ALIGHT
SUSTAINABLE AVIATION

GUIDELINE FOR SOLAR POWER PLANTS IN AIRPORTS

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RELATED GUIDELINES

Guideline for battery energy storage systems in airports

Guideline for charging infrastructure in airports

Guideline for smart energy management systems in airports

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INTRODUCTION TO ALIGHT

Alight is an EU 2020 Horizon project: A Lighthouse for the Introduction of Sustainable Aviation Solutions for the Future (ALIGHT). The consortium consists of 17 partners who have jointly committed to addressing the challenges of creating a transition in the aviation industry. Spread across 10 different European countries, the ALIGHT partners range from European airports to technology providers and knowledge institutions. The project is divided into two main focus areas: the supply, implementation, integration and smart use of Sustainable Aviation Fuel (SAF) and the development, integration and implementation of a Smart Energy system.

The smart energy section of the project addresses the full chain of system mapping, energy consumers, energy supply, including renewable energy and energy storage and energy management. In example, a Battery Energy Storage System (BESS) has been installed to gain valuable experience in, for example, the practical implementation of such a system in an airport, as well as how storage can aid in an increase in the use of renewable energy.

INTRODUCTION TO ALIGHT

INTRODUCTION TO THE GUIDELINE

This guideline provides best practices based on lessons learned in the ALIGHT project, related to implementing Photovoltaics (PV) in airports. The aim is to provide insights and help to overcome possible barriers related to mapping, planning, designing, and executing PV projects in airport environments. The guideline is divided into three main pillars: mapping, planning, and implementation.

The aim of the mapping phase is to create a solid base for the later decision making through initial analyses. The aim of the planning phase is to choose the relevant technologies and to ensure a thorough foundation of data and information for the implementation and commissioning phases. The aim of the implementation phase is to ensure smooth installation of PV panels.

As part of the ALIGHT project, four airports—Copenhagen, Rome, Warsaw, and Vilnius—serve as case studies for implementing smart energy solutions. These four airports are different in size, location and stage of development in the area of smart energy, offering diverse insights and learnings. Opportunities, challenges and lessons learned related to implementation of PV panels from the airports are described in this guideline.

Figure 1 – Location of ALIGHT airports: Copenhagen Airports in Denmark, Aeroporti Di Roma in Italy, Lithuanian Airports in Lithuania, and Centralny Port Komunikacyjny in Poland.

INTRODUCTION TO THE GUIDELINE

ALIGHT Airports

Copenhagen Airport

Copenhagen Airport is the lighthouse airport in the ALIGHT project, meaning that it is the primary airport. Copenhagen Airport is located 8 km from the city centre of Copenhagen. In 2023, CPH served over 26 million passengers.

Rome Fiumicino “Leonardo da Vinci” Airport

Rome Fiumicino “Leonardo da Vinci” Airport (FCO) is managed by Aeroporti di Roma (ADR), and it is located 30 km from the city centre of Rome. The airport received more than 44.4 million passengers in 2023.

Centralny Port Komunikacyjny

Centralny Port Komunikacyjny (CPK) is a part of a large infrastructure project in Poland. CPK airport will be a new international airport, located around 40 km from Warsaw. It is planned to be in operation from 2028. The airport is expected to accommodate around 34 million passengers, and with the ability to expand in the future.

Vilnius International Airport

Vilnius International Airport (VNO) is part of Lithuanian Airports (LTOU) and is located 5.9 km from Vilnius. It is the largest of the three commercial airports in Lithuania including Kaunas Airport and Palanga Airport. In 2023 the Vilnius airport served around 4.4 million passengers.

INTRODUCTION TO THE GUIDELINE

Motivation

Airports are energy-intensive infrastructures, requiring innovative solutions to meet the growing need for sustainable transition. As the aviation industry transitions toward carbon neutrality, integration of smart energy technologies has become essential to continue airport operations without compromising on their environmental responsibility.

This handbook serves as a practical guide for technical project managers, offering actionable insights of planning and implementing of PV in an airport environment. Through practical guidelines, case studies, and lessons learned, this report provides the readers with technical insights and strategic considerations for addressing the complexities of modernising energy infrastructure in airports.

There can be many rationales for an airport to invest in RES. An important reason is the transition from fossil fuel-based energy to renewable energy to reduce GHG-emissions and support the airport's sustainability goals. Another important point is that the security of supply within the airport can be improved by having RES producing energy locally in the airport grid, as the dependency on imported electricity from the collective grid can be reduced. This is also beneficial for the collective grid, as the collective grid operator (DSO/TSO) could limit the need for reinforcements in the grid, when production and consumption are geographically located in the same place. Additionally, from an economic perspective, the energy prices can be more predictable if energy is produced by the airport itself.

Transitioning local energy production from fossil fuels to renewable energy will likely improve the local environment and air quality at the airport. Moreover, there may be regional, national, or European incentives to invest in RES which is an advantage to be aware of. There might also be other potential revenue streams like selling over-production, leasing airport ground to other actors who will install renewable energy, delivering energy through local energy communities, or delivering grid supporting services.

The choice of RES should consider the airport's geographic location and the characteristics of the energy demand of the airport: e.g., if the airport has as large cooling demand in the summer and is located in an area with high solar irradiance, then PV could be a good match.

SMART ENERGY SYSTEM AS A CONCEPT

The energy system is smart when it can decouple the need for simultaneity between supply and consumption, while also prioritising delivering the cheapest and/or cleanest energy to consumers. A smart energy management system is needed to monitor the energy system, make decisions and control assets. Smart energy thus encompasses how the interaction between the various energy assets and energy sectors (electricity, heating/thermal, gas, transportation, and industry) can lead to a 100% renewable energy-based system in the cheapest and most efficient way.

Therefore, cross-sectoral synergies such as flexible production, different conversion technologies, demand-side-management, and a wide range of storage technologies, are necessary in smart energy systems. The concept of a smart energy system presented in Figure 2 is focusing on the electrical aspect of smart energy, including both physical assets such as PV and batteries and control assets like energy management system (EMS). Airports have multiple reasons to invest in renewable energy sources (RES). Transitioning from fossil fuels to renewables reduces greenhouse gas emissions and supports sustainability goals, while also improving local air quality.

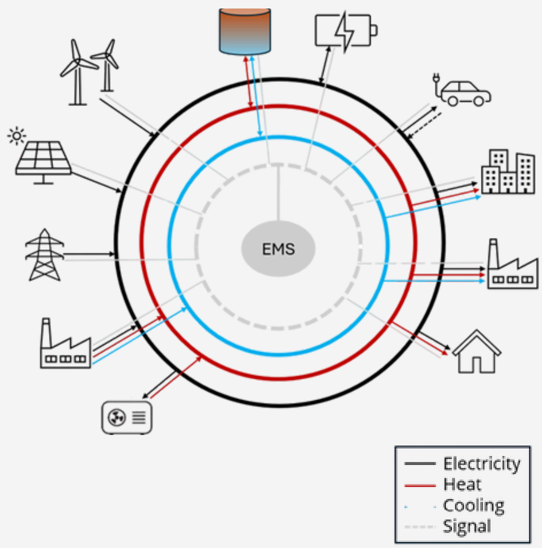


Figure 2 – Example of subsystems in a smart energy system.

Producing energy locally enhances security of supply and reduces reliance on the external grid, benefiting both the airport and the collective grid operator by limiting the need for grid reinforcements. Economic advantages include more predictable energy prices and potential cost savings. Airports may also benefit from regional or national incentives and can generate revenue by selling surplus energy, leasing land for renewables, or providing grid-support services.

The storage technologies among others can facilitate coupling between the energy sectors in an efficient and viable manner. The storage technologies cover all types of storages including electric, thermal, gas, liquid, etc. Thermal storages are often significantly cheaper than electrical storages and can advantageously be integrated into heat supply systems and thereby making the electricity demand for heat production (in e.g., a heat pump) more flexible. However, electrical storages play a pivotal role in enabling a more flexible, resilient, and renewable-based energy system, by balancing electrical generation and consumption, especially in systems with RES like solar and wind, which are intermittent. [1]

Energy Management Systems (EMS) and be used to enable flexibility in the airport energy system. It can be used to optimise energy usage, increase efficiency, and manage bottlenecks, potentially reducing costs and emissions. EMS integrates software and hardware to monitor and control energy production, storage, and consumption in real time, ensuring flexibility and maximizing value. EMS can also plan the delivery of grid services and help defer costly grid upgrades by rescheduling power flows and shifting loads, relying on controllable assets and storage.

SMART ENERGY SYSTEM AS A CONCEPT

Energy Flexibility

Flexibility is becoming more and more important with the increase of non-programmable renewable energy production, such as PV and wind turbines, necessary for energy system decarbonisation. Flexibility in energy systems can be achieved and utilised in various ways, offering numerous benefits. The adoption of smart energy technologies and the effective use of flexibility within an energy system can lead to reductions in greenhouse gas emissions, lower energy costs, and decreased reliance on expanded energy infrastructure.

As stated previously, energy storages are some of the elements that enable flexibility in the energy system [2]. Storage can be constituted by specific devices (e.g., battery energy storage or thermal energy storage) but can be found also in the thermal capacity in buildings through demand side management.When heat is provided by heat pumps, thermal storage or thermal capacity of buildings can provide flexibility in the electricity grid. This is because heat production can be adjusted to some extent without compromising indoor comfort, as thermal energy responds much slower to changes compared to electricity. This is a way of shaping the user’s energy demands. Other electrical loads may also be possible to control and shift in time to provide flexibility through demand-side-management or load-shifting.

ENERGY FLEXIBILITY

Flexibility use cases

Load shifting
Energy consumption can be scheduled to avoid short-term congestion at both local installations behind the meter and at the local distribution grid.

Peak shaving
Power peaks from high demand can be reduced by either reducing the power consumption, turning off some loads (load shedding) or by utilising additional power generation facilities or storage systems to feed the demand. Load-shifting can also be used as a measure to implement peak-shaving.

Energy arbitrage based on CO_2 emissions
By importing electricity during the hours with the highest share of renewable generation in the grid it is possible to reduce the CO_2 emission of electricity used.

Energy arbitrage based on costs
Purchasing electricity when prices are low and selling when the prices are high generates a profit from the price difference.

Delivery of ancillary services
Ancillary services refer to services that help maintain grid stability and reliability often at TSO level.

Optimising self-consumption from RES
By storing energy when RES produce more energy than needed to cover the demand, or by shifting the load to meet the RES production, thud the RES will be better utilised, and a higher share of the consumption will be covered by local RES.

TABLE 1

Impacts from different smart energy actions and technologies.

Aim/Goal	Smart energy actions	Method/technology
Reduce GHG-emissions of energy	Convert energy production plants from fossil fuel energy to renewable energy	Replace diesel generators for back-up power with a combination of RES and energy storage Replace natural gas or fossil fuel boilers with heat pumps Replace fossil fuel vehicles with electric, hydrogen or biogas driven vehicles
	Optimise self-consumption from local RES Energy arbitrage based on CO_2-emissions of electricity from the grid	Smart charging Load-shift of heat pump operation and HVAC etc. Energy storage
	Optimise self-sufficiency from local RES	Implement local RES Smart charging Load-shift of heat pump operation and HVAC etc. Energy storage

Reduce energy costs	Energy arbitrage based on costs	Smart charging Load-shift of heat pump operation and HVAC etc. Energy storage
	Optimise self-consumption from local RES	
Reduce the need for reimbursement of energy infrastructure	Peak shaving	Energy storage to absorb and deliver power as needed
	Load-shifting	Smart charging Load-shift of heat pump operation and HVAC etc. Electrical energy storage
Reduce the reliance of external energy providers	Optimise self-consumption from local RES	Smart charging Load-shift of heat pump operation and HVAC etc. Electrical energy storage
	Optimise self-sufficiency from local RES	Implement local RES Load-shift of EV-charging, heat pump operation, HVAC etc. Electrical energy storage

GUIDELINE FOR SOLAR POWER PLANTS IN AIRPORTS

To meet goals about a carbon-neutral energy supply in airports one possible solution is to install photovoltaics (PV) power plants on site. Many different technologies can be chosen for electricity production, but PV is a mature and well-known technology that could effectively utilise the large land-areas that airports typically have [4].

Airports in general are restricted by many regulations and a high focus on smooth operation together with high safety and security levels. Therefore, barriers such as legislation, future planned use of areas, and safety aspects regarding air traffic can be limiting for new projects.

An overview of a generic process, including steps identified through ALIGHT, is presented in table 2. The process is divided into phases, that are organised based on the probability of circumstances resulting in project rejection. Table 2 includes examples of recommended analyses related to each phase and the potential outcomes of the assessments conducted in the given phase.

CASE: RENEWABLE ENERGY SOURCES IN CPK

CPK plans to integrate RES to ensure a sustainable and efficient energy supply for the airport. CPK will build a PV plant designed to cover 30% of the total electricity demand as analyses have concluded this to be the most economically feasible size. In addition to PV, CPK is considering installing wind turbines, as this will ensure a more balanced energy production curve. The wind turbines must be installed at an appropriate distance to the airport to avoid interference with other airport operations and safety.

The first PV plant will have a capacity of 20 MW_p and will be built during the construction period of the airport i.e. in 2028.

TABLE 2

Overview of examples of relevant analyses

Phase	Mapping	Planning	Implementation and operation
Analyses and assessments	Initial sizing of PV plant Initial business case Sustainability assessment	Stakeholder analysis Mapping of potential areas Detailed analyses considering flight safety zones, security, glint and glare, wildlife, electrical infrastructure Implementation plan Scale up/roll out plan Tendering/procurement	Obtain relevant permits and approvals Site preparation Installation of chargers Integration into EMS Test and commissioning Monitoring and maintenance
Outcomes	Stop/go of the project Identification of economic break-even Identification of environmental impact Estimation of size, capacity and location	Stakeholder engagement System and infrastructure requirements Detailed dimensioning and location of PV plant Procurement of equipment	Approvals obtained Installation of PV plant components Connection to grid and EMS Monitoring production and performance

GUIDELINE FOR SOLAR POWER PLANTS IN AIRPORTS

Mapping

The screening process often includes a massive stakeholder engagement, a preliminary assessment could be beneficial for the decision organs to identify the overall economical break-even point, environmental impact, and scale of the project. At the end of this phase a stop/go gate could identify which process barriers will be present during the execution of the screening phases and justify the engagement and time consumption throughout the organisation.

CASE: ASSESSMENT OF PV SIZING AND LOCATION IN ADR

Initially, ADR made a screening to assess the possibility to install more PV on the roof, however, several issues, concerning statical and fire prevention issues were found. The static design of the building including margin for earthquake did not allow for additional weight on the roof. Moreover, the design of the building did not allow for the change in fire classification mandatory after the installation of a PV plant on its roof, as the panels could cause problems related to firefighting access.
Furthermore, heavy masses on the existing roofs could increase the risk of water leakages from the roof. There have already been water leakage issues with the existing roofs and the increasing amount of rain to be handled even without PV installations.

Therefore, the initial idea of using the existing roofs has been abandoned, and efforts were made to find a ground solution. The best area for this purpose was concluded to be the area along a runway, which has not been seen in European airports until now.

To assess the value of the project it will be necessary to know the approximate size of the power plant in terms of yearly energy production. To assess this, it is an advantage to make an initial energy analysis to determine how a PV plant can fit in the existing and future energy system. Collecting historical data and information about the electricity consumption, local electricity production and existing electrical storages are crucial in combination with estimates of future electricity demand. The energy analysis and the dimensioning of a PV power plant can be performed in many ways, some more sophisticated than others.

Here are listed some methodologies for defining the size:

- Simple PV-calculator for sizing PV-plants e.g., PVWatts Calculator [5]
- Defined by outer circumstances like space limitations
- Defined by economic limitations
- Scalable standard solution that can be increased over time if needed
- Simulation of energy system: This can be done on yearly basis or with a higher resolution to get a more accurate picture of the balance in the energy system.

When a suitable size is defined for the project, a preliminary business case evaluation should be conducted to assess the economic feasibility of the project. The business case assessment could include operational and capital expenditures, expected incomes, break-even point, early cost benefit analysis and risks.

To accommodate the fluctuating power production from local RES, it can be an advantage to combine them with an energy storage. The energy storage can be both electrical, chemical, electrochemical, mechanical, or thermal. As examples of electrical and electrochemical storages electric batteries, flywheels and power-to-gas can be mentioned.

Battery energy storage systems (BESS) can be used in different applications. Airports can utilise BESS to store surplus local renewable energy production, which can then be used later, where the demand is higher than the current local production.

Guideline for battery energy storage systems in airports

CASE: LTOU- MAPPING PHASE

For the planned PV plant, a detailed feasibility study was conducted to determine the most feasible plant size. The feasibility study investigated several scenarios including PV plants with and without batteries. Even though the investment in and installation of batteries are costly, this solution was chosen by LTOU. When the feasibility study was conducted, Lithuania experienced high electricity prices, why the purpose of batteries was initially to minimise the costs related to electricity by using the produced energy during the night and by selling excess energy to the grid in favourable hours. These prerequisites resulted in a payback period of 10-15 years.

A sustainability assessment of the project could be done to assess the impact of the project according to the airport's sustainability strategy. The sustainability assessment should have a similar weight in the decision of continuing the project planning as the economical business case. Moreover, the sustainability assessment should include initial analysis of nature and environmental conditions.

The process might include several iterations before the PV plant is viable both in area, capacity, and location.

GUIDELINE FOR SOLAR POWER PLANTS IN AIRPORTS

Planning

Initially in the planning phase information is gathered to streamline the workflow in the stakeholder engagement and analysis phase.

TABLE 3

Risk assessment and impact on airport operation and aviation

Installing PV in airports involves several risks and barriers that must be carefully managed to ensure safety and compliance of the airport as well as efficient operation and maintenance of the PV system. This section outlines some of the key risks and barriers associated with such installations.

Risks	Mitigations
PV plants can affect the communication, navigation and surveillance (CNS) systems, including surface movement radars (SMR), instrumental landing systems (ILS), multilateration (MLAT) and bird radars.	Sufficient investigations.
PV panels on ground can hide trespassing people.	National Aviation Safety Plans (NASP) requires that solar panels are placed a minimum of three meters from the perimeter fence.
PV panels introduce risk of electric shock if airplanes crash in the plant.	Respect flight safety zones when placing PV panels on ground.
Light reflections, which can distract pilots or ground personnel.	Perform glint and glare analysis. Use antireflective coating/surface of panels, adjust location, orientation and/or tilt.
PV panels on ground may attract wildlife.	Ensure access to lawnmowing or choose appropriate surface under panels.

STAKEHOLDER ANALYSIS

To mitigate the above-mentioned risks and barriers, and to ensure the project can be fulfilled, different stakeholders need to be involved.

Identification of relevant stakeholders is important to do in this phase. Relevant stakeholders can be internal or external stakeholders who can either decline the project, define design requirements or have interest in participation due to economic or strategic reasons.

EXAMPLES OF RELEVANT INTERNAL STAKEHOLDERS:

- Airport master planning
- Airport fire department
- Airport asset management (e.g. responsible for electrical infrastructure)
- Airport sustainability services (e.g. project driver)
- Airport security department
- Airport operation and maintenance department
- Airport wildlife department
- Airport safety department
- Airport communication, surveillance and navigation department
- Airport legal and planning department

EXAMPLES OF EXTERNAL STAKEHOLDERS:

- Distribution system operator (DSO) (e.g. for grid connection approval)
- Municipality (e.g. for land zone permit, building permit, occupancy approval)
- National or local fire authority
- Airport specific authorisation bodies (e.g. Danish Civil Aviation Authority (CAA), Italian Civil Aviation Authority (ENAC))

TABLE 4

Internal stakeholders from CPH engaged in PV projects.

Department	Concerns/responsibility	Mitigation/action
Operation & Maintenance	Lawn mowing under panels	Change in PV installation height to allow lawn mowers to operate under panels.
Wildlife Control	Attraction of birds sitting on panels/hiding under panels Longer grass might provide more food for birds, which can result in an increasement in birds	Investigations of robot lawn mowers, solar panel staructures high enought to allow normal lawn mowers, investigation of other ground surfaces
Security	People hiding under/behind panels or limited view for patrollers	Longer distances between panels, panels raised from ground
Rescue & Firefighting	Fire electrical installation	Sufficient procedures to handle electrical fires
Communication, navigation and surveillance	Interference with radar systems	Investigated in detailed analysis
Asset Management	Enough available electrical capacity in existing infrastructure?	Expansion of transformer
Airside Safety & Compliance	Flight safety zones areas, final safety risk assessment, glint and glare (reflections disturbing pilots and control tower)	Proper location, orientation, tilt and surface of PV panels. Identify and apply for approvals as early as possible
Legal & Planning	Support projects to ensure compliance with relevant regulations	
Sustainability Services	Carrying out projects related to sustainable development	

CASE: LEARNINGS FROM PV PROJECTS IN CPH

For PV projects in CPH, the planning department (AWS) must be included as a vital stakeholder as they ensure the involvement of all the other relevant internal stakeholders in the airport, which reduces the potential barriers to a PV project. The current 12 PV plants in CPH are regarded as a single system by the DSO. Therefore, it is necessary for CPH to impose requirements on the tenants' technical installations, such as the type of inverter, to ensure compliance with the grid operator's demands. Otherwise, the tenants' inverters would need to be replaced, which would be costly for CPH. The process of achieving grid compliance is one of the most time-consuming for CPH, and it is therefore pivotal to include the DSO and their contractors early in the process to mitigate the potential delays.

GLINT AND GLARE ANALYSIS

To obtain approval for PV facilities based on safety assessments, a key requirement is ensuring that glare from the PV panels does not cause any disturbance in the safe operation of aircraft and ATC towers. Therefore, a Glint and Glare analysis [6] must be conducted. The analysis might result in changes in the planned PV plant layout e.g., change in tilt angle of the panels, change in panel orientation, different surface of the panels, change in height and location of the panels, etc. These changes might affect the techno-economic feasibility of the PV plant, why the business case must be revisited.

CASE: STAKEHOLDER ENGAGEMENT AND ANALYSIS IN ADR

Glare analysis proved the most time-consuming, taking almost a year. Two external consultancy firms used FAA's SGHAT software to analyse all possible flight paths, aiming to avoid any hours of glare risk throughout the year. The simulation results were shared with ENAC (Italian Civil Aviation Authority), ENAV (National Agency for Flight Assistance), and the pilots' association.

Based on these analyses, ADR defined the optimal azimuth and tilt angle for installing the PV plant. The simulations concluded that to prevent glare issues, the PV plant should be located along only half of the runway, ensuring glare would not occur in any meteorological condition.

Another key issue was the risk of magnetic interference with the antennas used for ILS and Autoland systems. As these are sensitive systems, an EMC analysis was performed to check for radio interference from the PV plant's metal mass.

Due to these analyses and simulations, the PV plant's original design was reduced from 30 MW to 22 MW to minimise both glare and magnetic interference risks. For construction, the project followed the standard approval procedures in the sector legislation.

MAP AVAILABLE AREAS

The layout for the physical site must be acquired early in the process as it is essential for further planning. When identifying potential areas, it is important to engage with identified stakeholders to get confirmation of the availability of the area seen from different perspectives. Current and future plans for airport expansion or land use, flight safety zones, land division, identification marking, and security zones must be considered when mapping the physical layout, excluding obvious obstacles such as runways and roads. Moreover, environmental considerations and restrictions can also have an impact on the available area for the PV plant.

CASE: PV PLANT ALONG RUNWAY IN ROME

ADR have inaugurated a 22 MW PV plant located along the runway to enhance the utilisation of renewable energy. It will be the first of this kind in a commercial airport. ADR started to work on the first large PV plant in 2019 and commissioned the first part in January 2025.

CASE: MAPPING OF POTENTIAL AREAS IN CPH

A map similar to those made for CPH shown in Figure 4 and Figure 5 can be used to visualise the potential areas and be used iteratively as project changes and mitigations are implemented. Here is an example of ground areas, where the surface of the PV panels is changed to be textured, which significantly impacts the result of the glint and glare analysis and thereby the available areas. The same concept can be used for roof-mounted PV plants, where especially roof construction and bearing capability, roof orientation and pitch can impact the suitability of the roofs.

Figure 4 – Visualisation of potential areas for PVs without antireflective coating at CPH. These maps are part of a screening phase and do not show the actual applicability of the areas within the airport.
Green: feasible area, Orange: possible area, Red: not possible.

Figure 5 – Visualisation of potential areas with textured glass. These maps are part of a screening phase and do not show the actual applicability of the areas within the airport.

GRID CONNECTION ANALYSIS

When planning to install ground mounted photovoltaics it is important to be aware of underground power and signal cables in the intended area. If there are cables in the area it should be considered how the solar panels can be installed without damaging the cables. Moreover, it shall be considered if the cables need to be replaced or upgraded in the future (next 30 years). If possible, the cables can be moved before installation of the solar panels.

Before connecting solar panels to the grid, it is necessary to ensure that the Point of Connection (POC) and the local grid can carry the additional power. The local DSO should therefore be contacted early in the process, as grid limitations can influence the project both technically and economically

REQUIREMENT SPECIFICATION

A requirement specification can be made as a result of the above-mentioned analyses. This will therefore include both system and infrastructure requirements e.g., requirements for PV panels and power electronics, grid connection requirements, fire safety requirements, IT security requirements among others, which need to be identified and included.

CASE: PLACEMENT OF PV PLANT NEAR RUNWAY IN ADR

Initially, the PV plant was planned to be located with 150 m from the runway centreline, which is in accordance with EASA policies. This would result in a total capacity of 30 MW, however, for safety reasons the distance has been extended to 180 m from the runway centreline.

During the design phase, it was crucial to consider the firefighting requirements: To prevent the spread of fire, it was mandated to maintain at least a 5 m distance between rows of PV panels. This spacing was also necessary to avoid shadowing between the panels, which meant that no redesign of the PV plant was required.

TENDERING AND PROCUREMENT

There will typically be a tendering process before the purchasing of a PV plant due to the significant investment involved for the airport. To ensure a smooth tendering process it is necessary to establish concrete and clear requirements that the tenders must comply with e.g., sustainability goals, aviation safety standards, local and national environmental regulations, maintenance plans and performance guarantees etc.

IMPLEMENTATION PLAN

The planning department should establish a detailed implementation plan to ensure a structured implementation phase and to minimise costs (e.g., if cables must be installed in roads which must be reconstructed afterwards). The scope of the implementation plan shall be in line with the project size and can vary from being a simple project plan to an extensive project management plan including detailed budgets, identification and agreements with subcontractors, time schedule, logistics for construction especially important on airside and near runways.

SCALE-UP AND ROLL-OUT PLAN

A scale-up and roll-out plan can be made for large projects to reduce economic risks and to ensure that the system performance and impact is as expected before extending with new plants. For PV plants it can mean dividing the optimal size determined in the mapping phase into sub-plants and implement them in stages. Choosing the most suitable areas for the first stages can create high immediate value, but choosing areas with more restrictions can provide important insights and learnings which may open for larger areas to be included in the following stages. The plan can be reevaluated and adjusted based on experiences and results from the first stages.

GUIDELINE FOR BATTERY ENERGY STORAGE SYSTEMS IN AIRPORTS

Implementation and operation

PERMITS AND APPROVALS

The first step of implementation of PV systems in an airport is to ensure that all necessary permits and approvals are obtained. Airports are highly regulated environments, and the installation of PV systems must comply with aviation regulations, safety standards, etc. When all permits and approvals are obtained, the PV system can be installed.

SITE PREPARATION AND INSTALLATION

The installation of the PV plant in an airport involves several steps to ensure the system is safe, reliable, and compatible with the airport's existing infrastructure. Due to the operational complexity and safety-critical nature of airports, this process must be carefully executed with minimal disruption to airport activities.

When installing PV systems the following should be considered:

- **Electrical infrastructure:** Installation of components such as PV modules, inverters, transformers, cabling, and switchgear. The system must be designed to ensure compatibility with both the internal electrical network in the airport and the external, collective/national grid.
- **Integration with existing systems:** Coordinate with the airport's energy infrastructure to ensure seamless incorporation of the PV system without causing disruptions, e.g., when installing the panels.

CASE: LOCATION OF PV IN CPH

Currently, there are 12 plants in CPH with a total capacity of 4.5 MWp. In CPH, all solar panels are installed on the roof of buildings. The airport consists of buildings both owned by CPH and by others, but which are built on CPH's premises. This can pose challenges for CPH regarding the power quality at the common connection point to the DSO grid, which can result in curtailment.

INTEGRATION WITH EMS

For efficient energy management and utilisation, the PV system must be integrated into the airport's EMS. In order to ensure safe communication of data from the PV plant and the EMS, secure protocols must be used to prevent unauthorised access or cyber-attacks on the EMS.

TEST AND COMMISSIONING

Before the plant can be commissioned, the plant should be thoroughly tested to confirm system performance and safety.

The testing can include:

- Performance testing: Verify the energy output of the PV system under varying conditions to ensure that design specifications are met.
- Safety inspections: Conduct thorough inspection of the installation to confirm that it complies with relevant standards and protocols.
- Integration validation: Test the interaction between the PV system and the airport's EMS to ensure seamless operation without disruptions.

OPERATION, MONITORING AND MAINTENANCE

The needed level of maintenance of PV plants is dependent on the geographical location of the airport and PV plant. In Denmark, PV plants require minimal maintenance, especially for fixed panels mounted with a slope, where rain will, to some extent, wash the panels, whereas in Italy, additional washing of panels with pressurised water is needed, due to high content of sand and dust in rain. Is this is not done, it will affect the efficiency of the panels. It can therefore be beneficial to monitor the performance of the plant to be able to detect if additional cleaning is needed. In airports the main concern regarding operation may be on ground-mounted panels where lawn-mowing under the panels may require special equipment or procedures. Moreover, it is recommended to perform periodic system health checks of the civil (e.g., access roads, fences), mechanical (e.g., mounting structures, technical buildings), and electrical components (e.g., inverter, PV panels, monitoring systems). To ensure long-term performance, the PV system must be consistently monitored and maintained. It is recommended to use data from the EMS to track energy generation, detect anomalies, and predict maintenance needs, e.g., washing of panels.

Some of the relevant parameters to monitor are:

a. Energy produced (kWh): can be used to evaluate the systems efficiency and performance.

b. Efficiency: This is the ratio of energy output to energy input (from sunlight). Monitoring changes in efficiency over time can indicate degradation or maintenance needs.

Other nice-to-have parameters to monitor are:

c. Temperature of panels surface: Excessive heat can reduce panel efficiency. Monitoring temperature ensures panels are operating within their optimal range.

d. System voltage and current: These values provide insights into the electrical performance of the system. Sudden drops may indicate a fault or shading.

e. Fault detections: Error codes or fault signals. Early detection can reduce downtime

OUTLOOK

The transition to more sustainable energy systems in airports presents a transformative opportunity to reduce environmental impact, enhance operational efficiency, and align with global sustainability goals. By integrating renewable energy sources, energy storage, and smart energy management systems, airports can significantly reduce their carbon footprint, enhance energy efficiency, and improve operational resilience. These solutions enable airports to better align with evolving sustainability goals and regulatory requirements, such as the EU's Renewable Energy Directive (RED III). Operationally, smart energy solutions offer flexibility, allowing airports to fit energy consumption to fluctuating renewable energy production (e.g., solar and wind) and reduce dependency on fossil fuels.

The integration of energy solutions into airport operations offers a range of benefits considering environmental, economic, operational, and social dimensions.

- **Environmental:** Energy solutions enable reductions in greenhouse gas emissions through larger shares of renewable energy. Additionally, replacing local fossil fuel-based energy production improves air quality, benefiting both airport users and surrounding communities.

- **Economic:** Airports can realize long-term cost savings through enhanced energy efficiency and reduced reliance on fossil fuel. Price stability can be achieved through power purchase agreements (PPAs) or local renewable energy sources owned by the airport, and by creating revenue from grid services.

- **Operational:** Benefits include enhanced reliability of energy systems, ensuring uninterrupted power supply for critical airport functions. These solutions also improve an airport's resilience to disruptions, such as power outages or extreme weather events, thereby strengthening overall operational stability.

- **Social:** Adopting sustainable energy practices aligns airports with broader regional and national climate strategies. This also demonstrates the airport's commitment to addressing climate change and sustainability goals.

While challenges such as financial constraints, technical integration, and regulatory complexity remain, airports that proactively plan, engage stakeholders, and leverage available support mechanisms can overcome these barriers. Managing a diverse portfolio of energy assets, including photovoltaic (PV) systems, battery storage, and electric vehicle (EV) chargers, requires advanced expertise and planning. Airports will need to invest in workforce training, adopt advanced energy management platforms, and collaborate with energy experts to effectively operate and maintain these systems. By implementing future-proof energy systems and scalable infrastructure, airports can adapt to increasing passenger demands, technological advancements, and evolving regulations.

NEXT STEPS

Airports are highly energy-intensive and are under increasing pressure to become sustainable. PV is presented as a practical solution to produce renewable energy on site for increasing resilience, reducing greenhouse gas emissions and energy costs. To increase the benefits of local electricity generation, it is worth considering combining it with energy storage e.g., battery energy storage (BESS). Ensure that both PV on ground and on roofs are investigated to cover electricity consumption.

KEY ADVANTAGES FROM LOCAL PV:

- Reduce GHG-emissions of energy
- Reduce the reliance of external energy providers
- Can increase resilience during grid outages
- Stable and predictable energy costs
- May reduce energy costs

IF YOU ARE CONSIDERING INSTALLING A LOCAL PV, YOU CAN START YOUR WORK WITH THE FOLLOWING STEPS:

1. Engage stakeholders to map potential areas and mitigate potential barriers
2. Initiate a detailed mapping and feasibility study incl. dimensioning and business case
3. Define requirement specification for the PV plant(s)
4. Plan and execute projects

Mapping: Key questions

- What is the optimal size and location for the PV plant, considering current and future energy demand, available space, and economic feasibility?
- How will the PV plant affect airport operations and compliance?
- Which impact does the PV project have on the airport's sustainability strategy?

Planning: Key questions

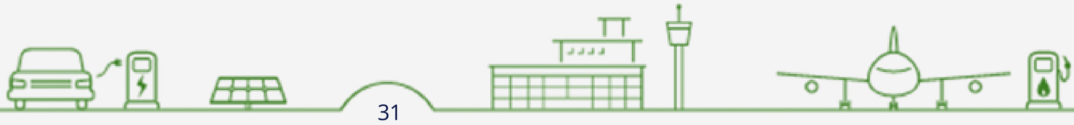
- Will the PV installation impact the airport's CNS system, and which mitigations can be done to minimize the impact?
- Are all relevant stakeholders involved in the planning process?
- Are all key risks and barriers (e.g., reflections, wildlife, maintenance etc.) found and assessed, and have relevant mitigation strategies been considered?
- What are the grid connection requirements and necessary infrastructure upgrades?
- Has a suitable area for PV installation been identified and validated?

Implementation: Key questions

- Have all necessary permits and approvals for the project been obtained?
- Is the site preparation plan thorough, addressing integration with existing airport infrastructure, minimizing disruption to operations, and ensuring electrical compatibility with both internal and external grids?
- How will the monitoring of the performance of the plant be ensured?
- Have testing and commissioning procedures been established to verify system performance, compliance and integration with airport infrastructure?

ABBREVIATIONS

Abbreviation	Explanation
ACA	Airport Carbon Accreditation
ADR	Aeroporti Di Roma (fellow airport in ALIGHT located in Italy)
BESS	Battery energy storage system
BMS	Battery management systems
BoL	Beginning of life
CAA	Danish Civil Aviation Authority
CNS	Communication, navigations and surveillance
CPH	Copenhagen Airports
CPK	Centralny Port Komunikacyjny (fellow airport in ALIGHT located in Poland)
DSO	Distribution System Operator
DTI	Danish Technological Institute
Dx.x (e.g., D4.3)	Deliverable
EASA	European Aviation Safety Agency
EMS	Energy management system
ENAC	Italian Civil Aviation Authority
EV	Electric vehicle
FAA	Federal Aviation Administration



Fellow airports	**Referring to airport partners in ALIGHT: ADR, CPK and LTOU**
HG	Hybrid Greentech
HVAC	Heating, Ventilation, Airconditioning
ICAO	International Civil Aviation Organization
ILS	Instrument landing system
Lighthouse airport	Referring to main demonstration airport in ALIGHT: Copenhagen Airports
LTOU	Lithuanian Airports (fellow airport in ALIGHT located in Lithuania)
Maglebylille	Referring to a physical demonstration site located inside CPH
MLAT	Multilateration
NASP	National Aviation Safety Plans
NPV	Net Present Value
POC	Point of Connection
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy sources
ROI	Return of investment
TSO	Transmission System Operator
SAT	Site Acceptance Test
SMR	Surface movement radar
WP	Work package

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