string polarity) and whether all modules are producing the voltage level as per the module data sheet. The test should be conducted for all strings. The open circuit voltage, Voc, of each string should be recorded and compared with temperature adjusted theoretical values.

7.2.3. Short Circuit Current test

This test verifies whether all strings are properly connected and the modules are producing the expected current. The test should be conducted for all strings. The short circuit current, I_{sc}, of each string should be recorded and compared with the temperature adjusted theoretical values.

7.2.4. Insulation Resistance Test

The insulation resistance of all DC and AC cabling installed should be tested with a megohm meter. The purpose of the test is to verify the electrical continuity of the conductor and verify the integrity of its insulation.

7.2.5. Earth Continuity Check

Where protective or bonding conductors are fitted on the DC side, such as bonding of the array frame, an electrical continuity test should be carried out on all such conductors. The connection to the main earthing terminal should also be verified.

After the above commissioning tests have been successfully completed and the correct functioning and safe operation of subsystems have been demonstrated, commissioning of the inverters may commence. The inverter manufacturer's directions for initial start-up should always be adhered to.

7.3. Grid Connection

Grid connection should only be performed once all DC string testing has been completed. It is likely that the distribution or transmission system operator will wish to witness the connection of the grid and/or the protection relay. Such a preference should be agreed in advance as part of the connection agreement. The grid connection agreement often stipulates the level of parameters—such as electrical protection, disconnection and fault—to which the PV power plant is required to adhere. Some location may also have standard grid code clearly specifying the compliance requirements. Usually, these conditions need to be met before establishing the grid connection.

7.4. Performance Ratio Test

This test checks if the power plant is performing at or above the performance ratio agreed or warranted within the EPC contract. A standard testing period is continuous testing for a minimum of five days of consecutive testing. It is desirable to test plant efficiency and reliability over a range of meteorological conditions.

The PR measured over the test period should be compared against the guaranteed value stated in the contract. If the measured PR exceeds the guaranteed value then the test is passed. If the measured PR is significantly below the guaranteed value, the contractor should perform investigations into the reasons for plant under-performance and rectify these prior to repeating the test.

7.5. Provisional acceptance

The criteria for achieving provisional acceptance should be clearly outlined in the contract issued to the supplier/developed and may include:

- Completion of all mechanical works
- Grid connection and energisation of the plant have been achieved
- All commissioning tests have been successfully completed
- The provisional acceptance performance ratio (PR) test has been passed
- All handover documentation is in place and hard and soft copies provided to the owner
- Operation and maintenance training of the Airport staff has taken place
- Any delay or performance-related liquidated damages (LDs) imposed by the Airport have been paid by the supplier/developer.

7.6. Intermediate and final acceptance

In addition to the short term PR test at provisional acceptance, the supplier/developer need to provide a PR guarantee to be measured at one or two separate occasions within the defects warranty period. The defects warranty period is usually two years following the date of provisional acceptance, during this period the contractor is responsible for the rectification of any defects that may be identified during this period.

Industry best practice is for the PR to be tested annually over the first two years of plant operation. Testing plant PR annually removes the risk of seasonable bias affecting the PR calculation and allows for a true appraisal of plant performance. PR testing over the first year of operation is referred to as the intermediate acceptance test while PR testing during the second year of plant operation is called final acceptance testing. If these performance tests are passed (along with other contractual conditions) then an Intermediate Acceptance Certificate (IAC) and Final Acceptance Certificate (FAC) may be issued by the Airport.

If the PR measured during the IAC or FAC tests were less than the guaranteed levels, then the contractor would be required to pay LDs to the owner to compensate for anticipated revenue losses over the project lifetime. There may be different means to estimate LDs. One way of estimating LD is calculating net present value (NPV) based on the revenue forgone over the life of the project as a result of the shortfall in performance.

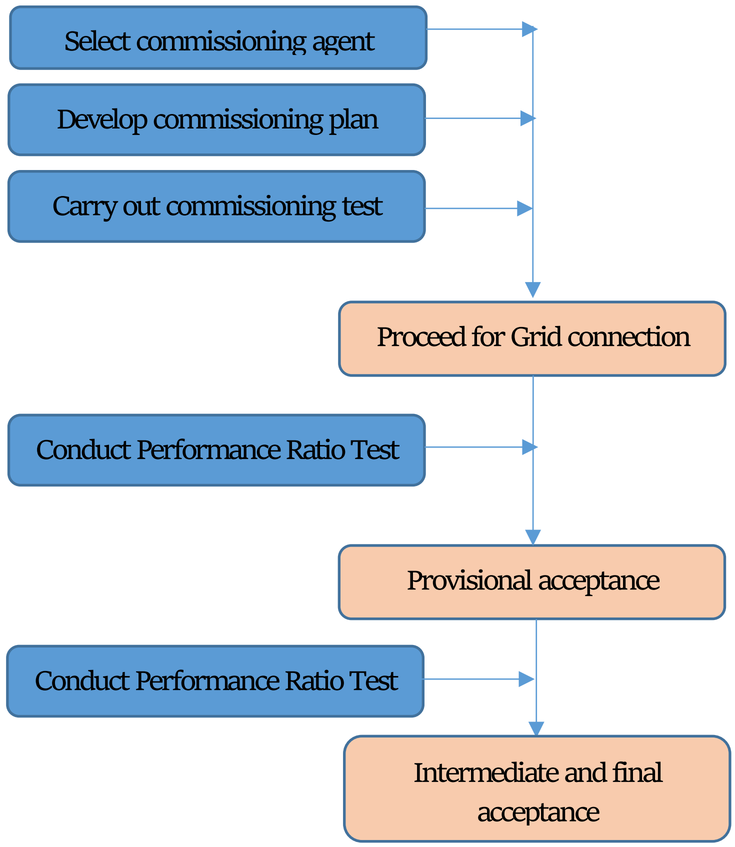
7.7. Outcome of Task 7

Completion of Task 7 will ensure that, all the testing and commissioning of the plant has been carried out and it fulfills all design, standards and regulatory requirements and the project is ready for synchronisation with grid. However, Task 7 will get terminated only after 2 year PR test is conducted and final acceptance is issued by the Airport to the supplier/developer.

7.8. Check list for carrying out commissioning of the solar PV plant, set up grid connection and plant acceptance

- ☐ Commissioning agency appointed
- ☐ Commissioning plan prepared by the agency and approved by the Airport operator
- ☐ Carry out polarity check
- ☐ Carry out open circuit voltage test
- ☐ Carry out short circuit current test
- ☐ Carry out insulation resistance test
- ☐ Carry out earth continuity check
- ☐ Review the requirements of grid connection and ensure compliance
- ☐ Conduct performance ratio (PR) test
- ☐ Review the PR test results with the agreed PR results as agreed with the developer/supplier
- ☐ Handover document received from the developer/supplier
- ☐ Any liquidated damages (LDs) imposed by the Airport have been paid by the supplier/developer
- ☐ Conduct 1 year PR test and complete intermediate acceptance
- ☐ Conduct 2 year PR test and complete final acceptance

7.9. Process flow of Task 7



Task 8- Operation & Maintenance

Intent: Ensure operation and maintenance requirements are fulfilled as per Original Equipment Manufacturers (OEM) recommendations

Compared to most other power generating technologies, PV plants have low maintenance and servicing requirements. However, proper maintenance of a PV plant is essential to optimise energy yield and maximise the life of the system.

8.1. Performance monitoring, evaluation and optimization

For ensuring performance monitoring, evaluation and optimisation the below actions may be implemented by the Airport-

- Conduct Plant performance monitoring with a schedule and Original Equipment Manufacturers (OEM) recommendations.
- Develop technical reporting with key performance indicators for the plant
- Develop Document Management System (DMS) to keep plant manuals and all other relevant documents updated
- Carry out continuous review of the plant performance to identify errors and minimise losses.
- Ensure all Safety requirements covering occupational safety, airport safety and aircraft safety addressed as per contract and airport operation.

8.2. Maintenance Management

Scheduled maintenance increases production and the life of the plant. However, it also adds cost to the project both in terms of expense and lost revenue due to stoppage of plant operation. Therefore, the aim should be to seek the optimum balance between the cost of scheduled maintenance and increased yield over the life of the system.

The solar plants should follow Original Equipment Manufacturers (OEM) recommendations, while conducting scheduled maintenance. Some of the scheduled maintenance activities are (13)-

8.2.1. Module cleaning

Module cleaning is simple but important task for improving plant performance as cleaned panels tend to generate more electricity as compared to panels with dust layers.

8.2.2. Module connection integrity

Checking module connection and ensuring its integrity is important for systems that do not incorporate monitoring at the module string level. If the plant does not use string level monitoring, then the Airport may ask the O&M contractor to check the connections between modules within each string on a regular basis.

8.2.3. Junction or string combiner box

All junction boxes or string combiner boxes needs to be checked at regular interval for water ingress, dirt or dust accumulation to ensure integrity of the connections within the boxes. Any loose connections may affect the overall plant performance. Any accumulation of water, dirt or dust may lead to corrosion or short circuit within the junction box.

If string level monitoring is not used, the Airport may ask the O&M contractor to conduct periodic checks, at least on an annual basis for integrity of the fuses in the junction boxes, combiner boxes and, in some cases, the module connection box.

8.2.4. Hot spots

It is very important to identify any faults in the PV plants and such hotspots may be detected through thermography. This helps in identifying weak and loose connections within the PV system, which is a common problem in hot climates where large variations between day and night temperatures may lead to loose connections. Thermography can also help in detecting hot spots within inverter components and on modules that are not performing as expected.

8.2.5. Inverter servicing

The scheduled maintenance of inverters should be treated as a key part of the O&M strategy as inverter faults are the most common cause of system downtime in PV power plants. Regular preventative maintenance for an inverter may include:

- Visual inspections
- Cleaning/replacing cooling fan filters
- Removal of dust from electronic components
- Tightening of any loose connections
- Any additional analysis and diagnostics recommended by the OEM

8.2.6. Structural integrity

The module mounting assembly, cable ducts and any other structures built for the solar PV power plant should be checked periodically for mechanical integrity and signs of corrosion. This will include an inspection of support structure foundations for evidence of erosion from water run-off (wherever required).

8.2.7. Balance of plant

The remaining systems within a solar PV power plant, including the monitoring and security systems, auxiliary power supplies, and communication systems, should be checked and serviced regularly. Communications systems within and externally connected to the PV plant should be checked for signal strength and connection.

8.2.8. Vegetation control

Vegetation control and ground keeping are important scheduled tasks for solar PV power plants. There is a link between this matter and the Airport's flora and fauna policy.

8.2.9. Unscheduled / preventive maintenance

Unscheduled maintenance is carried out in response to failures. As such, the key parameters when considering unscheduled maintenance are diagnosis, speed of response and repair time. The agreed response times and process should be clearly stated within the O&M contract

8.3. Spare parts

In order to facilitate a rapid response in the event of equipment failure, a suitably stocked spare parts inventory is essential. Spare parts and consumable inventory. In general, adequate supplies of the following essential components should be held:

- Mounting structure pieces.
- Junction/combiner boxes.
- Fuses.
- DC and AC cabling components.
- Communications equipment.
- Modules (in case of module damage).
- Spare inverters (if string inverters are being used) or components according to manufacturer's recommendations in the case of central inverters.
- Spare motors, actuators and sensors where tracking systems are used.

8.4. Performance monitoring, evaluation and Optimisation

To optimise system performance, Airports need to ensure that the plant components function efficiently throughout the lifetime of the plant. Continuous monitoring of PV systems is essential to maximise the availability and yield of the system.

8.5. Managing of end of life solar panels

Addressing the end of life solar panels is an important area. This is a growing area of concern and airports need to plan and manage end of life solar panels as well as other components of the plant. Many components of solar panels made of crystalline silicon can be recycled. In many countries waste/damaged solar panels are considered as electronic waste and needs to be managed as per the provisions of the regulations. Airports may address this issue by incorporating the panel management/ disposal requirements as part of panel supply or O&M contracts. The end of life disposal can also be incorporated in the supply or O&M contracts by the Airports. For more details on end of life management of solar panels, Airport may refer to IRENA report on this (19).

8.6. Outcome of Task 8

Completion of Task 8 will ensure performing required O&M activities of the solar plant and maintain optimum performance. This is a continuous task and needs to be performed throughout the life time of the project.

8.7. Checklist for carrying out O&M of Solar Plant

- The O&M contractor should be suitably experienced and familiar with the PV technology.
- Performance guarantees included in the O&M Contract
- Liquidated damages (LDs) condition is linked to performance guarantee.
- Spare parts management requirements are clearly defined in the O&M
- Rules for subcontracting clearly defined to ensure principal contractor is fully responsible for all sub-contractor works.
- All equipment of the plant to be maintained in line with OEM requirements.
- Preventative maintenance requirements are defined in contract so that the need for corrective maintenance is reduced

Solar Panels End-of-Life Considerations

According to World Economic Forum, Solar panel recycling is no longer an afterthought: it's an environmental necessity and an economic opportunity. A recent projections indicate recyclable materials from solar panels will be worth more than $2.7 billion by 2030, up from $170 million this year. Unlike many consumer electronics, solar panels have a long lifespan that extends 20 to 30 years. therefore, solar panel recycling is a relatively new concept, leading some to wrongly assume that end-of-life panels will all end up in the landfill. Although in its early stages, solar panel recycling technology is well underway. With the exponential growth of solar power, recycling should be scaled up quickly. Airports should have solar panel recycling in mind for plant decommission. This aspect is also discussed in Section 8.5 of this document.

Case Studies
Adelaide Airport

Adelaide Airport Ltd (AAL) completed construction of a 1.17MW solar PV installation on the multi-level car park roof in March 2016. It is the largest rooftop system, and second largest overall, in South Australia. It is also the largest rooftop installation at any Australian airport and one of the largest private, commercial (non-utility scale) arrays of any kind in Australia.

The system is expected to generate over 1.730MWh per year, which equates to approximately 10% of AAL's total electricity consumption. Between April and November 2016, AAL's retail metered electricity consumption was 10,873MWh and the solar PV system had generated 860MWh or 7.3% of overall use. System output will increase significantly in the upcoming summer months relative to consumption, and is on track to meet the 10% target.

Such a large-scale solar PV system was pursued for a slew of financial and non-financial benefits, notably:

- meeting the airport's corporate carbon targets and thereby supporting ACI *Airport Carbon Accreditation* status
- reducing risk exposure to increasing electricity prices
- enhancing the airport's reputation and environmental credentials
- meeting investors' environmental, social and governance (ESG) risk expectations
- improving potential rental returns from future surrounding commercial development
- investment toward energy self-sufficiency

A number of project elements are worthy of particular attention:

- this system was funded entirely by AAL, with no government support
- the project was one of the first globally to use SMA 60kW inverters – a larger commercial-scale unit – which resulted in a reduction in the inverter room footprint of 75%
- DC optimised (TrinaSmart) panels were used, reducing the performance limitations caused by shading and providing the best mitigation strategy for fire risk
- The contractor, Solgen Energy, committed to using 70% local labour and invited tertiary vocational students to participate in the system commissioning phase.

Project Graphics

Figure 14: Adelaide Airport 1.17MW Solar Installation

Figure 15: Rooftop View of Adelaide Airport Solar Installation

Figure 16: Inverter Room of Adelaide Airport Solar Plant

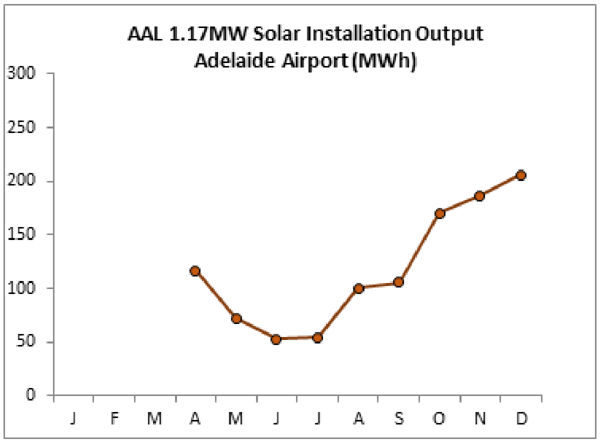


Figure 17: Adelaide Airport Solar Generation (Apr-Dec 2016)

Darwin International Airport

Northern Territory Airports has made a long-term commitment to using renewable energy across its three airports in Darwin, Alice Springs and Tennant Creek. The organisation is mindful of the contribution the aviation industry makes to greenhouse gas emissions, and is keen to lead the way for other airports – both national and international – by reducing its carbon footprint. This continued focus aims to minimise the airport's impact on the environment, optimise airside land use, increase non-aeronautical revenue and showcase new solar technologies, for the benefit of the organisation, stakeholders, community and the environment.

The series of solar power facilities across its three airports lead the way in development, innovation and investment. Northern Territory Airport's flagship facility, Darwin Airport Solar Project, is the largest airside PV (photovoltaic) solar facility in the world. It is also Australia's most northern multi-megawatt PV array and the largest BTM (behind the meter) system designed and built for a single building/facility in Australia.

The project was developed in two stages resulting in an impressive 5.5 megawatt facility. The development was managed entirely by the airport from beginning to end. This includes feasibility, design, construction and operation. Darwin Airport consumes all the solar power generated for its own use.

This facility generates 25 per cent of the airport's overall energy needs and meets 100% of the daily peak demand. Not only do the environmental benefits manifest with a 25% reduction in carbon emissions from stationary energy, the significant investment of capital towards this project, enables Darwin International Airport to hedge the exposure of the airport to fluctuations in electricity prices thus providing greater certainty for the broader airport community and interested investors, partners and stakeholders.

As early adopters of large scale solar in 2011, and with ongoing investment in ground-based and rooftop solar projects, NT Airports' renewable energy generation has achieved significant cost savings and emissions reductions. NT Airports is now leveraging further value from its renewable energy investments through seizing emerging market opportunities brought about by stakeholders wishing to reduce emissions and reduce energy costs.

For NT Airports, the emerging shared challenges of climate change have brought stakeholders together and been a driver for strengthening strategic partnerships with government and business. These valuable partnerships have enabled NT Airports to influence new policy, open up new markets (in renewable energy export, electric vehicle infrastructure and electric ground support equipment for airlines) and strengthen its reputation in innovation, corporate responsibility and climate leadership.

An organisation that welcomes innovation and understands the regional challenges of climate change and its impacts on stakeholders, is well placed to prosper in this new era.

Project achievements include:

1. The completion of Bay 2 apron, aerobridge, PCA in November 2021
2. The completion of 6 rooftop solar projects from 2017 – 2021 to support solar-generated energy for airline uses via the eGPU and PCA units
3. New solar investment showed that although DIA recently acquired two hotels and included them within their carbon accounting that DIA currently power 67% of the airport using solar-generated energy.
4. New aircraft ground power incorporates cutting edge battery powered solid-state converters that are charged via the airport's solar farm during the day.
5. An eGPU can supply electricity for up to ten standard aircraft turnarounds before needing to recharge.
6. Preconditioned Air will allow greater passenger and crew comfort while embarking/disembarking.
7. DIA is on track to meet its scope 1 and scope 2 net zero emissions reduction target by 2030
8. Greenhouse gas savings from the generation of renewable energy at DIA equates to a reduction of 4558 tonnes of CO_2
9. Each battery powered eGPU saves the equivalent of 100 acres of forest per year in CO_2 emissions
10. Efficient aircraft ground power and preconditioned air reduces carbon emissions and noise pollution, helping the airport to meet its environmental targets, increase safety and improve passenger comfort

Project Graphics

Figure 18: Darwin Airport Solar Project Stage 1

Figure 19: Darwin Airport Solar Project Stage 1, before and after

Figure 20: Darwin Airport feature in Territory Q magazine

Figure 21: View of Darwin Airport Solar Plant from tower

Figure 23: Ground source heat pump in International Terminal Building of Darwin Airport

AIRPORTS POWERED BY SMART THINKING

The operator of the Northern Territory's three main airports is using the power of the sun in an innovative, cutting-edge way.

Figure 22: Article on Darwin Airport in Northern Territory Business Magazine

Figure 25: Solar system on cold store Facility 2021

Figure 24: Recently installed preconditioned air unit Bay 2 – November 2021

Indira Gandhi International Airport

Delhi International Airport Limited is Asia Pacific's first Level 4+ certified Airport. The Airport is currently working towards becoming a Net Zero Carbon Emission Airport by 2030. As part of the Net Zero initiative DIAL has developed onsite solar PV plant. The current capacity of the solar plant is 7.84 MW. DIAL had setup a 2.14 MW solar plant in the airside area in January 2014 as pilot plant. This is the first MW scale solar project to be commissioned inside airport premises of any airport in India. Later on in 2016, DIAL added another 5.7 MW to the existing 2.14 MW plant.

For setting up the facility, DIAL conducted a feasibility study of all the available locations within the Airport. Various locations such as roof, car parking and land surfaces etc. were reviewed and finally location in the airside (Figure 19) was selected.

A special glare analysis was carried out to review the impact of the solar panels on runways and on airport operational procedures. The study was submitted to Directorate General of Civil Aviation, India (DGCA) and Airport Authority of India (AAI) and a special permission was obtained. The key criteria while selecting the PV modules were to ensure low glare and highly efficiency. DIAL has adopted two seasonal tilt (summer & winter) are provided for harvesting maximum energy yield and while ensuring the glare is minimised to an acceptable level.

DIAL also conducted geotechnical studies to determine the type of module mounting structure erection methodology. In the project column posts are rammed directly to the ground at a depth of 1.5 meters from the ground level. Four ramming machines were deployed at site for early completion of structure. The plant is currently operating successfully and generates approximately 11700 MWh of electricity per year. This also helps in avoiding approximately 9200 tCO_2/year.

Figure 27: Solar Plant location of Delhi Airport

Figure 26: Solar plant of DIAL

Kuala Lumpur International Airport

As part of Malaysia Airports Holdings Berhad's (MAHB) commitment and support towards Malaysia Government's commitment in reduction of Green House Gases (GHG), MAHB has pioneered into its maiden Renewable Energy initiative in Kuala Lumpur International Airport (KLIA) in 2012.

MAHB has completed the development of its impressive 14MWp Photovoltaic (PV) Solar Power Plant Facilities at Kuala Lumpur International Airport (KLIA) in 2013. The project includes the Development, Design, Engineering, Supply, Installation, Testing, Commissioning, Operation, Management and Maintenance of the Solar PV Facilities. This project was conducted through concessionaire agreement for a period of 21 years.

Utilising the available buffer area and space in KLIA vicinity, 10MWp Solar PV was installed as parking canopy at KLIA Long Term Car Park and another 4MWp was installed at KLIA Satellite Rooftop. The project does not require additional transmission lines as the installation of solar at both facilities are generated at the point of consumption.

The solar facilities are capable to generate up to 7% of the KLIA's total electricity needs and are expected to generate an average of 18,000 MWh yearly which is equivalent to carbon emission reduction of 13,811 tCO2e.

Continuing with the momentum of KLIA's success, starting from 2020, MAHB has expanded the solar implementation to other airports. As of 2022, Solar PV have been installed and commissioned at Langkawi International Airport, Penang International Airport, Kuantan Airport, Melaka Airport. Currently we are moving towards completing the installation and commissioning at other 3 other airports which are Kota Kinabalu International Airport, Ipoh Airport and Alor Star Airport. Upon completion of these 3 airports, MAHB will have an additional total of up to 9.5MWp of Solar PV facilities under its belt. The solar generation from these airports are estimated to reduce carbon emissions of around 7,000 tCO2e yearly.

Project Graphics

Figure 29: Rooftop, Satellite Building KLIA

Figure 28: Long Term Car Park KLIA

Figure 32: Rooftop Solar, Melaka Airport

Figure 31: Rooftop, Langkawi International Airport

Figure 30: Rooftop, Penang International Airport

Sharjah International Airport

By inspiring from UAE Vision 2021 and its national target to replace 27% of conventional energy sources with clean energy sources Sharjah International Airport Management decided to introduce clean energy sources at the Airport as a part of its "Go Green" Policy.

The "GREEN PARKING" Project was implemented at three locations in the airport. The project includes the installation of Solar lighting system at two newly build car parking's and pedestrian walk way in departure car parking. By choosing solar energy for lighting system for these areas Sharjah International Airport manage to avoid a marginal amount of energy consumption from conventional sources and replace it with clean energy sources.

The newly build car parking are new rent a car parking and Sharjah Airport Authority (SAA) management car parking. New rent a car parking located next to arrival car parking near the passenger terminal which planned and build to provide permanent parking facility to the cars belongs to rent a car companies operating at Sharjah International Airport. The new management car parking located next to SAA Building and designed to provide parking facility for Management staff at Sharjah Airport Authority and Department of Civil Aviation. The third area covered under "GREEN PARKING" project is the pedestrian walk-way from departure car parking to terminal building which provides easy access to passengers from departure car parking to departure terminal.

All three area's together cover a total area of 7773 m^2 with 33 solar panels installed across. A total of 30 numbers of street lights with 60 watt capacity and 20 number of street light with 9 watt capacity and 61 fluorescent lamps with 9 watt capacity connected to these panels to provide sufficient lighting from walk-way from the parking area. The total capacity of Solar panels installed is 8270 watts per hour.

Project Graphics

Figure 33: Car parking area of SAA (1)

Figure 34: Car parking area of SAA (2)

Figure 35: Management Car parking of SAA

Figure 36: Pedestrian walk-way in departure parking of SAA

Airport Solar Installation Parameters

Example 1: Kuala Lumpur International Airport

No.	Description	Inputs	Details
1.	Airport	Name	Kuala Lumpur International Airport (KLIA)
		Location/City	KLIA, Sepang, Selangor
		Country	Malaysia
		ICAO Code	WMKK / KUL
2.	Installation	Solar Capacity (in MWp)	14MWp
		Total Cost of the Plant ($)	Concession Agreement – Around RM200mil
		Total Land Occupied (Acres)	Site Area (PV area) 1. Satellite: 8 acres 2. Car Park: 16.9 acres
		Onsite/Offsite	Onsite KLIA
		Roof/Ground mounted	Satellite Building- Rooftop Long Term Car Park -Parking Canopy
		Airside/City side	Satellite Building (Airside) Long Term Carpark (Landside)
		Solar Generation Efficiency (Performance Ratio) (in %)	80%
3.	Energy	Overall Energy Demand (in Million Units/Year)	405,000MWh
		Solar Contribution (in Million Units/year)	18,000 MWh
		Solar Contribution to overall energy Peak Demand/ year (in %)	4-7%
		Solar Energy Use (Captive/Gird/Hybrid)	Captive
4.	Solar PV Module	Make	SunEdison MEMC
		Type	MEMC Multi Crystalline
		Specification	MEMC (285/290/295/300)
		Glare or Antiglare	Antiglare
5.	KPIs	Key Performance Indicator Used by the Airport for performance monitoring	Solar Generation Efficiency Performance (%) & Declared Annual Availability (DAA)
6.	Business Module	CAPEX Modal (One Time Investment by the Airport)/ - OPEX / PPA Model	Concession agreement
7.	Any other Information	• SMA Central Inverters (98% efficiency) • Long Term Car Park - 34,104 solar panels are used • Satellite Building - 13,920 panels are used	

Example 2: Indira Gandhi International Airport

No.	Description	Inputs	Details
1.	Airport	Name	Indira Gandhi International Airport, New Delhi
		Location/City	New Delhi
		Country	India
		ICAO Code	DEL
2.	Installation	Solar Capacity (in MWp)	7.84 MWp
		Total Cost of the Plant ($)	83,377 USD
		Total Land Occupied (Acres)	27.00
		Onsite/Offsite	Onsite
		Roof/Ground mounted	Ground Mounted
		Airside/City side	Airside
		Solar Generation Efficiency (Performance Ratio) (in %)	78%
3.	Energy	Overall Energy Demand (in Million Units/Year)	253 Millions
		Solar Contribution (in Million Units/year)	11 Million Units
		Solar Contribution to overall energy Peak Demand/ year (in %)	4-6%
		Solar Energy Use (Captive/Gird/Hybrid)	Captive
4.	Solar PV Module	Make	Canadian Solar / Renesola
		Type	Virtus II (Polycrystalline) 156 x156 mm, 72 (6x12) pcs in series
		Specification	• High Module Conversion Efficiencies • Mechanical Load Capability of up to 5400 Pa • Module Efficiency- 15.7%
		Glare or Antiglare	Antiglare
5.	KPIs	Key Performance Indicator Used by the Airport for performance monitoring	Solar Generation Efficiency (%)
6.	Business Module	CAPEX Modal (One Time Investment by the Airport)/ - OPEX / PPA Model	CAPEX
7.	Any other Information	• Plant Installed at South Side of RWY 11/29 and 1st of kinds Airport in Asia Pacific • Selected Non reflective Solar Photovoltaic solar panels • High efficiency Solar panels (15.23%) • High efficiency Central Inverters (98.60%) • Plant Load Factor greater than 17.5% despite severe winter period • Seasonal tilt of panels are maintained	

Abbreviations

AAL	Adelaide Airport Ltd
AC	Alternating current
ACI	Airports Council International
AP	Asia Pacific
AHU	Air Handling Unit
AM	Air Mass coefficient
BHS	Baggage Handling Ystem
BS	British Standard
CdTe	Cadmium telluride
CIGS/CIS	Copper indium gallium selenide
CMP	Carbon Management Plan
CO2	carbon dioxide
CSR	Corporate Social Responsibility
DC	Direct Current
DMS	Document Management System
EHS	Environment, Health and Safety
EN	European Standards
EPC	Engineering, Procurement and Construction
ESG	Environmental, Social and Governance
FAA	Federal Aviation Administration
FAC	Final Acceptance Certificate
GHG	Greenhouse gas
GPU	Ground Power Unit
HOMER	Hybrid Optimisation Model for Electric Renewable
HV	High Voltage
IAC	Intermediate Acceptance Certificate
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFALPA	International Federation of Air Line Pilots' Associations
IPCC	Intergovernmental Panel on Climate Change
iREC	International Renewable Energy Certificate
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
I_{SC}	Short-Circuit Current

IT	Information Technology
KLIA	Kuala Lumpur International Airport
kWh	kilo Watt hour
kWp	Kilo Watt (peak)
LCOE	Levelised Cost of Energy
LD	liquidated damages
MAHB	Malaysia Airports Holdings Berhad
MCB	Miniature Circuit Breakers
MTBF	Mean time between failures
MVA	Mega Volt Ampere
MWh	Megawatt hour
NOC	No Objection Certificate
NPV	Net Present Value
PCA	Pre-Conditioned Air
PR	performance ratio
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
PVOUT	PV power output
PVsyst	Photo Voltaic systems
RE	Renewable Energy
REC	Renewable Energy Certificate
RoI	Return on Investment
SAA	Sharjah Airport Authority
SAM	System Advisor Model
SCADA	Supervisory control and data acquisition
SoW	Scope of Work
STP	Sewage Treatment Plant
UAE	United Arab Emirates
UL	Underwriter Laboratories (UL, LLC)
USD	United States Dollar
VHT	Vertical & Horizontal Transmission
Voc	Open Circuit Voltage
W	Watt
Wp	Watt (peak)
WTP	Water Treatment Plant

References

1. (2019). *A Focus on the production of renewable energy at the Airport site.* ICAO https://www.icao.int/environmental-protection/Documents/Energy%20at%20Airports.pdf.

2. (2014). *Climate Change 2014 Mitigation of Climate Change.* IPCC.

3. (2018, December 5). *Position Paper - Solar Panel Installations at Airports.* Retrieved from https://www.ifalpa.org/publications/library/solar-panel-installations-at-airports--2744

4. (2019). Retrieved from World Energy Outlook 2019, IEA, Paris: https://www.iea.org/reports/world-energy-outlook-2019

5. (2018). *IPCC*. Retrieved from https://www.ipcc.ch/sr15/

6. (n.d.). *Zurich Airport*. Retrieved from Zurich Airport: https://www.flughafen-zuerich.ch/-/jssmedia/airport/portal/dokumente/das-unternehmen/politics-and-responsibility/environmental-protection/tools/airport-pv-analyzer_zrh.xlsx?vs=1

7. (2012). *Solar Photovoltaics.* IRENA.

8. (2020, April). *IRENA*. Retrieved from Global Renewables Outlook: Energy transformation 2050: https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020

9. (2013). *Solar Photovoltaics, Technology Brief.* IRENA.

10. (2012). *Utility Scale Solar Power Plants, A Guide For Developers and Investors.* IFC.

11. (2016). *EARTHING AND LIGHTNING OVERVOLTAGE PROTECTION FOR PV PLANTS, A GUIDELINE REPORT - NOVEMBER 2016.* https://www.undp.org/sites/g/files/zskgke326/files/migration/lb/Earthing-and-Lightning-Protection-for-PV-Plants-Guideline-Report.pdf.

12. (2018). *Upscaling Renewable Energy Sector Project: Report and Recommendation of the President.* Asian Development Bank (ADB).

13. (2015). *Utility-Scale Solar Photovoltaic Power Plants, A Project Developer's Guide.* International Finance Corporation (IFC).

14. (2022, July). *Annex 14: Aerodromes*. Retrieved from ICAO: https://store.icao.int/en/annex-14-aerodromes

15. (2018). *ICAO Doc 9184*. Retrieved from ICAO: https://store.icao.int/en/airport-planning-manual-land-use-and-environmental-management-doc-9184-part-2

16. (2010). *Technical Guidance for Evaluating Selected Solar Technologies on Airports.* FAA.

17. (2020). *GreenMatch*. Retrieved from https://www.greenmatch.co.uk/

18. (2019). *Solargis*. Retrieved from Solar resource map: https://solargis.com/

19. (2016), End of Life Management- Solar Photovoltaic Panels, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf?rev=49a75178e38c46288a18753346fb0b09

For information, contact:

Communications Department

Airports Council International Asia-Pacific

Unit 13, 2/F, HKIA Commercial Building

1 Sky Plaza Road

Hong Kong International Airport

Hong Kong SAR

Email: communications@aci-asiapac.aero

Website: www.aci-asiapac.aero

ACI Asia-Pacific advances the collective interests of the region's airports with governments and international organizations, and leads, facilitates and promotes professional excellence in airport management and operations.