Best practices for smart energy supply and management in Airports

collected as guidelines, handbooks, case studies and business case tools

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Table of content

1 Abbreviations and definitions 4
2 Executive summary 6
3 Introduction 7
4 ALIGHT and relation to other public deliverables 8
5 Smart energy system as a concept 9
5.1 Energy flexibility 10
5.2 Energy supply and storage 13
5.3 Energy Management Systems 15
6 Roadmap for smart energy supply and management 18
6.1 Mapping phase 18
6.2 Planning phase 19
6.3 Implementation and operation 21
7 International and European regulations affecting smart energy projects 23
7.1 International Civil Aviation Organization (ICAO) 23
7.2 European Aviation Safety Agency (EASA) 23
7.3 Renewable Energy Directive (RED III) 24
7.4 EU Energy Efficiency Directive 25
7.5 National and European technical regulations 26
7.6 Incentive programs for smart energy 26
8 Guideline for solar power plants in airports 28
8.1 Mapping 30
8.2 Planning 31
8.3 Implementation and operation 35
9 Guideline for charging infrastructure in airports 38
9.1 Mapping 40
9.2 Planning 42
9.3 Implementation and operation 45

10 Guideline for smart charging and vehicle-to-grid (V2G)....47
10.1 Mapping....50
10.2 Planning....54
10.3 Implementation and operation....55
11 Guideline for battery energy storage systems in airports....58
11.1 Mapping....60
11.2 Planning....63
11.3 Implementation and operation....67
12 Guideline for smart energy management systems in airports....70
12.1 Mapping....72
12.2 Planning....73
12.3 Implementation and operation....77
13 Case studies from the lighthouse airport and fellow airports....79
13.1 Copenhagen Airports (CPH)....80
13.1.1 PV plants....81
13.1.2 Electric Vehicles, V2G, and smart charging....86
13.1.3 Battery energy storage system (BESS)....87
13.1.4 Energy management system....97
13.1.5 Heat supply....102
13.1.6 Assessment of electrification potential - An energy system analysis....102
13.2 Aeroporti Di Roma (ADR)....105
13.2.1 Implementation of PV....105
13.2.2 EV charging infrastructure, smart charging and V2G....108
13.2.3 Energy storage and energy management systems....108
13.3 Centralny Port Komunikacyjny (CPK)....110
13.3.1 Renewable energy sources....111
13.3.2 Electric vehicles and charging infrastructure....111
13.3.3 Energy storage....111
13.3.4 Energy management system....112

13.4 Lithuanian Airports (LTOU) 113
13.4.1 PV Plant and batteries 113
13.4.2 Smart charging and V2G 115
13.4.3 Energy management system 118
14 Outlook 119
15 References 121
16 Appendices 124
16.1 Introduction to demonstration site: Maglebylille, Copenhagen Airport 124
16.2 Stakeholder analysis tool 126
16.3 Example of stakeholder engagement for PV projects 127
16.4 Communication, Navigation and Surveillance 132

1 Abbreviations and definitions

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
CCS	Combined Charging System
CNS	Communication, navigations and surveillance
CPH	Copenhagen Airports
CPK	Centralny Port Komunikacyjny (fellow airport in ALIGHT located in Poland)
CPO	Charge Point Operator
DSO	Distribution System Operator
DTI	Danish Technological Institute
Dx.x (e.g., D4.3)	Deliverable identification number
EASA	European Aviation Safety Agency
EMS	Energy management system
ENAC	Italian Civil Aviation Authority
EoL	End-of-life
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
GPU	Ground Power Unit
GSE	Ground Support Equipment
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
SoC	State-of-Charge
SoH	State-of-Health
V2G	Vehicle to grid
WP	Work package

2 Executive summary

This report provides comprehensive guidelines, case studies, and best practices for implementing smart energy solutions and management systems in airports focusing on renewable energy integration, energy storage systems, and energy management practices. It is tailored to assist technical project managers in planning, designing, and executing energy transition strategies, while addressing the specific barriers related to safety, regulatory, and operational aspects that may arise when smart energy projects are done in the airport environment, and to provide solutions for overcome these barriers.

The key pillars of this document include five guidelines for how to implement smart energy solutions in airports seeking to transition toward carbon neutrality while maintaining operational efficiency and safety, and learnings from existing airports collected in case studies. The guidelines pertain to the following topics:

1. Solar power plants in airports
2. Charging infrastructure for electric vehicles
3. Smart charging and vehicle-to-grid (V2G) capabilities
4. Battery energy storage systems (BESS)
5. Smart energy management systems (EMS)

For each topic, the guidelines provide structured guidance through mapping, planning, and implementation phases, highlighting potential barriers, stakeholder considerations, and technical requirements. The guidelines emphasize that successful implementation requires balancing innovation with strict safety and operational standards unique to airport environments.

The report identifies key challenges in implementing smart energy solutions in airports:

- Regulatory compliance with aviation safety standards
- Integration with existing infrastructure and operations
- Stakeholder alignment and engagement
- Technical considerations and safety requirements for smart energy systems in airports
- IT security for connected energy management systems

This report emphasises that smart energy solutions are essential for airports to achieve carbon neutrality and operational resilience. By implementing renewable energy, energy storage, and intelligent management systems, airports can align with global climate goals while optimising costs and maintaining safety. The guidelines and case studies can assist airports to overcome barriers and implement scalable, future-ready energy systems.

3 Introduction

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. By leveraging energy flexibility, such as demand-side management, vehicle-to-grid (V2G) technologies, and intelligent energy storage, airports can optimise utilisation of renewable energy, reduce greenhouse gas emissions, and enhance resilience against fluctuating energy demand and production. This report serves as a practical guide for technical project managers, offering actionable insights of planning and implementing renewable energy sources, energy storage systems, and smart energy management tailored to airport operations. 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. It emphasizes that a delicate balance between innovation and strict safety and operational standards is required in such critical environments. While the outlined solutions offer potential pathways to improve energy systems and future-readiness, the implementation is dependent on overcoming significant challenges, including regulatory frames, high safety and security levels, infrastructure constraints, and stakeholder alignment.

There is a general paradigm within energy supply as renewable energy sources are replacing conventional heat and power plants. This results in an energy supply source which is fluctuating, and which cannot be operated to directly match the energy consumption. Instead, there is a need for adapting the energy consumption to the actual production. This calls for new levels of flexibility in use of energy, flexibility through energy storage systems and smart energy management systems to prioritise and optimise how energy assets are operated.

Guidelines and case studies are presented in this report to inspire airports and help them getting started and overcome some main barriers that can be present. This is collected and presented in five guidelines within this report:

- Guideline for solar power plants in airports
- Guideline for charging infrastructure in airports
- Guideline for smart charging and vehicle-to-grid in airports
- Guideline for battery energy storage systems in airports
- Guideline for smart energy management in airports

4 ALIGHT and relation to other public deliverables

This deliverable has been written in the EU funded project "ALIGHT" work package (WP) 4 and presents best practices collected as guidelines, handbooks and case studies. Input will support replication effort in WP8 where tools dedicated to Smart Energy will be developed based on the inputs from WP4 and WP5, in collaboration with WP6, WP7 and WP9. International practices will also be derived from partners, as relevant, and used for input.

This deliverable covers sustainable energy supply, smart charging and vehicle to grid (V2G), energy storage and smart energy management.
This deliverable provides inputs to WP8 Replication toolbox dedicated to Smart Energy. Furthermore, this report provides guidelines for smart energy projects in airports and examples of smart energy projects from Copenhagen Airports and fellow airports.

As WP4 in the ALIGHT project is mainly focused on electricity supply and electric assets as a part of the smart energy supply, this is also the focus of this deliverable. Similar guidelines and case studies could be made for other energy supply chains such as hydrogen, geothermal, biomass etc.

Relationship with other work packages and deliverables within Alight are described in Table 1.

	Work package title	Relationship
WP 5	Smart Use of Energy	Close collaboration to ensure match between supply, consumption and energy management. Input to D5.1[1], D5.2[2], D5.3[3].
WP 6	Sustainability	Input to D6.4[4] Sustainability report
WP 8	Exploitation and Replication Toolbox	Input to D8.7[5] Replication toolbox for Smart Energy
WP 9	Airports development, transfer and tailoring of solutions	Case studies from fellow airports and input from D9.5[6]

Table 1 - Overview of relationship with other work within Alight.

[1] D5.1 Best practise toolbox for Greening of Ground Equipment and Passenger Transport, May 2025
[2] D5.2 Best practise toolbox on Greening of Airport Buildings with a smart energy management, Sep. 2025
[3] D5.3 Conceptual design for future aircraft stands, Sep. 2025
[4] D6.4 Sustainability Report, Nov. 2025
[5] D8.7 Replication toolbox for Smart Energy, July 2025
[6] D9.5 Detailed report on smart energy solutions transferred and tailored in fellow and other airports, May-25
All above reports can be found at Alight website after publication: https://alight-aviation.eu/

5 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 prioritizing 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 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 renewable energy sources (RES) like solar and wind, which are intermittent. [1]

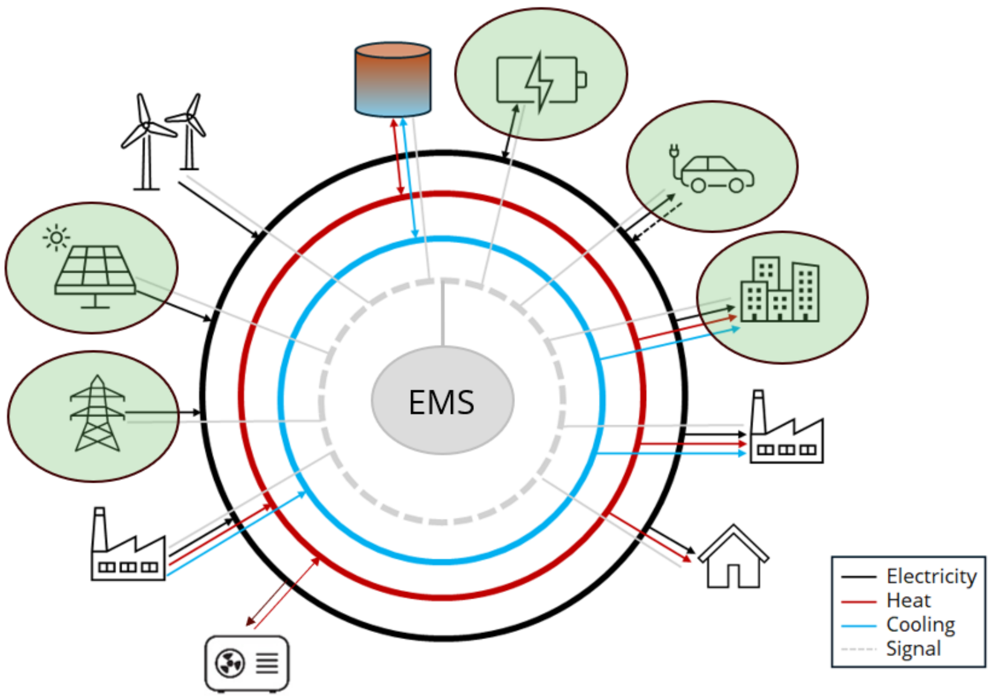

Figure 1 – Example of subsystems in a smart energy system. Green circles mark the objects mainly focused on in this guideline document.

In this guideline, the concept of a smart energy system presented in Figure 1 is focusing on the electrical aspect of smart energy. This guideline presents in more details project aspects of photovoltaics (PV) as local renewable production, EV charging as flexible electrical consumers, energy storage by a battery storage system (BESS), and energy management system (EMS) to utilise the different subsystems and optimise the CO_2-footprint of the electricity use.

A review of smart energy practices in airports focusing on challenges and opportunities for sustainable aviation has been made by University of Parma, Centre for Energy and Environment[7] [2].

5.1 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, storages are some of the elements that enable flexibility in the energy system [3]. 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. The flexibility potential can also optimise energy efficiency e.g., by allowing plant operation at optimal conditions. [4]
The potential of thermal capacity in buildings is further elaborated on in *D5.2 Best practise toolbox on Greening of Airport Buildings with a smart energy management*[8] together with other aspects of energy consumption monitoring, reduction and efficiency.

Also, EV charging, HVAC and other controllable loads can provide flexibility to the energy system and be managed to fit the RE production or to minimise power peaks, optimise CO_2-

[7] Article: A Review of Smart Energy Practices in Airports, Nov. 2024
[8] D5.2 Best practise toolbox on Greening of Airport Buildings with a smart energy management, Sep. 2025
All above reports can be found at Alight website after publication: https://alight-aviation.eu/

footprint or costs of the operation. This is in general terms referred to as demand-side-management.

Implementation of smart charging of electric vehicles is demand-side-management and can be used for multiple purposes, such as load-shifting, peak shaving, CO_2- and cost reductions and delivery of ancillary services. By introducing vehicle-to-grid (V2G), where the car battery can be discharged to the electricity grid, the EVs can be used as additional storage capacity. In airports both smart charging and V2G can be considered for airport vehicles, employee cars as well as passenger cars and public transport.

However, smart energy system measures related to heating, cooling and gas for the airport is not included in the guidelines presented in this report, but a case for CPH is presented about their shift from natural gas to heat pumps in Section 13.1.5.

Assets providing flexibility can be managed to fulfil different use cases or distinct operations. These use cases include:

- *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.

An overview of impacts from different smart energy actions and technologies can be found in Table 2.

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	Smart charging Load-shift of heat pump operation and HVAC etc. Energy storage
	Energy arbitrage based on CO_2-emissions of electricity from the grid	
	Optimise self-sufficiency from local RES	Implement local RE 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

Table 2 – Impacts from different smart energy actions and technologies.

5.2 Energy supply and storage

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. Another important point is the opportunity to reduce local greenhouse gas (GHG) emissions. 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. In addition to installing RES in the airport, the airport can consider buying renewable energy from off-site producers. This can either be at a contracted price often referred to as Power Purchase Agreements (PPA) or by buying electricity from the collective grid at market prices and then cover their total consumption with certificates on the origin of energy called Guarantee of Origin (GO). GO are certificates of renewable energy production under the Renewable Energy Directive (RED II), which can be traded in the market, and does not provide any direct connection between the RES and the energy consumption, but only covers a specific energy amount [5]. On the other hand, PPAs can be either physical/direct or virtual. With a physical PPA, the power is delivered through the electricity grid to the buyer. With a Virtual PPA, a contract is made where the buyer agrees to pay the difference between spot prices for their own used electricity supplied by their current supplier and the spot price for the produced renewable power agreed in the PPA. The PPA should include a Guarantee of Origin (GO) as evidence that electricity has been produced by renewable energy. [6]

The airport does not need to rely exclusively on one type of supply but can combine the supply types as needed. It is typically more economically viable to reduce energy consumption before installing RES that covers the entire demand. This could be by replacing conventional lighting systems with LEDs, upgrading HVAC (Heating, ventilation and air conditioning) systems, and improving building insulation. Some of these aspects are further elaborated on in ALIGHT deliverables D5.1[9] and D5.2[10].

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.

There can be different purposes of electricity storage and e.g., battery energy storage systems (BESS) can be used in different applications. This guideline will focus on BESS as energy storage system and the related opportunities and challenges in airports. First of all, 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. This can help maximizing the utilisation of installed renewable energy. The BESS can also be used for energy arbitrage, where electricity is bought when the CO_2-footprint and/or the prices is low by charging the BESS and sold (discharge the BESS to grid) when electricity is less sustainable, and prices are higher. BESS can also be utilised as power buffers for peak shaving high power loads, e.g., fast

[9] D5.1 Best practise toolbox for Greening of Ground Equipment and Passenger Transport, May 2025
[10] D5.2 Best practise toolbox on Greening of Airport Buildings with a smart energy management, Sep. 2025
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chargers to limit the load on electric infrastructure. BESS can also be used for ancillary services that helps stabilise the electricity grid such as frequency reserves and create a revenue from the BESS. A storage system is thereby an element providing a high degree of flexibility in the energy system, as described in Section 5.1.

5.3 Energy Management Systems

When introducing energy storage in an energy system the role of the energy management becomes even more dynamic. Where an energy system without storage is usually managed/planned by looking at the current and expected operation (consumption and production), the introduction of energy storage allows for flexibility in absorption of produced energy, due to the buffer capacity. The schedules of operations will become more complex in nature, especially in a diverse energy system like a modern airport, where the energy system might consist of several assets e.g.:

- Battery Energy Storage System (BESS)
- Electric Vehicles (EV)
- Heat Pumps and HVAC centrals, with thermal energy storage
- Ground support equipment

As many of these assets might have synergies, and if utilised, the operator can optimise the schedules of each asset, which can result in substantial economic saving and or CO_2 reductions. To be able to facilitate these opportunities, EMS are introduced. The main objective of EMS is to devise operational plans that allow an optimal use of resources, assets, as well as manage bottlenecks in the system, which helps postponing some investments and increase the energy system efficiency.

Main Use cases

EMS can be tuned to minimise GHG emissions from the energy system, maximize energy efficiency or utilisation of RES, minimise congestion and/or optimise energy costs by managing the sources of energy and energy-flow, including consumption, production, storage, and interchange with the electricity grid.

The EMS consists of both software and hardware components to optimise energy production, storage, and consumption of energy connected in the electrical distribution grid in the airport, by collecting, analysing, and controlling the energy flow in real time. The EMS is therefore an important element to ensure that flexibility potentials are fully exploited, and that the airport obtains the highest value of their energy system and infrastructure. The EMS can optimise the use of energy components to obtain different goals as highlighted in Section 5.1 and based on many different factors, such as forecasting on both energy demand, production, weather, prices, CO_2-equivalents etc.

The EMS implemented in CPH in ALIGHT, follows the concept presented in 13.1.4. Here only electrical energy is considered, covering electrical generation, storage and consumption. However, since the heating in the airport is partly delivered by a heat pump by means of electricity, the heating sector is indirectly included in the EMS concept for CPH, which is represented by the arrow going to HVAC. Potentially other sectors can be included in the EMS in the future.

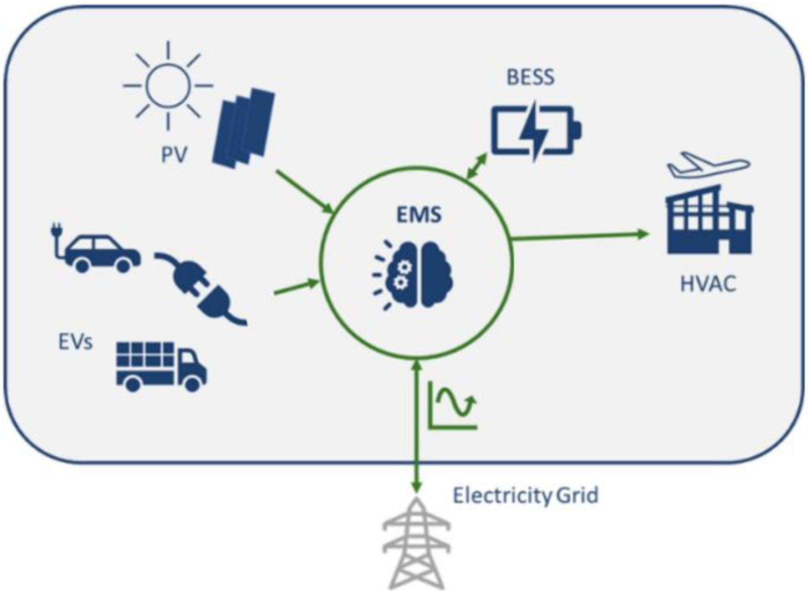

Figure 2 – The concept of an airport smart energy management system (EMS) with assets included in ALIGHT.

Providing flexibility services

In all European countries, transmission system operators (TSO) procure ancillary services to stabilise the grid frequency and restore it in case of major disturbances. The EMS can be used to plan the operation of the assets in the airport which are to deliver ancillary services, while ensuring functionality for the primary operation of the asset e.g.: As the majority of the operation at airports take place during the day from 4:00 am to 22:00 pm, where not all assets are in use, the EMS can handle planning and operation of the relevant units to deliver ancillary services.

Reduce investments in grid infrastructure

The EMS can reschedule the power flow within in an electrical system, for example if a main grid connection is congested, then the EMS can reschedule some operations for later times when there is less congestion. This is very helpful in retrofit cases, where the lead time of getting a new grid connection is too long, or physically changing some components is impossible. The shifting of consumption to a different time requires flexible and controllable assets and possible storages to enable load shifting at the airport.

6 Roadmap for smart energy supply and management

The purpose of the roadmap presented in this report is to outline a systematic approach for transitioning the energy system within the airport to encompass more sustainable and renewable energy sources. This section is based on work within ALIGHT, especially D4.1 Fossil Free Airport Roadmap infrastructure, supply, use and flexibility (confidential). The approach is divided into three overall phases as depicted in Figure 3. The roadmap is made generic to make it applicable to airports that differ in size, location, environmental conditions, or other properties.

Each phase has a specific focus and a set of objectives and are assisted with examples of key questions typical for each phase. Additionally, the phases of the roadmap also follow the chronological order, although without being an actual timeline. Each of the phases are more detailed described in the following sections.

Figure 3 – Overall phases for the process of integrating smart energy solutions.

6.1 Mapping phase

The aim of the mapping phase is to create a solid base for subsequent decision making and prioritising of actions. The mapping phase should include an overall economic analysis and an initial environmental assessment to evaluate the business case and environmental impact related to the project.

An energy analysis is recommended to give a solid technical understanding of the energy system, including potentials for and utilisation of RES, energy storage systems and smart energy management. Knowledge and information regarding the current energy demand and the development of the energy demand in the coming years/decades in the airport is a necessity to conduct an energy analysis. The data should include information about heat, gas, electricity, and potentially other energy sectors, to identify peak, average, and overall energy demands in all energy sectors in the airport. Knowledge about future plans for the airport should also be considered to ensure a sustainable and long-term solution, as many processes may undergo transition from fossil fuels to e.g. electricity. The energy analysis should also estimate the initial business case for the energy project, by estimating the overall costs and benefits related to the project. As stakeholders can have specific requirements for the system, the business case can be affected. More detailed budgets for implementation can be made in the planning phase after system and infrastructure requirements has been defined.

Besides the energy analysis and business case, an initial sustainability assessment should be conducted. The primary purpose is to identify overall sustainability and especially focusing on environmental impacts associated with the project at an early stage. This includes assessing effects on GHG emissions, wildlife, water resources, air quality, and land usage, which can affect the energy project framework.

Furthermore, the mapping phase should include assessment of the suitability of different energy resource technologies e.g., wind turbines, solar panels, hydro power, geothermal energy production etc. To assess the suitability of different energy sources it is necessary to map local weather conditions and natural energy resources, as this can make some technologies more attractive than others e.g., if there are local geothermal areas, or high solar radiation for PV.

All the obtained knowledge and collected data will form the decision-making basis for which projects the airport should proceed with and thereby bring into the next phase.

Mapping: Key questions

- How is the airport's supply of energy (heat, electricity, gas etc.)? What are the current sources of energy?
- What is the yearly energy demand? How are the energy demand expected to develop in the coming years/decades?
- What is the average and peak power demand? How are the power demand expected to develop in the coming decades?
- What is the need for the different energy forms now and in the future?
- Which possibilities do the local surroundings give?
- Which energy supply technologies and storages are available and how is the environmental and business case for them?

6.2 Planning phase

The aim of the planning phase is to choose the relevant technologies for the energy projects and ensure a thorough foundation for implementation and commissioning.

Energy projects often require collaboration with multiple stakeholders, it is recommended to initiate a stakeholder analysis as early as possible in the planning phase containing both stakeholder identification and engagement plans. The stakeholders can have important requirements to the system and/or infrastructure/surroundings, why it is important to involve them as early as possible. Some relevant stakeholders to identify and engage with are airport authorities, government agencies, energy providers, and airlines, to ensure that their needs and concerns are addressed. An example of a stakeholder analysis tool can be found in Appendix 16.2.

The planning phase also covers several detailed analyses, which depend on the project framework. The obtained knowledge and data in the mapping phase should be implemented in a feasibility study to evaluate the technical, financial, and operational viability of the proposed energy solutions. The analyses should give the optimal capacities, rated power, required areas, functionalities etc. for the energy projects. Concurrently to the feasibility study an environmental impact assessment (EIA) should be conducted to ensure that the project adheres to all relevant local, national, and international regulations and standard, and that necessary documentation and applications for permits and approvals are prepared.

When the project framework is determined, the more project specific analyses must be carried out such as glint and glare analyses, radar and communication interference analyses, risk assessment, operational impact analysis, infrastructure and network analysis both internally in the airport and related to integration into external systems. By conducting detailed analyses, airport authorities can make informed decisions, minimise risks, and enhance the likelihood of successful project implementation. The following guidelines highlights analyses necessary particularly for airports in relation to the specific topics.

Planning: Key questions

- What are the main purposes and goals by looking into new smart energy solutions?
- Which energy supply and storage technologies will be implemented?
- What will the sizes of energy projects be?
- Which stakeholders need to be involved?
- Is the infrastructure for the energy supply sufficient?
- Which safety measures needs to be taken?
- What are the requirements for the systems?
- Who can/shall deliver the energy supply/storage system?
- Are there any environmental impacts which need to be mitigated?
- Which technical and regulatory requirements need to be followed?
- Which approvals need to be achieved?
- Which KPIs will be used to evaluate the performance of the solutions and what data is needed?

6.3 Implementation and operation

The implementation phase is the last part in this road map. The implementation phase can be structured in many ways, hereunder presented with two stages:

1) Pilot implementation and test
2) Scale-up and roll-out phase

If a detailed feasibility study or simulation has been conducted this can replace a pilot implementation and test phase. It is though important to be aware that the pilot implementation will result in experiences related to the practical, logistic, and economic aspects of the project, which can be difficult to cover in a study, as many unforeseen barriers may arise during a pilot implementation.

Pilot implementation and test

The process of pilot implementation and test covers the first installation and implementation of new energy projects. This phase is meant for testing and optimisation of solutions planned toward a carbon neutral airport. It gives the opportunity to validate technologies and solutions, improve their designs, verify regulatory requirements and get experiences about practical and logistical aspects of the projects in a smaller and less critical part of the airport. This also reduces the economic risks before large investments are made in larger projects. A pilot project will often slightly extend the total time needed for the implementation phase but should help optimise a large-scale roll-out. With effective regulatory approval methods established and using parallel implementation planning the investment and labour-intensive phase can be shortened, minimising total costs and operational interference.

When the energy project is implemented a performance test must be performed to validate the solution concerning efficiency, reliability and integration of the new project into the existing airport infrastructure. Moreover, the pilot project should be used to identify and mitigate unforeseen risks, issues, or challenges that were not apparent during the planning phase e.g., technical glitches, safety concerns, operational disruptions, etc. Furthermore, the testing phase should also contain a financial assessment, where the financial assumptions (i.e. cost savings, return on investment, operational costs etc.) in the planning phase are evaluated and maybe refined before used as inputs for the larger roll out.

Pilot implementation and test: Key questions

- Are needed approvals for pilot project obtained?
- Are all needed approval-procedures for the full-scale project obtained or identified?
- Are infrastructures prepared for installation of energy supply systems and storages?
- How does the installed systems operate and perform?
- How does integration with existing SCADA, management systems, infrastructure, operational procedures etc. work?
- Do the costs match the expected business case?
- Have any unforeseen risks been identified? Which and how can they be mitigated?
- Are there any optimisation potentials before scale-up and roll-out? Either on technology/solution or on project process and execution?

Scale-up and roll-out

This phase involves expanding the project from the initial pilot implementation to a full-scale project in the airport. It should be considered whether there are any barriers for scale-up. This can be technical barriers within the chosen technology, logistical barriers e.g., on infrastructure, or regulatory barriers. This phase also includes optionally phase out of systems and technologies that are replaced by sustainable alternatives e.g., natural gas used for heating, diesel generators etc.

Monitoring the performance by implementing robust monitoring systems to continuously track the performance of energy solutions, using metrics such as energy consumption, cost savings, and system reliability can be beneficial. Moreover, monitoring performance can help to evaluate how the project is contributing to the airport's sustainability goal.

It is also important to maintain engagement with stakeholders to ensure continued support and collaboration, addressing any emerging concerns or opportunities for further enhancement.

Scale-up and roll-out: Key questions

- Are needed approvals for the full-scale project installation obtained?
- Are there any barriers (technical, logistical, or regulatory) for scale-up?
- Are all fossil fuels phased out? Why not?
- How is the project contributing to the sustainability goal?
- Should the large roll-out be conducted in several steps/phases?

7 International and European regulations affecting smart energy projects

Regulations for airport safety and operation can affect the opportunities and barriers for implementation of smart energy solutions in airports. This section will briefly introduce some of the regulations which may affect the smart energy projects in airports. For specific projects carried out it is recommended to be aware of the regulations and assess whether to look deeper into details. The responsibility of complying to these regulations might be placed in different departments of the airport or at external stakeholders.

7.1 International Civil Aviation Organization (ICAO)

The International Civil Aviation Organization (ICAO) is formed under the United Nations. ICAO develops policies, standards, and procedures for international civilian flights in cooperation with other organizations. [7] [8] ICAO also develops guidelines and shares best practices which may be relevant when planning new smart energy projects.

7.2 European Aviation Safety Agency (EASA)

The European Aviation Safety Agency (EASA) has a central role in ensuring aviation safety and environmental protection in Europe. EASA formulates and proposes rules, standards, and guidelines, certifies aircrafts and equipment, and approves and oversees organisations. [9]

The *Easy Access Rules for Aerodromes* incorporates a list of European regulations, annexes, and guidelines made by the European Union Aviation Safety Agency (EASA).

The Easy Access Rules for Aerodromes do not directly mandate the adoption of smart energy solutions but create a regulatory framework that impacts their implementation. Airports must align smart energy projects with safety, environmental, and operational standards outlined in the EASA rules. This ensures that innovations in energy management support sustainable airport development while maintaining compliance with European aviation safety and operational regulations.

EASA regulations primarily focus on safety and operational standards and intend to ensure that smart energy implementations do not interfere with:

- Aircraft operations
- Navigation systems
- Emergency procedures
- Ground handling operations

This can include specific Infrastructure requirements e.g. of lightning and power distribution. Examples of specific requirements in power distribution:

- Redundant power systems requirement remains mandatory
- Smart grid integration must not compromise backup power
- Load management systems must prioritize critical operations

The regulations also define critical areas which set some installation constraints. These include runway zones, taxiway areas, navigation aid protection zones and emergency access routes.

Other specific requirements to mention for solar and energy storage installations are:

Solar installations:

- Must be glare-assessed
- Height restrictions apply
- Must not interfere with radar systems

Energy storage systems:

- Location restrictions in operational areas
- Fire safety requirements

In general, it is required in the regulation that the member states ensure consultancy on specified topics, which may impact the safety of aerodrome operations.

7.3 Renewable Energy Directive (RED III)

The Renewable Energy Directive (RED III), formally known as Directive (EU) 2023/2413, establishes a common framework for the promotion of renewable energy across the European Union. It sets binding targets and provides guidelines for integrating renewable energy sources into various sectors, including transportation, heating, cooling, and electricity.

Through the RED III also airports need to contribute to the EU's overall target of at least 32% renewable energy by 2030. Airports must consider renewable energy options in infrastructure planning and development and are required to implement renewable energy solutions in both electricity and heating/cooling systems.

RED III sets targets for renewable energy in the transport sector, affecting airport ground transportation and encourages electrification of airport vehicles and equipment together with promotion of the use of advanced biofuels.

Moreover, it requires integration of renewable energy in new buildings and major renovations which affects terminal buildings, hangars and other airport facilities. To achieve this the airport must consider options like solar PV, geothermal, biomass heating/cooling.

Smart Grid & Energy Management:

RED III also supports the development of smart grids and energy storage systems, introduces demand response and flexible energy consumption and encourages digitalization of energy systems for better monitoring and control. This directive is not specific for airports but covers development and deployment of renewables in any context.

RED III requires Member States to simplify permitting and administrative procedures for renewable energy projects and sets maximum timeframes for permit granting.

RED III sets sustainability criteria for biofuels and biomass and requires certification and verification of renewable energy sources e.g. through Guarantees of Origin.

Through RED III allows Member States to create support schemes to promote renewable energy adoption, enables cross-border cooperation on renewable energy projects and provides framework for Power Purchase Agreements (PPAs), which can create opportunities also for airports.

7.4 EU Energy Efficiency Directive

The Energy Directive (often referring to the EU Energy Efficiency Directive, currently Directive (EU) 2023/1791) aims to promote energy efficiency across the European Union. Its primary purpose is to ensure the EU meets its energy efficiency targets, reduces greenhouse gas emissions, and advances toward climate neutrality.

The directive covers sectors including buildings, industry, transport, and energy supply including targets for measures for energy savings, energy audits, metering, and national energy efficiency strategies.

The Directive aims to make the supply side of energy – generation, transmission and distribution – more efficient, lower emissions, and foster the integration of renewable and recovered heat sources. It sets obligations for both public authorities and private operators to systematically consider and implement energy-efficient solutions.

Area	Directive's focus within the field of energy supply
Efficient generation	High-efficiency cogeneration, district heating/cooling
Transmission & distribution	Reduce losses, improve efficiency, enable demand-side flexibility
Heat recovery	Utilize industrial waste heat, support for heat networks
Infrastructure planning	Prioritize energy efficiency in all infrastructure development
Consumer empowerment	Smart metering, demand response, transparent information

Table 3 - summary of focus areas from the EU Energy Efficiency Directive within the field of energy supply.

7.5 National and European technical regulations

When connecting new electrical plants or electrical energy storage systems to the public grid. Technical requirements for grid connected systems are defined through network codes.

On the European level the following regulations are relevant:

- **Requirement for Generators (RfG):** *Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators*
- **Demand connection code (DCC):** Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection

As none of the European regulations cover electrical energy storage systems for now, other than pumped hydro, it is national regulations in force. An example of this is the Danish regulation issued by Energinet, transmission system operator (TSO) in Denmark: *Technical Regulation 3.3.1 – Revision 5 – Requirements for energy storage facilities.*

Depending on the specific project, energy technology and location other technical regulations may apply.

7.6 Incentive programs for smart energy

Relevant incentive programs for smart energy will be listed here. The incentive programs can be for renewable energy sources, electric vehicles, charging infrastructure, electrical flexibility assets such as energy storages or support to development of the transport/aviation sector etc. Examples of incentive programs given here can be national or European programs to help the reader to find actual and relevant programs.

Examples of programs:

- **Connecting Europe Fund:** LTOU has received funding to install electric networking and charging points for landside and airside vehicles and new electric GPUs to replace the old diesel GPUs.
- **Airport Carbon Accreditation (ACA):** This certification program has proven to be an effective and forward-facing tool supporting airports of all sizes and locations in reducing their impact on the climate.
- **European Innovation Fund:** Very large fund for demonstration projects showing low-carbon technologies. ADR has received funding for their BESS through the project “PIONEER” in collaboration with other partners.
- **Horizon Europe:** Research and innovation funding programme, which the ALIGHT project is supported by.

Guideline for solar power plants in airports

8 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 are a mature and well-known technology that could effectively utilise the large land-areas that airports typically have [2].

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 Figure 4. The process is divided into phases, that are ordered based on the probability of circumstances resulting in project rejection.

Figure 4 includes examples of recommended analyses related to each phase and the potential outcomes of the assessments conducted in the given phase.

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 PV plant 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

Figure 4 – Overview of examples of relevant analyses in each phase and the expected outcomes in each phase for PV plant projects.

The mapping, planning and implementation process related to PV plants in airports are described in the following sections.

8.1 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.

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 together 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 [10]
- 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 conduction 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 must be included.

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.

8.2 Planning

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

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. These are further elaborated on in Appendix 16.3.

It is very important to investigate if the PV will affect the communication, navigation and surveillance (CNS) systems. The risks PV panels can introduce to each of the systems (Explanation of purpose of each system can be found in Appendix 16.4):

- Surface movement radar (SMR): PV Panels can generate multi path/ghost echoes due to reflective surfaces of the panels. This can result in safety issues, as radar plots will not be correct.
- Instrument landing system (ILS): PV panels can compromise the safety and precision of the ILS system if installed near an ILS system. This can result in inaccurate guidance for the pilot.
- Multilateration (MLAT): Installation of PV panels near interrogators, used to airplane information send to the Air Traffic Management System, can affect and influence the precision of the surveillance tool.
- Bird Radar: detection of birds can be faulty if signal emitted by the bird radar gets reflected by the PV panels, which can decrease the sensitivity.

According to National Aviation Safety Plans (NASP) it is required that solar panels are placed a minimum of three meters from the perimeter fence. This is among other reasons to ensure that security personnels do not overlook anyone.

Risks related to airplane crash makes it important to be aware of flight safety zones, which will limit the available space for PV plants.

Another risk when introducing PV plants in airports is safety hazards from light reflections, which could distract pilots or ground personnel. To ensure this it is required to perform a glint and glare analysis.

Lawn mowing to mitigate birds and other wildlife is a crucial part of operation and maintenance, especially around airport runways. The presence of solar panels can complicate these activities and solutions for this need to be considered.

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. In Appendix 16.2, a structure of a stakeholder analysis can be found.

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))

See more about the potential role of each stakeholder in Appendix 16.3.

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[11] must be conducted. The analysis might result in changes in the planned PV plant layout e.g., change in tilt angle of the panels,

[11] Based on guidelines from Federal Aviation Administration (FAA): *Technical Guidance for Evaluating Selected Solar Technologies on Airports, April 2018* [23]

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.

<u>Map available areas:</u>

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.

A map similar to the once shown in Figure 5 and Figure 6 can be used to visualise the potential areas and can be used iterative 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 5 – Visualisation of potential areas for PVs without antireflective coating. These maps are part of a screening phase and do not show the actual applicability of the areas within the airport.

Figure 6 – 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.

<u>Grid connection analysis</u>

When planning to install ground mounted photovoltaics it is important to be aware of buried 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.

<u>Requirement specification</u>

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.

<u>Tendering and procurement</u>

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.

8.3 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.

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. There are different approaches to this, a solution from Copenhagen Airport is presented in Section 13.1.1

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 are 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. If not doing this, 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) 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.

Guideline for charging infrastructure in airports

9 Guideline for charging infrastructure in airports

As a part of the green transition, a significant amount of energy consumption is transitioning from fossil fuels to electricity, thereby making charging capabilities a necessity. To address this growing need, the airport must carefully evaluate various factors to develop a strategic and scalable approach to installing an effective and future-proof charging infrastructure.

The term “charging infrastructure” covers charging of all types of electric vehicles and appliances such as electric cars (EV), electric Ground Support Equipment (eGSE), electric buses, electric aeroplanes, electric Ground Power Units (eGPU) etc.

In Europe, there are two types of charging connectors/plugs: Type 2 and CCS, see Figure 7. The Type 2 connector is the standard AC charging plug in Europe. This connector supports AC charging up to 22 kW. The CCS (Combined Charging System) connector is primarily used for DC fast charging. It builds upon the Type 2 design by adding two additional pins for high-power DC charging, making it a "combo" connector. This connector supports significantly higher power level than Type 2, as the typical power levels are 50 kW for fast charging and above 150 kW for ultra-fast charging.

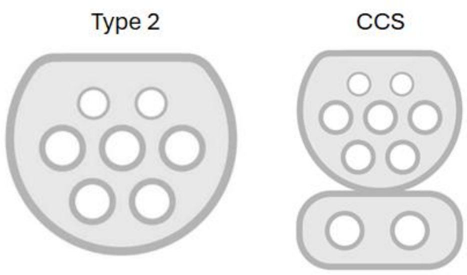

Figure 7 – Comparison of physical layout of charging connectors

Charge points can be divided into two overall categories:

- **Charging Destination**: These are charge points that are dedicated locations for charging of vehicles and appliances. Hence these locations need to have high power chargers installed.

- **Destination Charging**: This is where the user of an electric vehicle would go regardless of the charger such as parking lots at airports, shopping centres etc. Destination charging generally consist of AC chargers rated to 11 kW or 22 kW.

At landside, airports primarily have a need for destination chargers, because users travel to the airport regardless of the chargers. Fast chargers can be used in spaces of short period parking and for taxis and drop-off areas, where slow chargers can be used in the long-term parking spaces. At airside, chargers in the charging destination category with fast chargers to reduce the charging time for equipment.

This chapter presents guidelines related to charging infrastructure in airports considering both airside and landside. The illustration contains examples of analyses and assessments which can be conducted and the possible outcomes for each phase. The chapter follows the steps presented in the roadmap in Chapter 0.

Phase	Mapping	Planning	Implementation and operation
Analyses and assessments	Mapping of current charging infrastructure and electric fleet Predictions for future demand Estimation of needed chargers Initial business case Relation to overall sustainability plan	Infrastructure analysis (e.g., load flow calculations) Stakeholder analysis Ownership considerations Detailed implementation plan Scale up/roll out plan Tendering and 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 Estimation of chargers and power needed and price	Stakeholder engagement Ownership Detailed plan for implementation Electric infrastructure layout Procurement of equipment	Approvals obtained Installation of chargers Monitoring usage

Figure 8 – Overview of examples of relevant analyses in each phase and the expected outcomes in each phase.

The mapping, planning and implementation process related to charging infrastructure in airports are described in the following sections.

9.1 Mapping

<u>Mapping of the current infrastructure and electric fleet</u>

To understand the future needs and requirements for the charging infrastructure of the airport, it is essential to establish an overview of the current fleet composition and infrastructure. This includes both landside and airside vehicles, covering everything from passenger cars and buses to specialised GSEs. At this stage, it is important to map the number of electric vehicles and their areas of use. The planning department should also ensure that the airports replacement plans for the existing fleet is aligned with the electrification strategy and thus charging infrastructure plan.

A thorough review of the current charging infrastructure is necessary to assess its ability to support an increased electrification of the fleet, when estimating the need of chargers in the airport. This involves mapping the number of charging stations, their locations, capacities (kW), and usage patterns, including utilisation rates and peak load periods. This analysis will help identify potential bottlenecks and future needs for infrastructure expansion. The airport should also consider the connector type to facilitate future electrical use-patterns including charging of buses, eGSE, planes etc. Considerations about charging infrastructure for electric planes and eGSE's dedicated to aircraft stands are further elaborated on in *D5.3 Conceptual design of future aircraft stands*[12], *Infrastructure studies for future aircraft stands*[13] and *Push-back study*[14].

Projections of future demand

Besides airport related vehicles, the charging infrastructure for public charging should also be mapped and estimated. It is relevant to consider national projections for the share of EVs in the overall fleet. According to forecasts from Danish authorities and the EU, a significant increase in the number of electric and hybrid vehicles is expected by 2030 and 2050 [11]. This development must be considered to ensure that the airport's strategy aligns with national forecasts for the green transition.

Estimation of needed charging infrastructure

In the mapping phase the airport should identify the needed charging capacity considering the needed charging type (slow or fast) and charging level (maximum power of the charger). If the airport would like to provide smart charging and/or V2G they should consider which types of electric vehicles are most suited for their needs and assess the battery capacity of the available vehicles, as this will affect how much energy can be utilised for V2G operation. Moreover, it should be assessed if the vehicles used within the airport (e.g., shuttle buses, service vehicles) are V2G-compatible and whether the smart charging infrastructure can manage bidirectional energy flows. Details on smart charging and V2G are presented in Chapter 10.

[12] D5.3 Conceptual design of future aircraft stands, Sep. 2025
[13] Infrastructure studies for future aircraft stands, Sep. 2025
[14] Push-back study, Sep. 2025
All above reports can be found at Alight website after publication: https://alight-aviation.eu/

Initial business case

To assess the feasibility of installation of charging infrastructure an initial business case can be conducted. The business case can include:

- Capital expenditures: Cost of chargers, installation, site preparation, and infrastructure upgrades.
- Operation expenditures: Ongoing costs such as electricity, maintenance, software licensing, and customer support.
- Potential revenue: such as pay-per-use charging fees, partnerships with EV service providers, etc.

Sustainability assessment

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 assessment should cover if the installation of EV chargers supports the overall goals such as reducing carbon emissions.

It should also be considered whether the electricity supplied to chargers is sourced from renewable energy and the implications for the business's sustainability goals.

9.2 Planning

When the potential for chargers has been mapped in the initial phase, suitable locations must be selected. This requires thorough planning to achieve optimal placement, where considerations regarding the number of chargers, electrical infrastructure, and physical location should be included. Therefore, relevant stakeholders should be involved early in the planning process to mitigate potential barriers. The involvement can be structured in a stakeholder analysis (see tool in Section 16.2).

The stakeholders may include:

- Airport master planning department
- Airport sustainability department (e.g., ensuring project is aligned with sustainability goals)
- Airport fire department
- Airport asset management (e.g. responsible for electrical infrastructure)
- Distribution system operator (DSO) (e.g. for grid connection approval)
- Parking facility operators

- Airport tenants and businesses
- Municipality (e.g. for land zone permit, building permit, occupancy approval)
- National authority (e.g., Italian law regarding fire risks)
- Vehicle and equipment manufacturers to ensure compatibility and support.

Detailed analyses

The detailed planning can consist of several analyses, which assist to ensure an effective, scalable and cost-effective implementation.

Space allocation

The optimal zones for charging stations, such as parking lots, employee parking areas, or near terminals must be identified, considering the estimated number of chargers needed, physical space required for installation, accessibility (e.g., in case of fire in chargers or vehicle), and efficient traffic flow around the charging areas.

Electrical analyses and layout

The power needed for charging depends on the type and number of charging stations as well as the specific needs of the users, e.g., long-term parking might require slow charging, whereas charging of eGSEs might require ultra-fast charging due to operational schedules where predictable power requirements are essential. Airport users, such as passengers and staff, often have varying charging time windows, ranging from brief stays in pick-up/drop-off zones to extended periods in parking lots. The allowable time and power level for charging are thus key parameters to consider.

To ensure that the electric infrastructure in the airport can accommodate the expected power demand without causing grid congestion and disruptions, both internal grid analysis and coordination with the DSO must be conducted. For the internal analysis the peak demand taking into account simultaneous charging at multiple stations during busy periods. If the internal grid cannot accommodate the charging infrastructure a need for grid reinforcement (cables, transformers, etc.). The cooperation with the DSO should clarify the impact the additional loading will have on the external power grid. This detailed load analysis is necessary to determine whether the existing grid can handle the increased demand or if upgrades to substations and transformers are required. If the roll-out of the charging infrastructure is divided into several phases, the design and layout of the initial infrastructure must ensure that future expansions can be integrated seamlessly.

The peak demand can however be lowered by the airport by load management measures such as smart charging, peak shaving, limiting the allowed charging power, etc., or by installing a battery supplying energy during peak demand and thereby reducing the load on the grid. If the airport will facilitate V2G, it must be evaluated whether the electrical grid (incl. components like transformers, protection equipment etc.) can handle bidirectional flows. Moreover, initiate cooperation with the utility company regarding V2G to avoid possible grid congestions and consider if it is possible to integrate RES such as PV or wind turbines. The optimal locations for V2G-compatible charging stations to maximise convenience and efficiency, should also be identified. Smart charging and V2G are elaborated in Chapter 10 and energy storage in Chapter 11.

Ownership – internal vs. external

When it comes to ownership of the charging infrastructure, a decision must be made on whether the airport should own and operate the facilities itself or collaborate with external stakeholders. Considerations to make for the two ownership categories could be:

Internal ownership:

- Advantage: Full control over operations and maintenance, tailored solutions, and potential revenue from charging and implementation of smart charging solutions.
- Disadvantage: Higher initial investment costs and requirements for technical expertise.

External ownership:

- Advantage: Lower initial investments and the ability to leverage the experience and technology of external partners.
- Disadvantage: Less control over operations and dependency on third parties. Procedures or regulations of payment structure and responsibility between parties are not fully developed, which complicates implementation of V2G. [12]

The airport can consider which ownership structure that makes sense for each area, and thereby not having the same ownership for all chargers.

<u>Requirement specifications, tendering and procurement</u>

Requirements for the chargers and infrastructure can be formulated in both functional and non-functional requirements. The requirements can include specifications for:

- Type of chargers and number of chargers
- Power requirements
- Compliance with standards

<u>IT security</u>

A plan for the validation of the system by the customer must be established to ensure that the system complies with the technical specifications.

The technical specifications are used in the following tendering and procurement phase.

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/roll out plan

If the implementation of chargers and charging infrastructure is performed in more phases a detailed plan for the scale-up and roll out should be established to minimise costs and delay in roll out. All relevant steps described in the detailed analyses sections should be conducted for each of the later implementation steps. The plan can be reevaluated based on monitoring of performance and usage of the chargers implemented in the previous phases.

9.3 Implementation and operation

The implementation and construction phase of charging infrastructure in airports is a critical stage where the project transitions from planning to physical execution.

Installation of chargers

Before construction begins, it is essential that all necessary permits and approvals are obtained, and that the airport in collaboration with the local DSO ensure availability of sufficient power from the DSO grid. Moreover, the designated site must be cleared while minimising disruption to other airport operation, hence the continuous stakeholder engagement. Hereafter the installation of the chargers can be accomplished along with grid reinforcing activities if required e.g., electrical cabling, upgrade of transformers, etc. Additionally, communication lines and protocols should be installed as well, in order to monitor the usage and eventually control the chargers. The control is however dependent on the ownership of the chargers.

Testing, commissioning and monitoring

Once all equipment is installed, thorough testing and commissioning are critical to ensure the system functions correctly. The tests should encompass testing of performance, safety inspections such as compliance with relevant standards and policies, and functioning software integration i.e., payment systems, user interfaces, receiving data for monitoring the usage of chargers. The monitoring could include KPIs like:

1. Charging time: Tracks how long the EV was connected and charging (hours)
2. Charged energy (kWh) and power (kW): monitors the power level during the sessions. Both peak and average power should be tracked.
3. Idle time/plug occupancy: Measures the time the EV remains connected to the charger after charging is complete.

If the airport facilitates V2G and smart charging the EMS should monitor and optimise the V2G operations and performance through smart charging based on operational data. Finally, the airport should develop a maintenance schedule for periodic inspections.

Guideline for smart charging and vehicle-to-grid in airports

10 Guideline for smart charging and vehicle-to-grid in airports

As equipment in airports are replaced with electrical alternatives in the coming decades, it enables the possibility of smart charging and V2G. The required power demand (average and peak) for all equipment should be identified. Furthermore, operating patterns must also be mapped, as this information is required to assess if there is a potential for smart charging without disturbing the primary airport operations. Smart charging and V2G can be considered for both airside operations, landside operations and passenger charging facilities.

Smart charging is an intelligent approach of charging EVs, where the charging is optimised considering different factors such as CO_2-intensity of available electricity, grid utilisation, electricity prices, mobility needs, etc., instead of only seeking to charge the battery as fast as possible and as soon as it has been connected to a charger. This requires applications which communicate with both the electricity grid and the consumer i.e., EV, the charger and a management system. The Vehicle-to-Grid (V2G) technology enables EVs to deliver electricity to the electrical grid by discharging the battery of the EV. The schedule for V2G can be optimised by considering the same factors as for smart charging.

As airports have large parking facilities the implementation of smart charging and V2G can contribute to reduce carbon emissions, support low-emission mobility, and enhance grid flexibility for renewable energy integration. Moreover, long-term parking is easy predictable as it is typically booked in advance and plug-out of the vehicle is well-planned. Similarly, charging of GSEs would be well-planned and easy to predict as their operations are planned according to flight schedules and other usual airport operations.

The potential of smart charging and V2G is further elaborated on in the whitepaper *Potential for smart charging and V2G*[15] developed in ALIGHT [13].

In Table 4 an overview of parking duration and potential use cases are compared.

[15] Potential for smart charging and V2G, Dec. 2023: https://alight-aviation.eu/

Use Case	**Very Short-term Parking (< *30 min*)**	**Short-term Parking (*½ - 2 hrs*)**	**Long-term Parking (2 – 24 hrs)**	**Very Long-term Parking (24+ *hours*)**
Peak shaving	(✓)	✓	✓	✓
Electricity cost reduction	✗	(✓)	✓	✓
CO_2-emission reduction	✗	(✓)	✓	✓
Energy arbitrage (*V2G*)	✗	(✓)	✓	✓
Ancillary services*	(✓)	✓	✓	✓

Table 4 – Overview of parking duration compatibility with flexibility use cases.
**The value of ancillary services is enhanced by V2G-capabilities and requires a certain fleet-size.*

The mapping, planning and implementation process for smart charging and V2G is described in the following sections. Further elaboration on methodology for assessment of V2G-potential in an airport is described in the report *Assessment of vehicle-to-grid potential in airport fleets*[16].

[16] Assessment of vehicle-to-grid potential in airport fleets, Nov. 2025: https://alight-aviation.eu/

Phase	Mapping	Planning	Implementation and operation
Analyses and assessments	Impact on operation Initial business case Sustainability assessment Fleet analysis Analysis of charging facilities Use scenarios	Stakeholder analysis Implementation plan Financial considerations Owners Tendering and procurement	Installation of chargers SW Platform Integration into EMS Test and commissioning Scale up/roll-out Monitoring
Outcomes	Defined use case for smart charging Identification of investment costs Identification of environmental impact	Stakeholder engagement Detailed plan for implementation Ownership Procurement of equipment	Installation of compatible chargers Establishment of SW platform to handle smart charging and V2G Monitoring usage Integration into EMS

Figure 9 – Overview of examples of relevant analyses in each phase and the expected outcomes in each phase.

10.1 Mapping

In the mapping phase the purpose is to assess the potential barriers for and benefits of smart charging and V2G.

<u>Risk assessment and impact on airport operation and aviation</u>

The main concern and risk when implementing smart charging and V2G in airports may be regarding IT and cyber security of the airport data and systems. This may include fulfilling national law under the Directive (EU) 2022/2555, known as NIS2, specific requirements for information security in aviation made by EASA (EU Regulation 2019/1583) among others. Proper design of software integration into the airport is necessary together with proper handling of sensitive data about critical infrastructure, the electric vehicle, the user considering also the General Data Protection Regulation (GDPR). Any mishandling of personal or operational data can result in legal penalties.

When applying smart charging and/or implementing V2G to use the EV-battery for other purposes than driving it may affect and require some behavioural changes. In the transition from fossil fuels to electric equipment users are already required to learn the charging needs of the equipment and the charging procedures. This first step is expected to be the primary behavioural challenge. When introducing smart charging or V2G the benefits can be even higher if the user is plugging in the vehicle as soon as not in operation, and not only when needed, to enhance the time periods where the vehicle is available in the energy system. The ideal patterns for charging are dependent on the type of equipment, operational pattern of the equipment and availability of charging points.

If the airport would like to include the passenger cars to provide V2G, they should consider how to ensure fairness, proper functionality and smooth implementation:

1. The airport should consider who will benefit financially from the service, as multiple actors are included in the action; 1) the airport owning the charging infrastructure, 2) car owners, 3) third parties such as V2G platform operators, or electricity providers.
2. The airport needs a system to recognize vehicles capable of V2G functions, and where the car owner can provide consent to participate with V2G.
3. The airport must consider how to balance V2G usage with ensuring that car owners have their vehicles charged as needed. Many chargers do not inherently know the SOC of the connected vehicle. This requires integration with vehicle data or the use of smart chargers capable of advanced communication.

<u>Initial sustainability assessment and business case</u>

The sustainability assessment for smart charging and V2G may focus on the environmental impact, considering GHG-reductions from the electricity used for charging the electric vehicles and equipment.

The initial business case may include estimates of:

- Initial and operating costs related to smart charging software solutions (this may in some limited forms be part of the EV charging operators software already or part of other energy management systems implemented in the airport).
- Initial costs for replacing or upgrading conventional charging facilities to V2G
- Potential reduced costs for EV charging sessions
- Potential reduced costs for electricity infrastructure upgrades (like cables, transformers etc.)
- Potential revenue from delivering grid services, like participation in market for ancillary services
- Potential reduced electricity costs due to better utilisation of local renewable energy production

The business case could also include planning costs related to e.g., involving internal IT and Cyber security departments to ensure sufficient IT security levels and for personnel to select chargers to be included, compile data to do a mapping of the technical potential.

The knowledge of the possible gain/benefits of smart charging and V2G can be used in decision-making processes, to have awareness of derivatives prioritising EVs and GSEs and potentially V2G compatible vehicles and charging infrastructure.

The airport should consider how smart charging and V2G in the airport contributes to the sustainability goals for the airport. Depending on the use cases chosen for smart charging and V2G as presented in Section 5.1, the sustainability impact can be different. The airport should establish relevant measurable objectives to evaluate the impact and define a baseline to compare and monitor the impact of smart charging in the future to the baseline.

Fleet analysis to assess the potential and availability of vehicles for smart charging and/or V2G

To assess the potential energy and power for smart charging and V2G in an airport fleet different approached can be used. The assessment can be based on:

- Theoretic analysis of the potential of the existing and future fleet in the airport
    - Depending on the existing fleet and the availability of data this can be done in many ways. A case study for CPH has been performed and can be seen the report *Assessment of vehicle-to-grid potential in airport fleets*[17].

The proposed method here is a theoretic analysis to get an estimate of the potential. After this analysis it is recommended to continue with a market analysis where focus is on the vehicles which showed to have the highest potential.

The first step of the analysis is to decide which parts of the fleet that shall be included in this analysis.

Step 1: Estimate total battery capacity of the (assumed) electric fleet.

Step 2: Analyse the availability of the total battery capacity based on schedules for the vehicle operations (usage pattern).

To simplify the analysis of the fleet the vehicles can be divided into categories based on their battery capacity (if not already electric then an expected battery capacity can be used) and/or their usage pattern.

[17] Assessment of vehicle-to-grid potential in airport fleets, Nov. 2025: https://alight-aviation.eu/

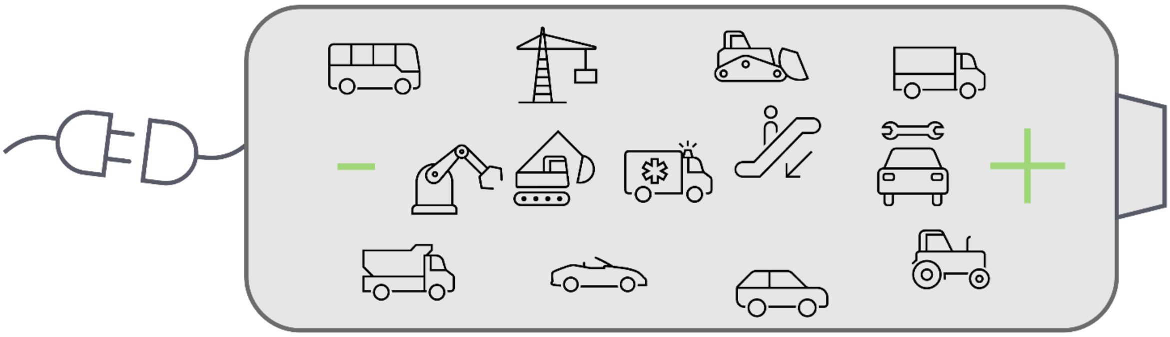

Figure 10 – Conceptual sketch of total battery capacity of fleet used for V2G in airports.

Step 1 will give a good indication of which vehicle types that may be of highest interest, as vehicle categories with a noticeable battery capacity can have the largest impact.

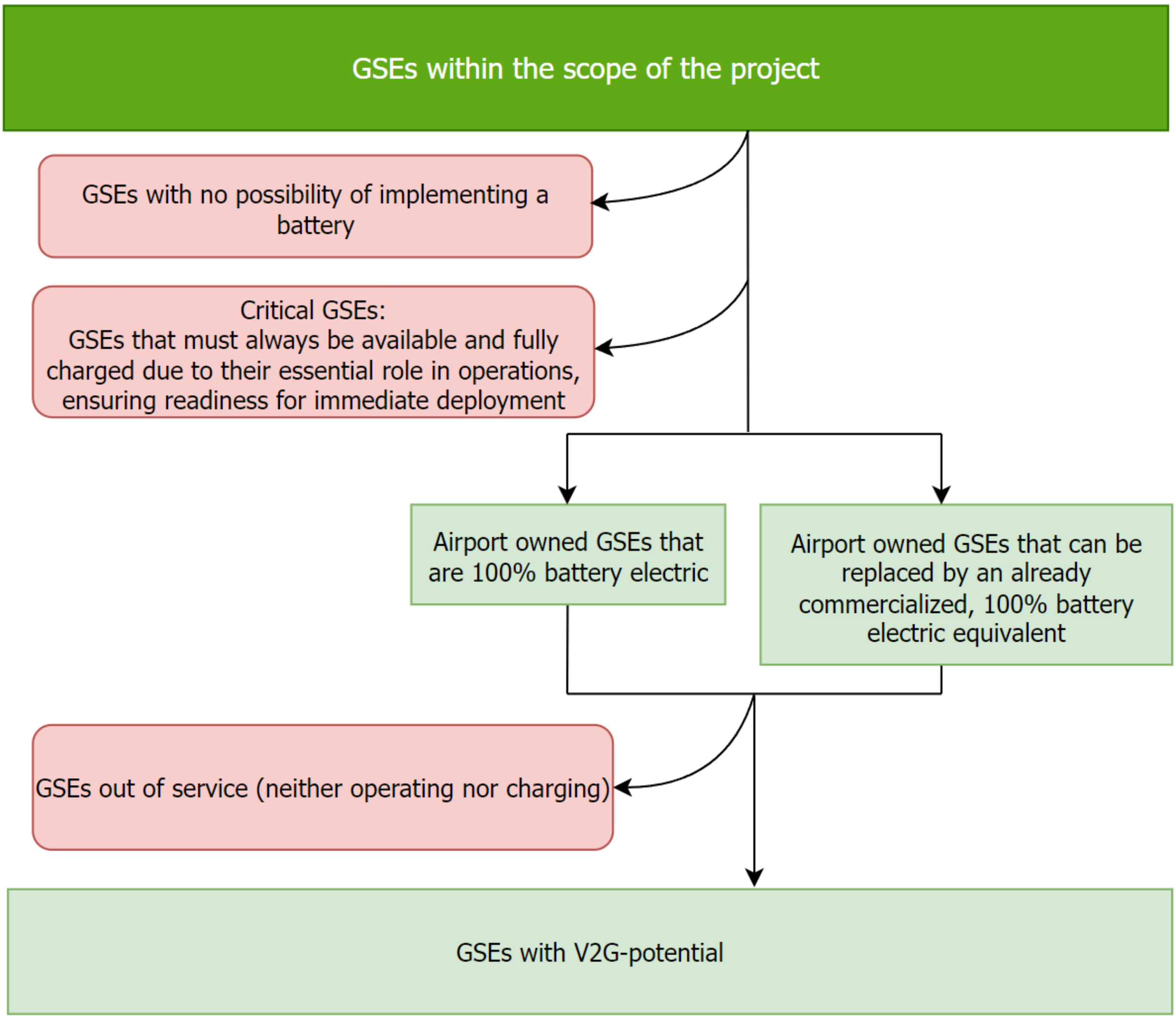

Figure 11 – Identification of GSEs/equipment interesting for further V2G-assessment.

Step 2 is necessary to assess the availability of battery capacity and thereby what is actually possible without disturbing the airport operation. The availability will depend on the operating schedules compared with the charging time for the vehicles. This means that the sizing of chargers and number of chargers available has an impact on the potential for utilising the battery capacity in the vehicles, when they are not operating.

Analysis of charging facilities

Besides analysing the fleet, it is important to analyse the capabilities of the charging facilities. This includes technical assessment of chargers' hardware and communication protocols, communication and remote-control possibilities together with identification of owner and charge point operator (CPO).

- Assessment of existing charging facilities and their compatibility with smart charging systems and vehicle-to-grid.
- Market analysis of available technologies (especially for V2G, where both chargers and vehicles shall support V2G)

10.2 Planning

Stakeholders

Mapping the usage patterns of GSEs may require either specific data on the vehicles' operations or charging sessions (if already electrified) or insights from personnel in the airport operations and knowledge about constraints (e.g., weather, air traffic and critical operating equipment).

Relevant internal and external stakeholders can be:

- Owner of charging infrastructure (if infrastructure is not owned by the airport)
- Charge point operator (if existing charging facilities are not operated by the airport)
- EMS/software developers
- Distribution and/ or transmission system operator (DSO or TSO)
- Airport IT department
- Airport cybersecurity department
- Airport master planning department
- Airport operation department (representing vehicle operators)
- Airport parking department (if passenger cars are considered to be used)
- Balance responsible party (relevant only if ancillary services are considered)
- Aggregator
- EV owners (if passenger cars are considered)
- Electricity supplier

Descriptions of the roles and responsibilities of actors especially relevant when considering ancillary services can be found in *Potential of smart charging and V2G*[18] [13].

Requirement specification and procurement

The outcome of the above-mentioned analysis can be specific requirements for new electric equipment procured in the airport, for new charging facilities procured and installed or requirements for energy management systems or similar software to manage the charging sessions. For vehicles and charging facilities especially requirements on plugs, bi-directional capability and charging protocols are of high importance. Important specifications for software solutions includes requirements for IT and cyber security together with requirements for communication interfaces and protocols to integrate with new or existing facilities.

These requirements can then be used for the procurement and tendering of the chargers and software.

Implementation plan

The planning department should establish a detailed implementation plan to ensure a structured implementation phase and to minimise costs (e.g., if only some chargers are installed with smart charging capabilities). 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, ensuring safe integration into the IT network etc.

10.3 Implementation and operation

Installation of chargers

The implementation can be divided into two phases 1) pilot and 2) full-scale:

1. Pilot Programs and Testing:

Start with a pilot project to test the smart charging or V2G concept at a smaller scale, learn from the experiences, and refine the approach.

a. Install equipment (a limited number of chargers) including connecting to the public grid, integrating robust cybersecurity measures to protect the system and airport from potential threats, and install communication systems to facilitate smart charging.

[18] Potential of smart charging and V2G, Dec. 2023: https://alight-aviation.eu/

b. Establish clear metrics to evaluate the performance and success of smart charging and V2G systems during the pilot phase.
c. Plan to ensure that vehicles always have sufficient state of charge to perform their primary functions.
d. Design dynamic charging and discharging schemes/protocols that do not disrupt airport operations.

2. Full-scale and future scalability:

After a successful pilot program, it is time to scale up and include more charging points and vehicles to be included in smart charging and/or V2G setup.

a. Design the management system to be scalable, allowing for future expansion as technology evolves and demand increases.
b. Ensure the system can integrate new technologies and advancements in charging facilities and vehicles.

Software platform

Besides of installation of physical chargers, a software platform should also be implemented. The platform must ensure compatibility with different EV manufacturers and charging station standards. The software must ensure protection of sensitive data and ensure secure communication between charging stations and vehicles.

Integration into EMS

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

Monitoring

To monitor the use of EV chargers effectively for smart charging and V2G applications, several key parameters can be considered. These parameters help in assessing the performance, efficiency, and impact of the charging infrastructure:

1. Charging session data:
    a. Energy delivered: Measures the total energy transferred during a charging session (kWh)
    b. Charging power: Monitors the power level during the session (kW). Both peak and average power.

c. Session duration: Tracks how long the EV was connected and charging (hours)
d. State-of-Charge (SoC): used for monitoring the state of the battery to ensure that the battery is charged when the user need the car while performing V2G when plugged in.

2. Grid interaction parameters:
    a. Bidirectional Energy Flow (kWh): Monitors the amount of energy sent back to the grid in V2G scenarios.
3. Other parameters:
    a. Time-of-Use (ToU): Logs when charging occurs (e.g., peak vs. off-peak hours) to optimize energy costs and grid load balancing.
    b. Idle time/plug occupancy: Measures the time the EV remains connected to the charger after charging is complete, which can inform user behaviour and charger availability.
    c. Carbon Intensity of the Energy Mix: Tracks the source of electricity (e.g., renewable vs. fossil fuels) to evaluate environmental benefits.

Guideline for battery energy storage systems in airports

11 Guideline for battery energy storage systems in airports

This guideline focuses on guidelines for implementing batteries in airports; other storage technologies also have a pivotal role in the green transition but is not covered in these guidelines.

A Battery Energy Storage Systems (BESS) consists of three main components:

1. **Batteries**: The components where the electricity is stored. Battery cells are built together to form modules/packs with voltage, current and energy ranges suitable for the application. The battery cells are electro-chemical and can have various designs, both in terms of chemical composition and physical structure.
2. **Inverter** (converter): Power electronic component that handles energy conversion between the grid/RES (AC- or DC-systems) and the battery (DC-system).
3. **Battery Management system** (BMS): Monitoring and controlling the operation of the battery to ensure safety, optimize performance, and prolong its lifespan.

The size of the BESS is characterized by its energy capacity, often stated in kWh or MWh. The charging and discharging power of the BESS are determined by the inverter specifications measured in kW or MW together with the batteries capabilities of charging and discharging rates related to the energy capacity (c-rate). Larger BESS may use multiple inverters for scalability.

Phase	Mapping	Planning	Implementation and operation
Analyses and assessments	Initial sizing Use scenarios Initial business case Sustainability assessment	Stakeholder analysis Detailed analyses (grid, size, communication) Fire safety Implementation plan Scale-up plan Tendering and procurement	Obtain relevant permits and approvals Site preparation Installation of BESS Integration into EMS Test and commissioning Monitoring and maintenance
Outcomes	Estimation of capacity Defined use case for BESS Identification of economic break-even Identification of environmental impact	Stakeholder engagement Detailed sizing of system Electric infrastructure layout Defined safety precautions Procurement of equipment	Approvals obtained BESS installed Connection to grid and EMS Monitoring production and performance

Figure 12 – Overview of examples of relevant analyses in each phase and the expected outcomes in each phase.

11.1 Mapping

The best foundation for evaluation of whether an energy storage system will improve the energy system is to collect historic data of consumption and production. This is the case both for thermal and electrical storage systems.

The following sections focus on electrical energy storage, specifically battery energy storage systems (BESS).

<u>Use scenarios</u>

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. This can help maximizing the utilisation of installed renewable energy. The BESS can also be used for energy arbitrage, where electricity is bought when the CO_2-footprint and/or the prices is low by charging the BESS and sold (discharge the BESS to grid) when electricity is less sustainable, and prices are higher. BESS can also be utilised as power buffers for peak shaving high power loads, e.g., fast chargers to limit the load on electric infrastructure. BESS can also be used for ancillary services that helps stabilise the electricity grid such as frequency reserves and create a revenue from the BESS. A storage system is thereby an element providing a high degree of flexibility in the energy system.

Below is an overview of different use scenarios for BESS:

- *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, the RES will be better utilised, and a higher share of the consumption will be covered by local RES.

Figure 13 shows a simple schematic of an energy system where a BESS is used for optimising self-consumption from a PV system. Without the BESS the household in this example uses 30% of the PV power produced, the rest would have been exported to the grid. By adding a BESS, the self-consumption has been increased with additional 30%, why the total self-consumption is now 60%.

Additional to the self-consumption it is relevant to consider the self-sufficiency, which indicates how much of the consumption is covered by local RES. The level of self-consumption and self-sufficiency a highly dependent on the size of the RES compared with the consumption together with the timing of the production versus the consumption and can be used when dimensioning both local RES and energy storage.

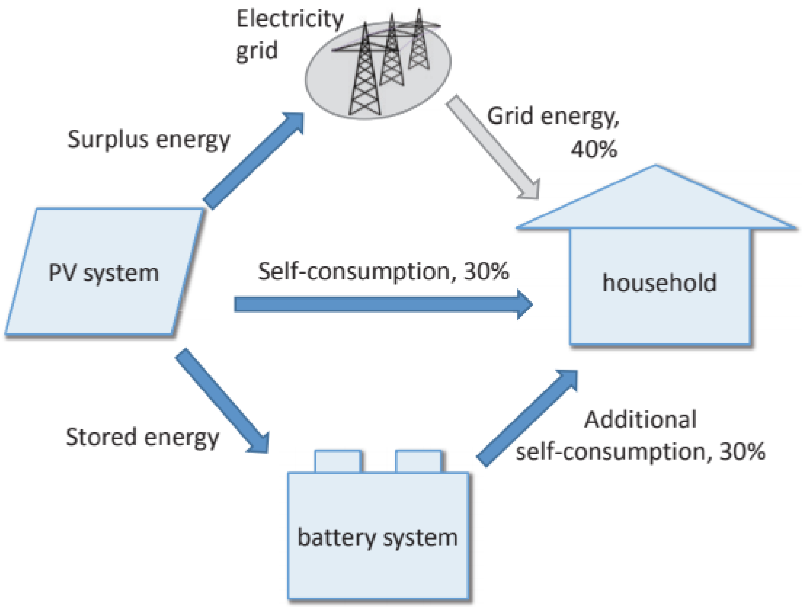

Figure 13 – Example of a battery system used for optimising self-consumption from a PV system [14].

<u>Initial value assessment and dimensioning</u>

An initial screening of the need for or the potential for a storage system is recommended. The screening should encompass both an initial business case evaluation and a sustainability value assessment. This can be based on generic use case scenarios for the BESS presented in Section 5.1, where both intended usage, and potential usage can be included.

This initial screening also includes an initial business case taking potential cost reductions, revenues and expenses into account. Furthermore, a sustainability assessment is recommended to cover the advantages a BESS can have related to CO_2-emissions, utilisation of renewable energy and roll-out of further electrification.

The initial business case, sustainability assessment and dimensioning will be an iterative process as their results impact each other.

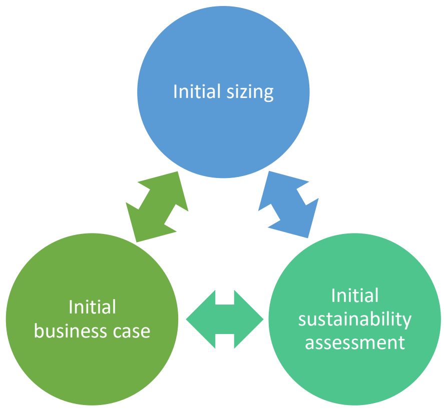

Figure 14 – Iterative process of the initial screening.

The main results from the dimensioning are the optimal energy and power capacity of the BESS, when looking at the circumstances of the grid it will be integrated into. Therefore, relevant historical data must form the basis for the calculations, such as:

- Power in point of connection (grid power, import/export)
- Power from local energy producers (e.g. PV, wind etc.)
- Electric energy consumption

The dimensioning can be based on:

- Simple calculations based on typical yearly local energy production and consumption and typical power-levels
- Simple or detailed simulations based on relevant historic time series data
- Future increase in energy demand
- Budget limitations
- Regulatory limitations
- Learning by doing, by choosing a modular and scalable solution

Designing for scalability will provide flexibility to adjust to future needs. Some solutions are storage modules built into containers that allows for extending the system energy and power capacity with additional containers. Other solutions are individual racks (smaller storage modules) which allows for even higher freedom of scalability but may have higher costs and may uptake more land area.

11.2 Planning

Risk assessment and potential impact on airport operations

As larger battery systems are not a typical asset to have in airports (yet) many uncertainties can rise.

The risk of a fire in battery systems can be a high concern internally in airport departments, by national or local fire authorities and by aviation authorities. A fire in a lithium-ion battery is difficult to fight and the smoke development are significant for batteries. As the penetration of battery systems into the market are increasing significantly, especially due to development in the electric vehicle market, the experiences with larger battery systems and fire handling are improving. Many different mitigation strategies can be chosen to minimise the risk of a fire and to minimise the consequences in case of fire, including limit smoke development and fire spread. This may include:

- Sprinkler system to cool and limit fire spread
- Water filling strategies for storage modules
- Fire walls to segmentate the storage system and limit fire spread
- Locating the storage system with sufficient distance to other critical infrastructure
- Ensuring access roads for firefighting equipment

- Installing early warning systems
- Ensuring that battery modules and battery management system (BMS) are certified to applicable safety standards e.g. EN 62619
- Physical road barriers to minimize the risk of collisions
- Ensuring that service and maintenance procedures are followed according to the supplier
- Water collection to minimise the environmental impact from firefighting
- Sufficient training of airport fire fighters and personnel working around the batteries including updated emergency plans

Stakeholders

As part of the planning phase, it is important to identify relevant and necessary stakeholders for the coming approval phase together with construction and implementation phase.

It may be necessary to involve the following stakeholder to install and get a BESS into operation inside an airport. It will be both internal stakeholders, who belong to and work inside the airport, and external stakeholders with different responsibilities.

Internal stakeholders:

- Airport fire department
- Airport master planning
- Airport asset management (e.g. responsible for electrical infrastructure)
- Airport sustainability services (e.g. project driver)

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. Italian Civil Aviation Authority (ENAC))
- National or local environmental authority

Requirement specification for energy storage system and infrastructure

Requirements for the BESS need to be formulated including both functional and non-functional requirements. Requirements to the system can come from the end user, in this case the airport, and from external stakeholders. This can be grid connection requirements, fire safety requirements, IT security requirements among others, which need to be identified and included.

A plan for site acceptance test (SAT) shall be made together with requirement specification to make sure that the system can be validated by the customer before taken into operation. An example of a SAT specification can be seen in a case study for CPH described in section 13.1, where a BESS has been installed and demonstrated within ALIGHT.

Infrastructure

Firstly, having the requirements for the system and its surroundings and then comparing with the existing infrastructure is necessary.

This includes investigating infrastructure for:

- Foundation on site
- Electricity grid and electrical connection
- Access roads to/from the site
- Signs, light, drain water system etc. on site
- Communication and IT

Secondly, planning the needed changes and upgrades can be done. This depends on dimensions of the BESS, requirements from authorities i.e. regarding access roads and drain water systems.

Foundation

Ensure that the site can support the weight of the BESS, which can be significant, especially for containerized systems.

Depending on the ground conditions, this may require soil reinforcement or the installation of a concrete foundation. An example of a foundation for a system of 0.9 MW / 1.2 MWh BESS in Copenhagen Airports can be found in section 13.1.3.

Electric infrastructure

Regarding electrical infrastructure it is important to be aware of whether additional load and bidirectional power flow can be handled by the existing infrastructure. Both cables, transformers and switchboards need to be considered. Ensure that transformers and switchgear are scalable for future expansions and plan for cable ducts or conduits to allow for future scalability.

Consider locating the BESS close to RES or large power demands depending on the use scenario for the BESS to minimise energy losses and increase the potential impact of the BESS.

Moreover, it is important to make sure that the existing grid connection agreement allows power export to the grid, if this is part of the use scenarios for the BESS. Contacting the local DSO as early as possible is recommended, as needed grid extensions can take months or years, and energy system approval processes can be extensive and have long durations as well.

Access roads to/from the site

Plan for access roads to allow for the transportation of large components during installation, including cranes to lift modules or containers if needed.

Ensure that firefighting vehicles have adequate access to the site during construction and when the BESS is commissioned and in operation.

Signs, light, drainage systems etc.

Specific signs indicating that the BESS is an electrical installation, containing batteries, not for unauthorised personnel etc. may be required by internal departments in the airport. Moreover, specific requirements for lights on the site should be considered.

Plan for effective rainwater drainage system to prevent water pooling around the BESS installation.

Environmental authorities may require drainage systems to safely handle contaminated water from firefighting.

Communication and IT

Depending on how the BESS is expected to be controlled, it is important to consider how communication with the BESS is going to be implemented. If third parties are involved in the control e.g., though an energy management system, secure solutions must be developed by collaboration between the airport IT department and the energy management system operator.

Installation of a power meter and connected dashboards are recommended to ensure that the system performance can be monitored.

Tendering and procurement

There will typically be a tendering process before purchase of a BESS will be executed as it may be a large investment for the airport.

When preparing the tendering material, it needs to be clear which requirements the tenders are expected to be responsible for as they may be covered by different companies, like a technology provider and an entrepreneur for the site preparation. Interfaces between these are important to define clearly. Airports may have their own procedures and requirements for tendering processes, that need to be followed. Considerations about service agreements should also be part of the tendering and procurement process.

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 systems. For BESS it can be by dividing the optimal size determined in the mapping phase into sub-systems and implement them in stages. Choosing modular solutions gives the opportunity to extent a system with new modules along the way. By ensuring that considerations about scale-up has been part the planning process, the costs and work associated with new projects can be held at a minimum. The site and infrastructure (e.g., electrical cables, transformers, switch boards etc.) can be prepared for future upgrades either by already installing over capacity or by making cable ducts and allocate space in electrical panels.

The plan can be reevaluated and adjusted based on experiences and results from the first stages.

11.3 Implementation and operation

Permits

In general, there is a significant need for stakeholder involvement at an early stage, prior to addressing regulatory matters. It is important to be aware of the time required to internally align on the appropriate conditions and location, as this phase can take longer than anticipated. This should be carefully considered in the overall process.

Typically, numerous approvals that must be in place before initiating any work, and the same applies to the installation of this asset. Examples of permits needed are listed below:

- Land zone permit
- Environmental approval
- Grid connection agreement and approval
- Construction Permit
- Fire Safety approval
- Occupancy Permit

The permits needed vary from country to country and it is therefore necessary to identify national and local regulations and circumstances. The authorities responsible for issuing the permits will also differ as it is often national or local authorities. Examples of permits and responsible authorities can be found in case studies for Copenhagen Airport (Denmark) and Aeroporti Di Roma (Italy) in Section 13.1 and Section 13.2.

Site preparation and installation

Site preparation may include:

- Electrical infrastructure ready for extra bi-directional power: Transformer(s), electrical switch board, cables
- Building and/or foundation for BESS: Reinforcement of existing foundation or reinforcement of ground may be needed to carry the weight of the BESS.
- Drainage of rain- and wastewater
- Establishment of communication lines and equipment
- Fire handling: Prevention, detection, alarm, protection, and extinguisher systems

If the implementation is divided into multiple stages with a pilot demonstration phase at first, it is important to consider if any of the surrounding installations shall be prepared for future up-scaling. This can be electric switch boards, cables, foundation etc.

Integration with EMS

For efficient energy management and utilisation, the BESS must be integrated into the airport's EMS. In order to ensure safe communication of data from the BESS and the EMS, secure protocols must be used to prevent unauthorised access or cyber-attacks on the EMS. There are different approaches to this, a solution from Copenhagen Airport is presented in Section 13.1.1.

Operation and maintenance

The deployment phase begins with receival and continues with installation and commissioning. A SAT as planned in the specification phase should also be made.

The last phase is operation where the BESS can deliver the services it is intended for. It can be integrated in a local smart energy management. During operation there is a need for periodically maintenance, which normally follows instructions from the supplier.

Monitoring and evaluation

To monitor the operation of a BESS, various parameters should be considered to ensure efficient, safe, and reliable performance. The parameters can include:

- Charge and discharge power
- State of Charge (SOC): Indicates the capacity of the battery as a percentage.
- State of Health (SOH): Reflects the overall health and aging of the battery as a percentage of its original capacity.
- Energy Throughput: Tracks total energy charged and discharged over time.
- Temperatures of the BESS, e.g., average temperature of each module
- Safety and protection parameters such as over/under voltage alarms, overcurrent, thermal runaway detection etc.

End of life

The European Batteries Directive (Regulation (EU) 2023/1542) extents the responsibility of the producer, by requiring the battery producer to ensure and finance that the batteries can be collected for reuse or recycling. [15]

Airports buying battery energy storage systems and other applications including batteries should be aware of this and are recommended to ensure that this responsibility is taken by the producer.

The airport can also consider reuse of batteries inside the airport energy streams, as airports with large electric fleets of vehicles and GSEs will be able to collect a significant number of batteries with a second life potential. Batteries in vehicles are typical reaching end-of-life (EoL) criteria for their specific application with a higher state of health (remaining energy capacity and performance) than required for i.e. stationary applications like BESS, as illustrated in Figure 15.

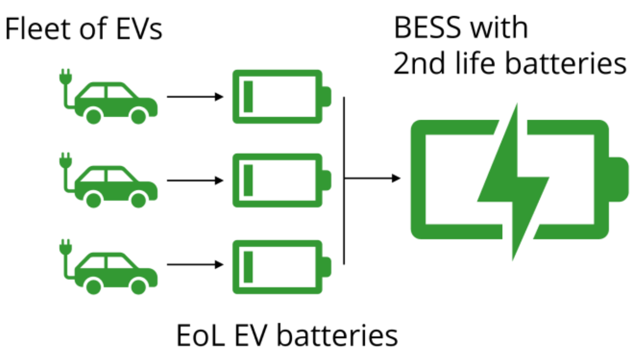

Figure 15 – Concept of reusing batteries in 2nd life applications.

Guideline for smart energy management systems in airports

12 Guideline for smart energy management systems in airports

An EMS is a technology or software that helps monitor, control, and optimise how energy is distributed. A smart energy management system can ensure utilisation of energy assets, it can optimise the energy prices, the CO_2-emissions related to energy production and use, and it can improve utilisation of the local energy infrastructure. Further use scenarios are described in the following sections.

The logic of the EMS can be based on a range of sophisticated algorithms defining rules and restrictions for the units in the energy system, e.g., to maximise self-consumption from RES in the airport, charge the BESS to maximise utility, or reduce the electrical load to minimise congestion in the grid etc. In order to have a well-functioning energy system, the EMS often includes forecasting on both energy demand, energy production, weather, prices, CO_2 equivalents etc. The EMS can also contain an interface platform, where users can access information, live and historical data, manage energy flows, etc. The optimisation will typically run in parallel with the operation, meaning the controller is updated with the actual state of the system and starting from this information forecasts the future operating conditions. The controller implements the next step of the schedule and runs again the optimisation [16]. With these advanced control devices, the airport can also coordinate its management with the network operators (e.g., electrical energy and natural gas DSOs, district heating and cooling operators) [17] by providing them services (e.g., frequency regulation) or with other actors (e.g., by exchanging energy in an energy community).

Phase	Mapping	Planning	Implementation and operation
Analyses and assessments	Energy system overview Use scenarios Data sources Communication	Design criteria Stakeholder analysis Implementation plan IT and cyber security Ownership Tendering and procurement	Demo-test Integration with other systems Test and commissioning Monitoring Maintenance
Outcomes	Overview of the components in energy system Defined use case for EMS Overview of data availability and needed actions	Stakeholder engagement Detailed functionality of EMS Ownership is clarified Procurement of equipment	EMS is tested on small scale EMS is integrated into energy system in the airport Monitoring production and performance

Figure 16 – Overview of examples of relevant analyses in each phase and the expected outcomes in each phase.

12.1 Mapping

Energy system overview

To determine if and to which extent an EMS can bring value it is necessary to establish a good overview of the existing and future energy system of the airport and its energy assets.

When mapping the existing energy system, it is relevant to obtain specification of energy assets and conditions like:

- Local electricity production
- Local heat production
- Energy infrastructure capacity and its limitations
- Energy storage systems (both electrical, chemical, mechanical and thermal)
- Energy meters and data availability
- Main energy consumers (like EV charging stations, buildings, electric aircrafts, heat pumps etc.)
- Critical energy consumption/consumers
- Energy supply contracts (e.g. grid connection agreement)

For all assets it must be investigated if they are flexible and controllable and how they can be managed. The conclusion of the mapping shall give a clear overview of:

- What can be improved in the existing energy system?
- What kind of data is needed for doing smart energy management?
- Which components are interesting
    - Are there any flexible assets?
    - Are they controllable? Fully, partly? Under which conditions and constraints?

Use scenarios

An EMS can be designed to optimise on various aspects and to consider multiple factors in the optimisation process. The EMS can ensure that advantages of controllable energy producers, consumers and storage systems are utilised. The following use cases described requires physical assets that can uptake or deliver the energy as the EMS' optimised schedule prescribes.

- *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.

12.2 Planning

Stakeholder analysis

When planning to implement an energy management system, different stakeholders are important to identify and engage with at an early stage.

Some relevant internal and external stakeholders can be:

- EMS/software developers
- Owner of charging infrastructure (if existing charging facilities are not owned by the airport)
- Charge point operator (if existing charging facilities are not operated by the airport)
- Energy asset suppliers and operators of e.g., BESS and heat pumps
- Airport IT department
- Airport cyber security department
- Balance responsible party (relevant only if ancillary services are considered)
- Aggregator
- EV owners (passengers, if passenger cars are considered and field operators for GSEs)
- Airport Operation and Maintenance department
- Airport Energy department

IT and Cyber security

It is important to be aware of IT and cyber security requirements for an EMS to be implemented in the airport. It may be the airports own security procedures defining the requirements for the system provider.

To allow external technology providers to communicate with assets inside the airport different solutions can be used. One example is to use network tunnelling, like virtual private network (VPN). If the technology provider does not comply to the IT security requirements, but need access to airport data, like live data for electricity consumption and/or production, it is an opportunity to let the airport push data to a cloud-based storage, like Azure Blob (binary large object) storage [18], and let the technology provider access the data through this platform.

Data sources and communication

Data and communication regulations for airports vary from one country to another, but in all cases vendors that are expected to deliver data-related services whether in operation or monitoring should have the necessary security systems in place. Therefore, the communication and data setup should be decided based on associate risks and the general trust in the different components.

Different examples of communication configurations that can be adopted are presented. These examples are provided for clarity purposes, but there can be other cases.

Example 1: An airport might decide to let their suppliers access assets inside of the airport firewall when they have guarantees that all their communication and data is safe and will not be shared with third parties and that the different suppliers have implemented all the necessary security methods to protect their data.

Example 2: The EMS supplier does not fulfil all the requirements set by the airport; therefore, the airport can only share read-only data with the EMS supplier and allow it to control assets through the battery supplier. This is the current case at CPH.

Example 3: The airport deems that sharing data outside of its premised is too risky, so it can decide to operate the assets locally including EMS and battery monitoring system, with encrypted access to outside suppliers for maintenance/updates.

In Table 5 the suppliers' satisfaction of security requirements for communication and data handling for each example are illustrated.

	Satisfaction of safety requirements		
	Example 1	**Example 2**	**Example 3**
EMS supplier	✓	✗	✓
Battery supplier	✓	✓	✓
Internet/cloud	✓	✓	✗

Table 5 – Examples of suppliers' satisfaction of security requirements for communication and data handling.

This kind of configuration/design decision should be taken at an early stage as it will necessitate some procurement decisions in buying equipment, setting up secure communication channels and as well the need for third party help and review of the design. Moreover, it should be considered which type of communication the data collection will use, and how the EMS will obtain the data, e.g., how to read relevant data from specific meters and how often.

Similarly to communication, it is recommended that at an early stage the following is decided, in case an airport decides to publish data outside their premises:

- The data lifetime in any kind of third-party storage solution.
- The data sharing mechanism: should the supplier fetch data or does the airport push data.
- Checking mechanism that assures that only the relevant data is shared, and no leaks happen.

As systems evolve and as the necessity for data increases, the database design becomes as important as the EMS design itself. The EMS can only advise correctly if the data are of a good quality, not stale and not corrupted. Therefore, the data flow should be stable, consistently working and replicable for quality checks. To be able to satisfy the latter, a proper data model should be in place, and it should take into consideration the various systems that will be integrated e.g., EVs, BESS, etc. The data model is key to the success of the EMS system and therefore it is recommended that the design starts at the mapping phase.

<u>Design criteria and integration with other systems</u>

The EMS design should meet both operational and regulatory needs of the airport. As described previously, the EMS should monitor and control, when possible, the various assets in the airport energy system to optimise the energy system and increase the efficiency. Therefore, the airport should consider which assets that should be incorporated into the EMS, including considering if and how they can be controlled. Since the energy system of the airport may evolve, expand and change over time, it should be possible to adapt the EMS to include new assets and changes to accommodate future airport expansions. Additionally, the EMS must be designed to withstand operational disruptions or cyberattacks.

If the airport has existing management systems (e.g., building management systems etc.) it should be considered if existing management systems should be merged into an overall EMS, exchanging data with an overall system but keep operating separately or if it should be kept entirely separated. There are advantages and disadvantages of both. Advantages of a combined EMS could be that the potential for utilising energy flexibility across different energy sectors will be increased and easier. The electrification of e.g., vehicles, equipment, aircrafts, and heat generation make it more obvious to optimise the energy use and production with existing electricity and heat/cooling use in buildings through an overall energy management system. A disadvantage of combining existing management systems into one is that it is a large task and there is a risk that the combined management system will be either too complex or missing details that were else handled in the specific management system. It is also possible to keep the individual management systems and integrate inputs/outputs from them into an overall energy management system.

When designing the EMS the airport should consider having a user-friendly interface with real-time data visualisation and reporting tools.

Tendering and procurement

When requirements to the EMS is defined the airport can initiate a tendering process to find an appropriate collaboration partner and/or software company to design and implement the energy management system.

Implementation plan

An implementation plan shall ensure that the EMS can smoothly be integrated into the airports existing infrastructure and other management systems, dashboards etc.

- Define which data to be exchanged between systems
- Define communication interface

Consider implementing stepwise and plan the order of integrating the different assets into the EMS.

12.3 Implementation and operation

Testing/demonstration in laboratory environment

When developing a new energy management system, it is an advantage if the system can be tested in a laboratory environment, to ensure safe and robust operation when implemented in the airport. This can e.g. be with a setup of hardware-in-the-loop, to validate the functionalities of the system both in terms of communication setup, response times, and optimisation algorithms to check if the system acts as expected.

This has been done in ALIGHT where the EMS developed by Hybrid Greentech has been tested at Danish Technological Institute in EnergyFlexLab [19]. A physical BESS and physical EV chargers has been used together with simulated PV and a load profile representing the airports electricity consumption.

Test and commissioning

Before the EMS can be commissioned, the functionality must be tested to ensure:

- Reliability of the data pipelines from the data providers.
- Performance of the EMS in combination with controllable assets compared to simulated baseline.
- Reaction and capability to adjust operation based on feedback from assets.
- Capability of the EMS to operate according to the specific use case (cost reduction or CO_2 reduction or other).

Testing of subsystems with hardware, to anticipate control issues and specific behaviours of the systems in question that will arise during the commissioning.

- Testing of EMS logic, response times and operational schemes (e.g., in test environment or for a pilot area etc.)
- Testing of communication with physical assets (e.g., EV chargers) and controllability of these.

As an initial step in testing, these functionalities will be verified with the actual assets intended for the demonstration activities on an individual basis to isolate any potential asset-specific issues. The energy system often consists of multiple assets, each having its own data entry, physical behaviour, and control architecture, enabling individual testing. By testing each of the assets individually, it allows for highly flexible test planning, and if some asset is not ready for testing, it can either be replaced with another source, a synthetic model, or excluded from testing altogether if no suitable method is available at the time. In the subsequent step, the system will be tested as a whole to apply the previously specified use cases.

Performance monitoring

To monitor performance of the EMS and its impact it is necessary to be sure about the use cases and the optimisation parameters. Often the optimisation parameters will be either CO_2, costs, congestion management or a combination of those.

GHG emission reduction can be achieved by time shift of operation of electric demand (load shift). Flexible loads that can be used for this purpose may include HVAC-systems, heat pumps, and EV charging. For thermal purposes it is also worth to consider the opportunity of reducing the setpoints for periods, as the response time for thermal energy in a building is long and studies shows that people will not recognise temperature deviations around $\pm$0.5°C. With large terminal buildings even small temperature deviations can result in noticeable energy amounts. [2]

To maximise awareness of the impact of a smart energy management system it is recommended to prepare dashboards or other systems to visualise data enrich the value of the data.

Maintenance

Maintenance of an EMS is needed to ensure that communication equipment, data storage hardware and software solutions are working proper.

The optimisation algorithms may need periodic refinement to adapt to new energy assets, operational changes, or updated goals. Regular updates to the EMS software are required to address bugs, improve performance, and ensure compatibility with IT and cyber security protocols. Moreover, when new energy assets are added, there is a need for updating the software and integrate new communication devices.

13 Case studies from the lighthouse airport and fellow airports

As a part of the ALIGHT project four airports are participating as potential end users of the solutions and guidelines. These four airports are different in size, location and stage of development in the area of smart energy. They therefore provide different case studies of smart energy systems and different related learnings. Copenhagen Airports is the Lighthouse airport in the ALIGHT project, meaning that majority of demonstration activities are performed there. The project also includes three fellow airports, who will provide learnings and knowledge from their smart energy projects during ALIGHT. The airports are located in Copenhagen, Rome, Warsaw, and Vilnius (marked with green in the figure below).

Figure 17 – Location of ALIGHT airports: Copenhagen Airports in Denmark, Aeroporti Di Roma in Italy, Lithuanian Airports in Lithuania, and Centralny Port Komunikacyjny in Poland.

This section presents case studies from Copenhagen Airports and the fellow airports focusing on process and considerations regarding implementation of RES, electric vehicle (EV) infrastructure, energy storage systems, and energy management solutions at the airports. The aim is to highlight the opportunities, challenges, and learnings associated with implementing renewable energy projects, smart charging infrastructure, and energy storage solutions at these airports.

13.1 Copenhagen Airports (CPH)

Copenhagen Airports (CPH) covers two Danish airports: Roskilde Airport and Copenhagen Airport. The primary is Copenhagen Airport and is lighthouse airport in the ALIGHT project. Copenhagen Airport is located 8 km from the city centre of Copenhagen. In 2023, CPH served over 26 million passengers.

CPH has an ambition to become a green-powered airport and thereby achieving carbon neutrality by 2050. Therefore, several projects are initiated, such as installation and commissioning of heat pumps for space heating by utilising excess energy from wastewater and air to reduce use and dependency on natural gas. Moreover, CPH has invested in a BESS and implementation of roof-mounted PV. As a step towards being carbon neutral, the GSE fleet of the airport will undergo a transition from being fossil fuel based to electric and potentially hydrogen based.

The airport itself had an annual energy consumption of 99 GWh in 2024 covering heating, ventilation, charging of equipment etc. In 2024 the total electricity consumption of both the airport and all their tenants was approximately 100 GWh/year with a share of almost 50% between the CPH (appr. 51 GWh) and tenants (appr. 49 GWh). [20]

	Amount	Unit	Status
Roof-mounted PV	4,376 (CPH owned: 2,193)	MWp	Implemented
Ground-mounted PV	None	N/A	N/A
EV chargers (AC 11 kW)	410 (11 kW)	kW	Implemented
EV chargers (DC 50-400 kW)	20	Units	Implemented
Public EV chargers (AC 11-22 kW)	N/A	-	N/A
Public EV chargers (DC 50-400 kW)	18	Units	Implemented
BESS capacity	0.9/1,2	MW/MWh	Implemented

Table 6 – Overview of installed solar power, EV chargers and electrical energy storage in Copenhagen Airport per March 2025.

A description of the demonstration site, Maglebylille in Copenhagen Airports, can be found in Appendix 16.1.

Renewable energy supply strategy

While CPH has not yet formalized a stand-alone strategy for renewable energy supply, the airport is actively transitioning toward a cleaner and more resilient energy profile. A key strategic goal is to ensure that 100% of the electricity used at CPH comes from renewable sources by 2025, thereby significantly reducing Scope 2 emissions and supporting the airport's broader decarbonization agenda.

To achieve this, CPH has entered into a long-term Power Purchase Agreement (PPA), primarily based on wind energy, which covers the vast majority of the airport's electricity needs. The remaining share is supplemented by self-produced solar power, expected to make up 4.5% of electricity consumption in 2025. The PPA provides both emissions reductions and long-term price stability. It is a direct PPA, meaning CPH purchases green electricity directly from a renewable energy producer, enabling full traceability and impact on additionality.

In addition to the shift to green electricity, CPH is phasing out natural gas use by 2030. This transition involves substituting gas with renewable electricity and district heating. The electricity portion will be fully renewable, while district heating will largely come from bio-waste and sustainable biofuels. CPH also continues to electrify its vehicle fleet and replace diesel and gasoline with electricity or biofuels.

These combined efforts enhance the resilience of the airport's energy supply, while supporting a steady decline in fossil fuel dependency and CO_2 emissions across energy-related activities.

13.1.1 PV plants

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.

Learnings from PV Projects in CPH

Potential barriers and impact on aviation

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.

National regulation

Environmental Impact Assessments (EIA)

Under Danish law, EIAs are mandatory for decisions significantly impacting the environment. This applies to plans, programs, and projects. In some cases, an environmental screening determines the need for a full EIA, while in others, an EIA is required directly.

For on-ground PV installations, local authorities must prepare an EIA because the planning involves both physical planning and use. At minimum, an EIA screening is required, and if potential impacts are identified, a detailed EIA must be conducted.

Project owners can skip screening and proceed with a full EIA to expedite timelines or avoid complaints. For CPH's investigations in Kastrup and Roskilde, both locations would require a full EIA has been required as both salamanders and certain orchids have habitats in the investigated areas.

Producer of electricity
The determination of whether The Owner is considered a producer of electricity under the Danish Electricity Supply Act depends on the size or capacity of the PV plant. If the capacity exceeds 25 MW, The Owner will require a license from the Danish Energy Agency. If the capacity exceeds 10 MW, The Owner will need permission from the same agency. Obtaining a license or permission is likely to impose obligations, such as those pertaining to the use of photovoltaics.

Other legislation in Denmark, affected neighbours (The Renewable Energy Act[19])

The RE Act contains four schemes with the aim to enhance the local acceptance and commitment to development of PV and wind turbine projects. The four schemes are administrated by the Danish Energy Agency. The four schemes are:

[19] Consolidation Act on the Promotion of Renewable Energy, LBK no 1031 of 06/09/2024

1. **Depreciation Compensation Scheme**: Neighbours within 200 meters of PV-panels can claim compensation for property value depreciation exceeding 1%. The rule does not apply to companies.
2. **Sales Option Scheme**: The Owner must offer to buy properties within 200 meters if requested by affected neighbours within 200 meters from the PV plant.
3. **RE-Bonus Scheme**: Neighbours within 200 meters receive an annual "Green"-bonus based on the PV plant's production until the PV plant is decommissioned or the neighbours vacate the properties.
4. **Green Pool Scheme**: The Owner pays a lump sum of DKK 40,000 per MW produced to the municipality, supporting local projects and green initiatives.

Mapping of potential areas

Initially in the mapping phase the present local plan for CPH was included in the screening of potential areas for PV installations. The airport area is divided into five areas in the local plan: West, East, South, North, and the Middle. Each area has a unique plan, allowing for different land use opportunities. When the possible areas have been chosen, more detailed analyses were conducted. To minimise potential barriers with glint and glare from the PV plant, the relevant stakeholders were included. The analyses conducted provided more details to the mapping of potential areas, and presented them in a visual way, where green is high potential, orange is little potential, and red is not viable. The coating of the PV plants is included in the screening, where the potential areas in CPH are very limited for PV projects without antireflective coating as presented in Figure 18. By choosing PVs with textured glass, the potential areas are enhanced, see Figure 19.

Figure 18 – Visualisation of potential areas for PVs without antireflective coating. These maps are part of a screening phase and do not show the actual applicability of the areas within the airport.

Figure 19 – 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.

Stakeholder identification and engagement

Several stakeholders have been involved in the PV project. This stakeholder identification is then used to develop a comprehensive stakeholder engagement plan, which outlines the strategies for engaging with each stakeholder and addressing their concerns. Many of the stakeholders will provide specific requirements to the PV plant or restrictions.

Some of the internal stakeholders of CPH and their area of concerns are presented in Table 7.

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	
Security	People hiding under/behind panels or limited view for patrollers	Longer distances between panels, panels raised from ground
Rescue & Firefighting	Fire in 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	

Table 7 – Internal stakeholders from CPH engaged in PV projects.

Furthermore, external stakeholders and authorities have been involved in PV projects in CPH. These includes:

- Municipality of Tårnby

- Tårnby fire department
- Naviair
- Other airports for knowledge sharing
    - Groeningen Airport
- Consultancies or other specialists:
    - TO-70
    - PagerPower Ltd.
    - Birdstrike Management Ltd.
    - Groenleven / BayWa
- Danish Civil Aviation Authority

13.1.2 Electric Vehicles, V2G, and smart charging

In recent years, CHP has implemented a large number of 11 kW EV chargers. On landside the chargers are mainly installed in parking garages for customers and employees. On the air-side, the number of installed Type 2 EV chargers is more limited. These are available for both internal and external parties. Regarding DC charging, CPH now has approximately 10 fast-charging points. So far, these are primarily located on the landside, though a single 175 kW charger has been installed at a demo site at airside.

Currently, V2G is not possible in CPH with the already installed and available equipment. Some of the electric GSE's still relies on regular CEE plug charging and existing EV chargers us-ing CCS are not bidirectional. Therefore, this does not support flexibility as of now and would require a transition in technical standards and replacement of charging equipment.

In a few locations, CHP has implemented load sharing for some groups of charging stations. In some areas, the available energy for charging will be shared between the chargers if all are in use. This is implemented by a fuse limiting the delivered power in the distribution panels. Ad-ditionally, a pilot project has investigated the possibility of adjusting charging levels between vehicles depending on the energy produced by the PV panels and the state-of-charge (SoC) of the vehicle.

<u>Fire handling</u>

CPH has implemented a range of fire safety measures in the parking facilities to ensure effi-cient handling of fire in EVs and BESS:

- Sprinkler systems installed in the parking facilities adhere to the standard require-ments outlined in CEA 4001. These systems are not specifically designed for EV-related fires but provide general fire suppression capabilities to enhance safety in the event of a fire.

- The Rescue and Firefighting team are equipped with specialised tools including cooling systems (see Figure 20) and fire blankets to contain and avoid spreading of fire from one EV to another.
- To further enhance safety, CPH has planned an investment in a FirstMover device (see Figure 21). This equipment will allow the safe removal of a burning EV from the parking facility, minimizing risks to nearby structures and other vehicles.
- For incidents occurring on the apron or taxiways, CPH's firefighting protocol includes using tow trucks to remove burning vehicles from building facades. This ensures that fires are isolated and prevents the spread of flames to critical airport infrastructure.
- For energy storages firefighting equipment must be installed on site for the specific installation. The specific procedures depend on the installation:
    - For PV systems the inverter is disconnected as a first step to cut off power. Foam-based extinguishing is used to suppress fires in PV installations.
    - For BESS the cabinets are designed to allow water filling. This measure effectively cools the system and reduces smoke development, as described in detail in the following section.

Figure 20 – Specialised sprinkler rack to cool burning EV and avoid spreading.

Figure 21 – FirstMover-tool used to move EVs in case of fire.

13.1.3 **Battery energy storage system (BESS)**

Use cases and dimensioning

The intended use of an energy storage in CPH is to support the general building consumption together with an expected increasing number of charging stations, to serve the many different vehicles operating in the area. Moreover, the BESS is intended to support to local produced electricity from solar panel systems installed on rooftops. A local heating plant, consisting of gas boilers and heat pumps, provides district heating to the area and can use power from the installed BESS.

The BESS is intended to be a key asset to enable flexibility potential in other controllable assets and the demonstration in ALIGHT will provide insights into how future solutions should be shaped to achieve the best results in reducing GHG emissions.

The clear objective of installing a BESS as part of the ALIGHT project is to test various control and operational scenarios when connecting it to the different energy sources and consumers, to identify the optimal control paradigm for the assets.

The dimensioning of the BESS in CPH was primarily based a simulation of historic data of PV production and historic electricity consumption at the transformer station where the BESS should be installed. A simulation to size the battery and calculate the net present value (NPV) and return of investment (ROI) when assuming delivery of ancillary services were performed. The simulations showed a positive Net Present Value (NPV) for BESS within 700-1400 kWh, but that the optimal size would be above 1400 kWh.

The BESS is small compared to the airport's overall electric energy use, with a power capacity at peak equal to about one-twelfth of the airport's electric base load. Despite its scale, the installation plays a key role in advancing sustainability, optimising energy use, and managing demand-driven distribution. The system's capacity allows for testing various purposes and opportunities of the BESS, which will support decisions of potential up-scaling. A larger BESS at CPH is expected to have impacts as described in Table 2.

Risk assessment and requirement specification

A risk assessment of having a BESS in the airport has been performed and CPH has defined fire safety requirements to the system consisting of requirements to safety distances, fire systems, smoke alarms, disconnection opportunities, signs among others.

Other system requirements have been defined based on the energy system analysis, budget, IT security requirements from CPH, general safety recommendations for BESS including relevant standards for battery cells and systems together with standards for battery management systems (BMS).

All requirements have been compiled into tendering material.

Tendering process

In the process of getting a BESS in operation in CPH, especially the tendering process, the site preparation and the approval process has taken a long time.

Requirement specification for the BESS was formulated and incorporated into the standard form for tenders in CPH. The tendering material were sent out to eight selected candidates for delivery of the BESS and a final agreement was made approximately 26 weeks later. As the standard form for tenders in the airport is extensive and requires a large amount of work from the suppliers to fill which, combined with the requested size of the BESS, limited the number of incoming bids. Many suppliers of BESS did not offer solutions smaller than a couple of MW.

System description

The system is located in the western part of the airport, which is designated as CPH's internal maintenance area (see Figure 34, Appendix 16.1) This area hosts numerous buildings and assets, serving various purposes such as equipment storage, workshops for both internal and external equipment, and local heat production. The installation site was selected for several reasons: primarily, it has been designated as a special demonstration area for the project, where multiple activities will take place. Additionally, this location allows for the concentration of activities in a low-traffic area, ensuring that customers are not affected by the demonstrations. The area is also suitable due to the presence of various energy producers and consumers.

After receiving bids, a system with high scalability was selected. To meet the budget a compromise on having a guaranteed energy capacity of 1000 kWh over the system lifetime were made and the system size was reduced from 18 racks to 15 racks.

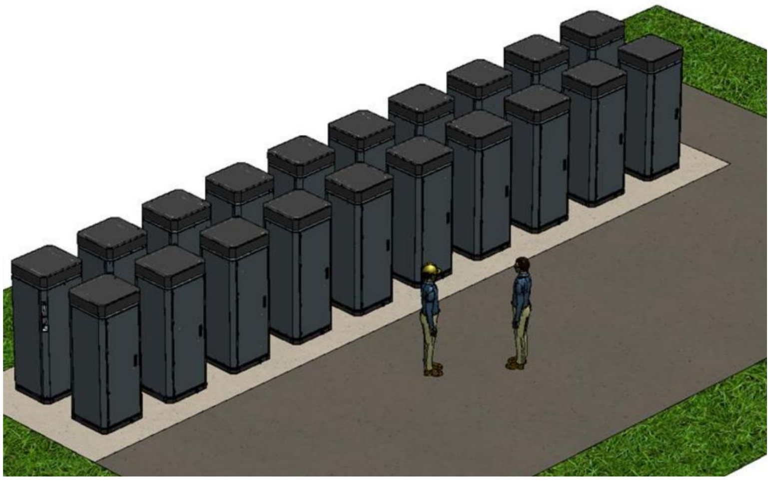

Figure 22 – Conceptual design and layout (here an example with 20 racks).

Technical specifications for the individual racks and the complete BESS are listed in Table 8 and Table 9. The final installation of the 15 racks can be seen on Figure 27.

Technical properties of the entire system	
Number of racks	15
Nominal energy (Beginning of life (BoL))	1200 kWh
Nominal energy (End of life (EoL) = 7000 cycles or until SoH = 70%)	700 kWh
Available energy (BoL)	1000 kWh
Nominal power	840 kW*
Nominal voltage	4 x 400 V AC
Recommended ambient temperature	-25°C to 40°C
Site layout	3 x 5 racks

Table 8 – Technical properties for the BESS.
**Nominal power reduced from installed 900 kW to 840 kW to be able to operate as a N-1 scenario, where one inverter can be out of service without impacting the performance.*

Technical properties of a single battery rack	
Battery chemistry	Li-ion (Lithium-iron-phosphate (LFP))
Nominal energy	80 kWh
Nominal power (inverter)	60 kW
Nominal voltage/operating voltage	760 V DC / 700-840 V DC
BMS	Individual cell voltage monitoring and cell module temperature monitoring
Droop control	Build-in inverter; FFR functionality
Charge/discharge temperature (cell)	0-45°C
Operating ambient temperature	-25°C to 40°C
Dimensions	D 800 mm x W 846 mm x H 2177 mm
Cooling standard	Forced air passive cooling via heat exchangers
Cabinet	Fully self-contained system with coated, vandal resilient steel enclosure. Including fire hose coupling.
IP rating	IP55

Table 9 - Technical properties for the one individual rack.

The layout of the system is shown in Figure 23. Infrastructure has been prepared for future extensions. With the high degree of scalability of the system itself, it can easily be extended if needed.

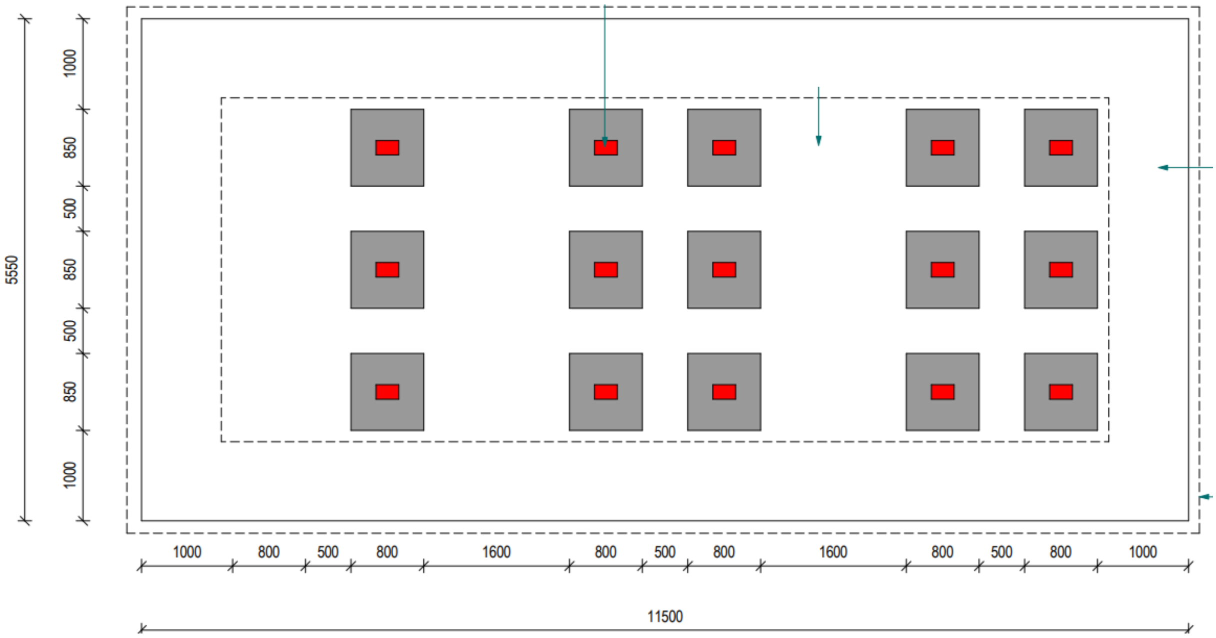

Figure 23 – Layout of the BESS in Copenhagen Airports with 15 racks.

<u>Risk assessment of specific system and fire safety considerations</u>

A risk assessment has been made on rack level by the supplier, Xolta, to create transparency of the system, related risks and implemented control and mitigation measures.

Many design considerations have been made to minimise the risk of a potential battery fire.

This includes, but is not limited to:

- Individual battery racks spaced with 50 cm, see Figure 27.
    - Limit a potential fire from spreading
    - Easy access for fire fighter personnel
    - Independent operation by racks not affected by the fire
- Distance between closest battery rack and building is minimum 6 meters
- Connector for fire hose on each rack, see Figure 24.
    - Easy access to cool down the battery and limit fire spreading inside the battery rack and to surroundings.
    - The ability to fill each rack with water will reduce the smoke development in case of a fire.
    - Water filling tests has been performed to ensure that the racks could be filled with water within 10 minutes, see Figure 25.
- Battery chemistry is LFP, which has a higher resistance to thermal runaway and therefore less tendency to set on fire.

- Batteries are tested according to EN 62619 and are UL 1642 certified to ensure a high level of safety at cell and module level.
- Professional design of enclosure, mainly consisting of steel and with individual steel cases for each battery pack inside the racks and double shelving between packs to provide thermal insulation and delay fire propagation.
- Gas relief valves to mitigate over pressure in each rack and gas and smoke sensors in each rack, that can be connected to external fire warning system.
- No outside air is circulated in the system, which prevents fresh oxygen supply

Figure 24 – Individual battery rack from Xolta. All racks are equipped with a connector for a fire hose, so they can be filled with water in case of fire.

Figure 25 – Water filling tests has been performed to ensure sufficient design of the cabinet and sealings. The racks were required to be filled with water within 10 minutes, and the 2nd test was successful.

Environmental considerations

A connection to the existing drainage system has been established, along with new wells for collecting water used in firefighting. During firefighting, the emergency services can close the regular drainage using a valve and connect a submersible pump to recirculate water to the affected cabinet without requiring a fire truck or hydrant for water supply.

After firefighting is complete, the water can be removed from the well and kept away from the main drainage system.

Site preparation

The preparation has consisted of:

- Cabling conducts and cabling
- New switchboard
- Reinforcement of the soil
- Concrete foundation
- Water sewage
- Installation of lights
- Installation of concrete crash barriers
- Information and warning sign together with emergency stop

In Figure 26 a schematic shows the concept of the electrical connections. The red line marks the boundary of the BESS suppliers' delivery. CPH has been responsible for the electricity connection of each rack to their electricity infrastructure.

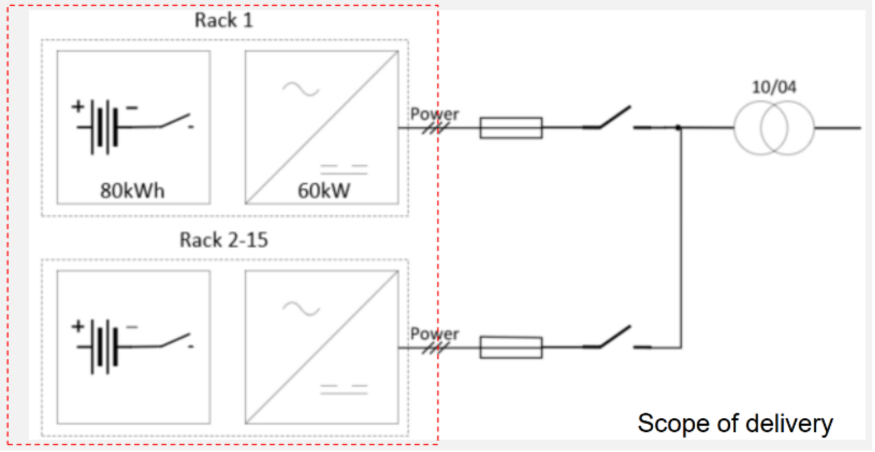

Figure 26 – Schematic illustrating connections of each rack through 3 x 400 V AC lines, fuses and disconnectors.

Figure 27 – The final installation of the BESS consisting of 15 racks from Xolta.

<u>Approvals obtained</u>

In Denmark the BESS is considered a building, which requires various permits from the municipality, following a specific application process. Additionally, since a live asset is being connected to the electrical grid, an application must be submitted to the DSO for approval.

Approval	Requested	Approved	Purpose	Approving authority
Land zone permission	March 2023	June 2023	To ensure that the proposed use or development of the land complies with existing zoning laws, regulations, and planning policies established by the local authority.	Municipality

Construction Permit	March 2023	July 2023	To ensure that the proposed building work complies with relevant building codes, zoning laws, safety regulations, and other applicable standards.	Municipality
Grid connection approval	January 2023	Temporary: December 2023 Final:	Ensures that the asset can connect to the grid safely, reliably, and in compliance with all technical, safety, and regulatory standards.	DSO
Occupancy Permit	May 2024	August 2024	This final approval is a crucial step in the building process, ensuring that the completed project meets all regulatory requirements and is safe for occupancy.	Municipality
Environmental approval	March 2023	July 2023	Focus on the impact of a project on the natural environment and compliance with environmental laws, including noise.	Municipality (part of construction permit)
Fire safety approval	March 2023	July 2023	Ensures that buildings are designed, constructed, and maintained to prevent fires and protect occupants in the event of a fire.	Municipality / Local fire authority (part of construction permit)

Table 10 – Specific approvals obtained for the BESS installed in Maglebylille in Copenhagen Airports.

13.1.4 **Energy management system**

In CPH an EMS is implemented and demonstrated within the ALIGHT project. The EMS is provided by Hybrid Greentech, a Danish expert and software company with focus on energy storage systems.

The activities in CPH (site in Maglebylille) aim to demonstrate the following use cases:

1. Optimising CO_2 footprint of EV charging, uncontrollable consumption and BESS.
2. Provision of ancillary services while optimising for reducing CO_2 footprint.

Moreover, in these two use cases, tests for peak load shaving, load shifting using the EVs, and PV time-shift will be conducted.

System description

The EMS is implemented as a cloud-based solution with interfaces to several providers of data for several assets at the airport. Moreover, the EMS can integrate public and subscription-based data sources (such as electricity prices, forecasts, usage data for assets) and generate schedules for the controllable assets i.e. BESS, EV chargers at the Maglebylille site based on several algorithms. An overview of the interfaces and examples of information is illustrated in Figure 28.

The main logic of the EMS is that it reads forecasts and based on these, it decides on an operational plan, for example the operator can decide to do CO_2 optimisation, and then the EMS should determine what is the best operation, e.g., by charging the BESS when the CO_2 intensity in the grid is low and discharge to the grid when the CO_2 intensity is high.

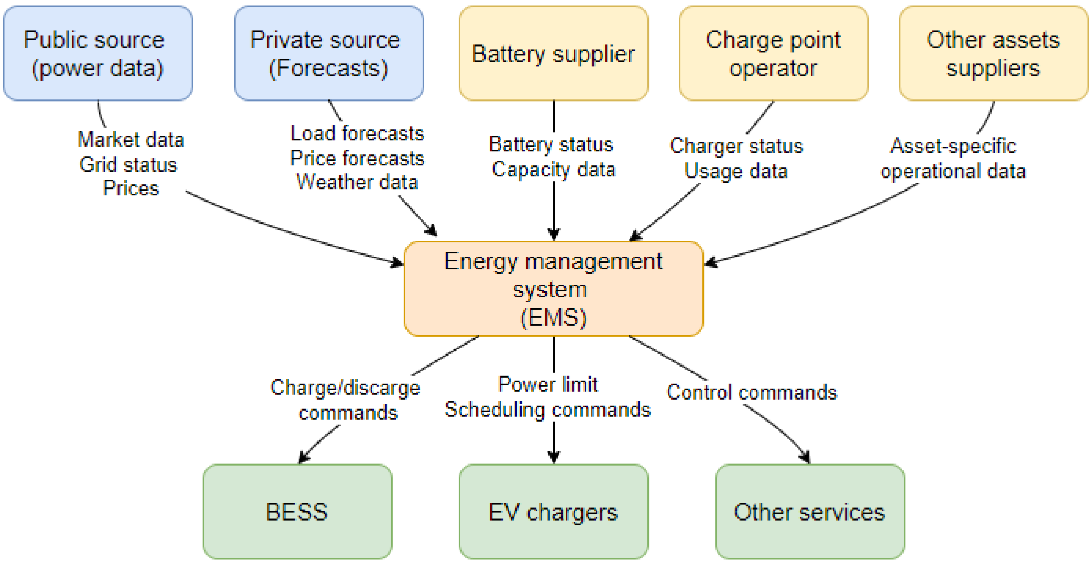

Figure 28 – Overview of interfaces with EMS at CPH.

Testing and demonstration

The demonstration of the EMS relied on data from inside the airport systems. The data was made available by setting up scripts inside CPH systems to export a copy of the relevant data to a cloud infrastructure outside the protected airport systems. That way, the cloud services could be performed by an actor not fulfilling the strict requirements to cyber security otherwise necessary to protect the integrity of the airport operations. The data was planned to be exported as an automated batch operation every 5 minutes, thus creating a latency of 5 minutes. The EMS provider accepted this solution of receiving data in 5 min batches.

The control signals for the specific assets are provided through the operational systems for the BESS and EV portfolio respectively, the latter is still under discussion, but it is expected to be cleared in time to be able to demonstrate.

The testing conducted during the ALIGHT project was done in two phases in coordination between DTI, HGT and CPH. Phase 1 for testing BESS and phase 2 for testing characteristics of EV chargers.

In the first phase the following was tested:

- Basic logic as described in the previous section.
- Test data pipelines resiliency.
- Test BESS response time and validity of forecasts and related operational plans.

The tests of the first phase were performed in the period between 17/1/2023 and 17/2/2023, and during the testing period there was few downtime periods, one that was notable on the 21/1/2023, otherwise not many problems were observed mainly due the laboratory setup at DTI is quite resilient, so testing could be performed without interruptions.

The first series of test proved that the BESS could be charged when the CO_2 intensity is low (see Figure 29) and discharged when the CO_2 intensity is high (see Figure 30).

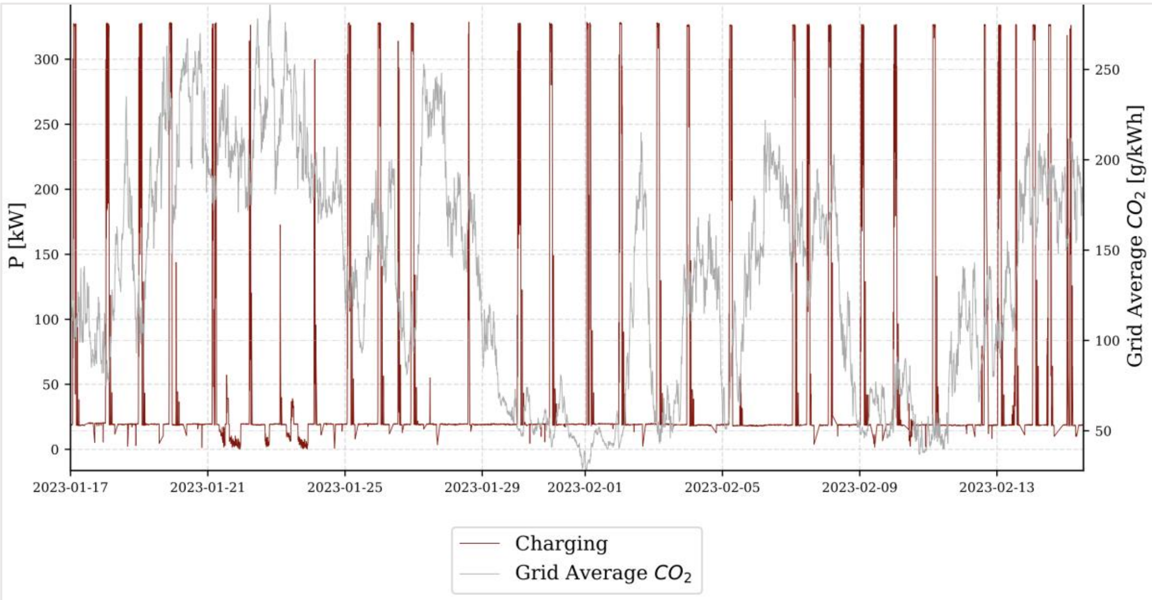

Figure 29 – Charging of BESS depending on the CO_2 intensity in the electricity grid.

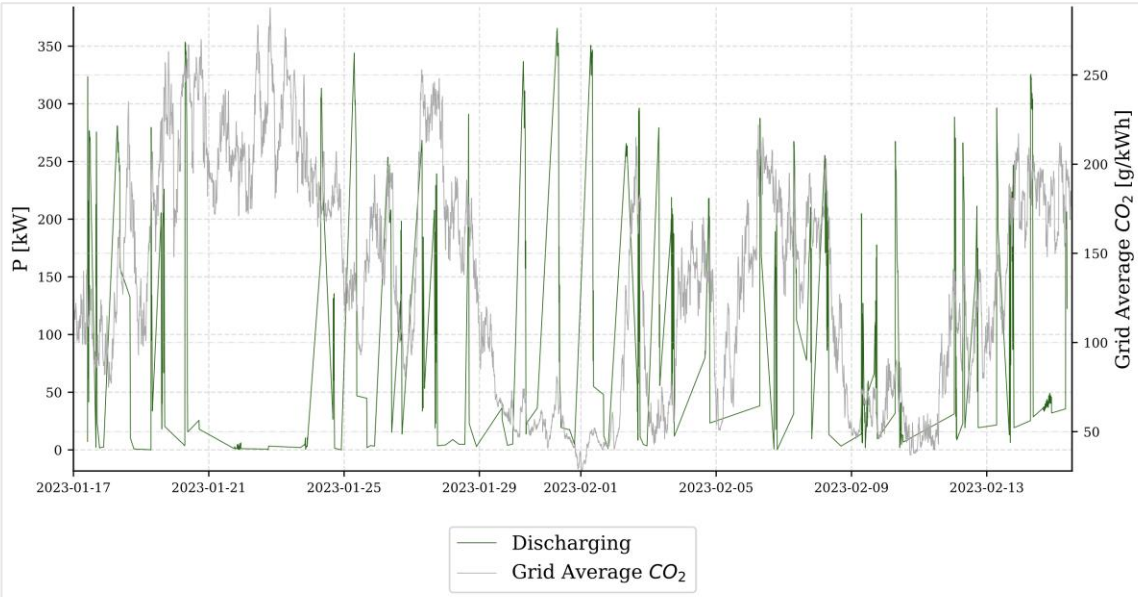

Figure 30 – Discharging of BESS depending on the CO_2 intensity in the electricity grid.

In the second phase of testing, the purpose of testing was to gain knowledge about the operations of EV chargers and relevant characteristics such as response times, response metrics (is the response consistent), and addressing logic and communication to EV chargers.

The tests concluded that the cloud-based EMS software was ready to be adapted and deployed for the demonstration site in Maglebylille.

<u>The data and communication solution at CPH</u>:

At the time of making the communication and data design it was deemed that the fastest and safest solution to be able to operate the BESS and the EMS was to let the BESS and EV supplier to communicate with their assets, rather than letting the EMS supplier do this. A solution where the EMS have access to read-only data from the airport was chosen (corresponding to example 2 introduced in Section 12.1), since it might have resulted in delays in the project if the EMS supplier had to implement the necessary security requirements. Moreover, this solution provides only one entry point per asset, which allows better control from the airport side. A similar approach is going to be adopted for the control of EV chargers.

On the data sharing side, and due to the security requirements of the airport, only data that are operated by third parties are shared directly with suppliers whereas any other data is pushed by the airport periodically and the airport possesses full control on what is to be shared and when.

For EV chargers the EMS supplier, Hybrid Greentech, is working with the charge point operators on a solution that allows the EMS to control chargers without passing information on the location of the chargers and/or their physical IDs. This approach means it is not necessary to handle sensitive information in the EMS and GDPR is handled by the charge point operator.

An overview of the data and communication streams for the EMS and relevant assets in CPH are illustrated in Figure 31.

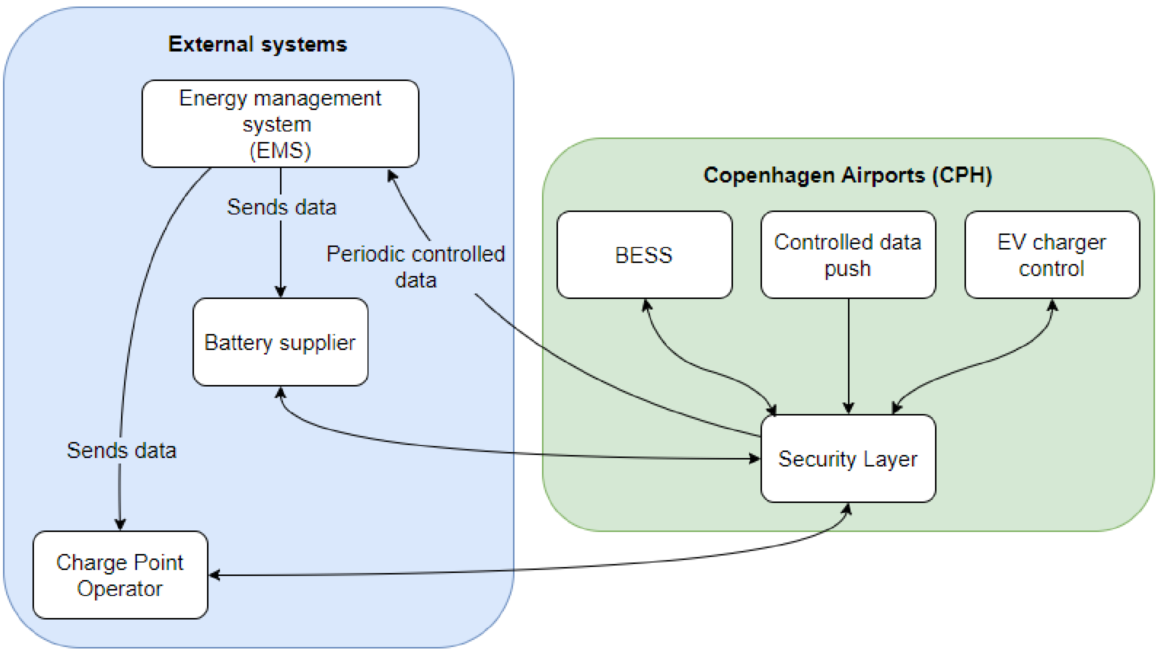

Figure 31 – Data and communication streams between external asset suppliers and CPH.

13.1.5 **Heat supply**

The heating supply in CPH is generally managed differently depending on the specific area of CPH being considered. A robust district heating network has been established from the local district heating supplier, supplying a significant share of the airport area. In the past, there have been discussions about expanding the district heating network to cover a larger share of the heating demand in the area including both the airport and the local community.

In the other areas of the airport, a more decentralised heating supply system exists. In recent years, efforts have been made to identify viable alternatives to natural gas boilers involving heat pumps, resulting in a current heat supply by numerous small air-to-air units, several larger heat pumps throughout CPH.

In 2017, the old natural gas boilers at the demonstration site in Maglebylille were replaced with more efficient, condensing boilers, complemented by a heat pump capturing energy from exhaust gases to boost heat production for district heating. However, the system still remained entirely dependent on the operation of the natural gas boiler.

During the project period of ALIGHT, further investigations were conducted to determine what would be required to generate district heating from the heat pump alone. As a result, energy sources in the surrounding area were examined, leading to the utilisation of surplus dry coolers to capture energy from the outdoor air temperature. Additionally, at a nearby site groundwater needed to be pumped up and purified to maintain acceptable pollution levels. This pumped water was subsequently used for various purposes, including wash halls, cooling plant, server room cooling, and toilet flushing. The water pipeline was redirected to pass through the heating plant before being sent back for its intended purposes. This redirection enabled the extraction of energy from the water (by cooling it) to generate heat.

In addition to the existing heat pumps at the heating plant in Maglebylille, a new heat pump was installed in series. This installation allows the area to be fully supplied with heat from heat pumps except during wintertime, resulting in a substantial annual reduction in natural gas consumption of approximately 200,000 m^3.

13.1.6 **Assessment of electrification potential - An energy system analysis**

In addition to the experiences described from CPH, DTI will conduct an energy system analysis for the electrification potential in CPH. The aim of this section is to present the methodology used for the energy system analysis as well as the prerequisites and assumptions in the assessment. This can serve as inspiration for other airports.

The objective of this energy analysis is to evaluate the electrification potential of CPH by examining the requirements of energy system components during the transition from a conventional airport to an electrified aviation hub with significantly increased electricity demand. This analysis aims to address the following key questions:

- What are the optimal capacities for integrating PVs and BESS within the local energy system to support the shift towards an electric aviation airport, which includes electric airplanes, eGSE, and V2G capabilities?
- What are the potential benefits introduced by V2G technology in the airport's energy system?
- What level of self-sufficiency can be achieved in such a system?

In Figure 32 an illustration of the energy system analysis is presented including the needed inputs and outcomes of the analysis.

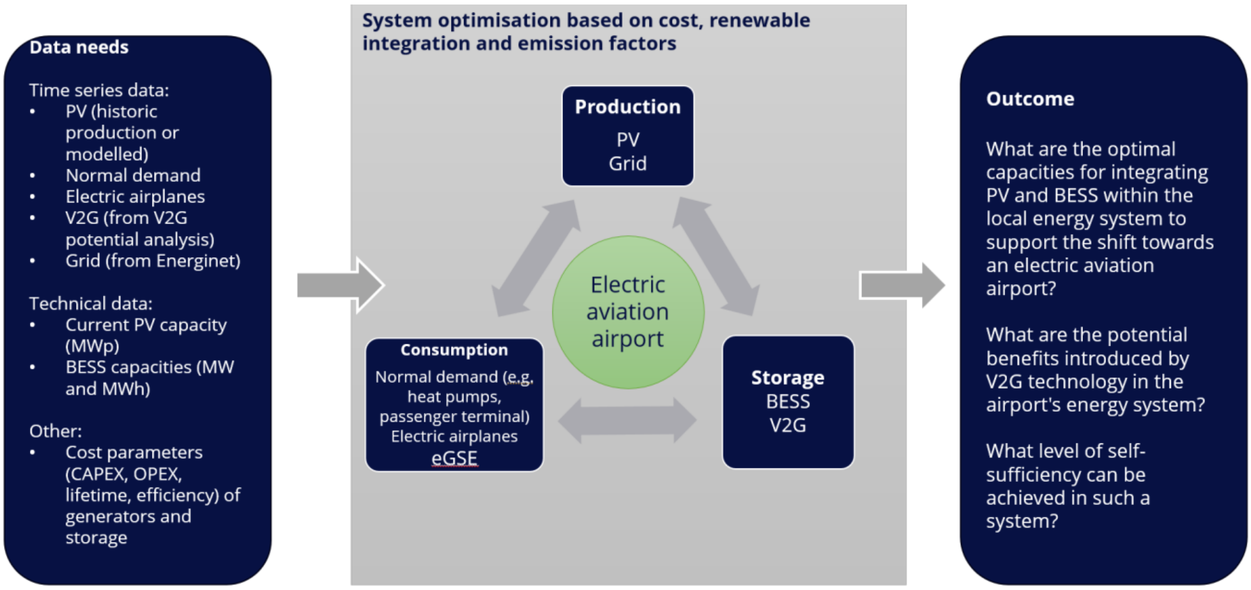

Figure 32 – Illustration of energy system analysis.

Prerequisites and assumptions

A key prerequisite for the energy analysis is the availability of the required data for the specific case under consideration. These requirements are outlined under the section "Data Needs". In instances where the data listed under "Other" cannot be collected for the specific case, literature-based data can be utilised instead. However, this approach will result in a more generic representation rather than reflecting the specific technology being demonstrated.

The analysis will be conducted on a full year of operation. The specific year is determined by the available data.

The analysis will combine both historic data and qualified estimates of electric demand for e.g. electric airplanes, eGSE's and V2G availability in CPH assessed in ALIGHT (See report on *Assessment of vehicle-to-grid potential in airport fleets*[20] and *Infrastructure studies for future aircraft stands*[21]).

The fundamental of the energy system model is preserving energy conservation:

$$renewable\ production - demand = balancing + import/export$$

Each generator and storage can be constrained or optimised unbounded. Emission factors from the grid as well as electricity spot prices will be included. The system optimisation will prioritise lowering emissions related to the electricity consumption by increasing the renewable penetration and minimise the costs. Energy system topology can reflect line/transmission constraints (see Figure 33).

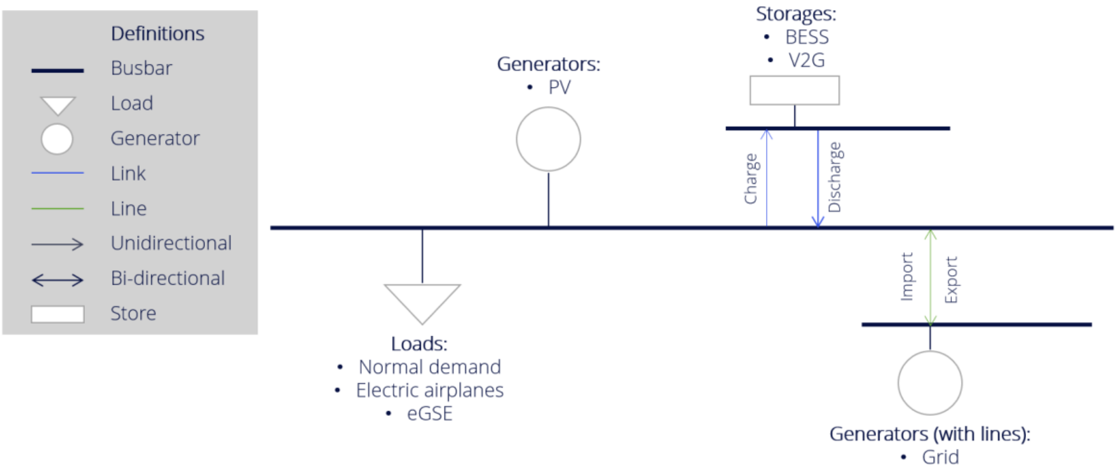

Figure 33 – System model topology.

Scenarios

The energy system model analysis comprises three scenarios, each representing a different stage of electricity demand as the system transitions towards a fully electrified aviation airport.

Reference	Baseline (present configuration with fixed PV and BESS)
Scenario 1	Baseline + electric airplanes + eGSE + PV and BESS optimised
Scenario 2	Baseline + electric airplanes + eGSE + V2G + PV and BESS optimised

[20] Assessment of vehicle-to-grid potential in airport fleets, Nov. 2025
[21] Infrastructure studies for future aircraft stands, Sep. 2025

13.2 Aeroporti Di Roma (ADR)

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.

ADR have several on-going projects related to renewable energies. In beginning of 2025, ADR have inaugurated a 22 MW PV along the runways to enhance the utilisation of renewable. Moreover, ADR has invested in a BESS consisting of second-life car batteries.

The airport had an annual electrical energy consumption of around 153,9 GWh/year in 2023.

Table 11 below shows an overview of installed PV, EV chargers and BESS in ADR.

	Amount	Unit	Status
Roof-mounted PV	0,8	MWp	
Ground-mounted PV	22	MWp	Installed and in operation
EV chargers	Slow chargers of 7.4 kW, Fast chargers of 22 kW, and ultra-fast chargers 50 kW are all present in FCO		
BESS capacity	2.5/10	MW/MWh	

Table 11 – Overview of installed solar power, EV chargers and electrical energy storage in Aeroporti Di Roma per March 2025.

13.2.1 Implementation of PV

ADR in its Fiumicino airport is, have inaugurated a 22 MW PV plant located along the runway. It will be the first of this kind in a commercial airport. ADR started to work on the first large PV plant in 2019.

National regulations

In Italy there are specific regulation for the construction phase of a PV plant. In recent years, different regulation bodies have been working to speed up the authorization process to be able to reach the carbon reduction goals.

The approval process of the PV plant in ADR began in 2021. Back then it was necessary to produce a so called "*Verification of subjectability to EIA (Environmental impact assessment)*" and an "*Overall authorization*". Both documents have been approved in December 2022.

Currently, the approach of identifying suitable areas for PV plant installation in Italy is changing. As of now, the Government has written a list of suitable areas, which consider spatial and environmental aspects, and are therefore particularly suitable for renewable energy projects.

One of the essential approvals is related to the connection of the PV plant to the national electrical grid. Both Fiumicino and Ciampino Airports have been operating as energy distributors since July 2019, and thanks to this nature they can manage internal issues in an easier way.

The airport mapping, planning, and implementation process

The PV plant project has been planned to be designed and realised in different phases.

Mapping phase

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.

In the initial phase of the project, ADR has screened many areas considering soil type, absence of obstacles, glare analysis, etc.

Planning phase

In this phase ADR prepared all the documents needed for all the authorizations for both national regulations and civil aviation sector by ENAC.

Because of its specific location this PV plant had to be conformed to many different requirements and many different authorities have been involved in the permitting phase: 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.

Stakeholder engagement and analysis

In this phase ADR shared with all the stakeholders involved in the project and collected their suggestions and needing. The stakeholders are ENAC, ENAV, pilots' association, fire fighters, and all the internal ADR departments involved in the process.

Regarding analyses, the most time-consuming analysis was related to glare, which needed to be addressed to avoid problems during all the phases of the landings and take-offs. It took almost a year to manage this challenge. Two independent external consultancy firms conducted the analysis using the official software from FAA named SGHAT (Solar Glare Hazard Analysis Tool). They analysed all the possible foreseen flight paths, aiming to avoid even a few hours of glare risk throughout the year. The result of the simulation was shared with ENAC (Italian Civil Aviation Authority), ENAV (National Agency for Flight Assistance) and pilots' association.

As a result of all these analyses ADR could define the best configuration in terms of azimuth and tilt angle to install the PV plant. In the various simulations it was concluded, that to avoid glare problems it would be necessary to locate the PV plant just along half of the runway. This specific location prevents glare issue throughout the year in all investigated meteorological conditions.

Another important issue to solve was the risk of magnetic interference with the antenna used for the ILS and Autoland navigational aide. As these systems are very sensitive, it was necessary to analyses, if there were any risks for the antenna to be disturbed by all the metal mass supporting the PV panels. Therefore, an EMC analysis of the PV-plant in relation to radio interference with ILS and communication was performed.

As a result of all these analysis and simulations the initial design of PV-plant had to be reduced from 30 MW to 22 MW to avoid also risks of magnetic interference and glare. For the construction phase, the PV plant followed the approval steps defined by the sector legislation[22].

[22] (Decreto legislative 387 del 2012 (art. 12) – AU e D.lgs. n. 152/06 – VIA).

13.2.2 **EV charging infrastructure, smart charging and V2G**

ADR has opened an entire parking lot exclusively for hybrid and electric vehicles. ADR has installed three types of EV chargers with rated power of 7.4 kW for slow chargers, 22 kW for fast chargers, and 50 kW for ultra-fast for passengers.

ADR has conducted analyses on how the electrical grid will be affected by the increasing demand from EV chargers by 2025. The analyses concluded that the security of supply will not be affected, as the existing cogeneration plant and the ongoing installation of PVs should be able to cover the demand.

To increase the opportunities for firefighting of an EV fire and minimise the consequences ADR has chosen to locate all EV chargers at ground level in parking areas.

V2G is not yet a viable solution in ADR, primarily due to the complexity in permitting phase, technology maturity and complexity of stakeholder involvement.

13.2.3 **Energy storage and energy management systems**

ADR are at the time of writing installing a BESS with a rated power of 2.5 MW with a total capacity of 10 MWh, with a planned commissioning in beginning of 2025. The size of the BESS was determined by availability, price and technical capabilities. The system has also been simulated by the system integrator, where different sizes of BESS were tested. The BESS is co-founded by the EU Innovation fond.

The BESS in ADR is made of 2nd life car batteries, where three different suppliers are delivering the battery cells. All the batteries are produced by major car manufactures. The communication strategy must ensure a functioning and seamless operation of the batteries as a single BESS.

In the planning process of the BESS in ADR the strategic placement of the system was considered to ensure both functionality and accessibility of the BESS. The BESS is placed in containers housing both batteries and necessary auxiliary systems. The containers require a substantial area of around 3 000 m^2 which limited the possible areas resulting in the BESS being located next to an access road and surrounded by buildings. Despite the location of the system being adjacent to buildings and an access road, no specific safety distance has been planned, as the layout of the containers includes a fire protection system. The system consists of hydrants and sensors connected to a central control system. In the event of a fire, these extinguishers are automatically activated, filling the containers with CO_2 powder based on data from smoke and temperature sensors.

Various stakeholders have been involved in the BESS project. ENAC have been involved in the authorisation of the project and construction of the site. The firefighting department is handled by an external company located in the airport. They have been involved in the planning process by approving the fire protection system for the BESS. For the maintenance of the BESS, ADR has signed a service contract with the system integrator for the first year.

ADR has multiple of BMS systems related to different energy sectors: one for heat and cooling, one for electrical plant, one for monitoring energy dense assets, etc. ADR currently utilises the EMS that monitors the consumption of various assets. This provides valuable insights that can inform the planning and execution of future projects.

The system integrator installs an EMS considering only the BESS, however ADR are expecting to integrate an overall EMS connecting PV, BESS, EVs and consumption in the future into the existing BMS infrastructure. The EMS of the BESS can operate to minimise costs and/or CO_2 emissions.

13.3 Centralny Port Komunikacyjny (CPK)

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.

CPK has a target to be CO_2 neutral since its inauguration and does therefore include energy production generated on-site exclusively from renewables. It is expected that local PV will cover 30% of the electrical demand. This includes electricity production from PV, heat and cooling delivered by heat pumps, and possible green hydrogen for GSEs and other equipment. However, additional electricity supply from the grid will also be necessary. The aim is to import only electricity delivered by sustainable sources.

Table 12 contains description of CPK targets and expected plans.

	Amount	Unit	Comment
PV	200	MWp	Cover 30% of electricity demand
Wind turbines	N/A	MW	Considered
eGSE chargers	20-40	MW	
Chargers in parking lots (>22 kW)	20-70	MW	Both for public and employees
BESS capacity	100/200	MW/MWh	

Table 12 – Targets and expected plans for CPK.

The construction of a greenfield airport many of the typical challenges associated with existing infrastructure, location constraints, and environmental restrictions can be avoided. However, significant financial investments are required for the development of essential systems, including electricity, heat, and water networks, as well as the construction of sewage treatment facilities, waste management systems, etc. When designing and building critical infrastructure such as the power supply system, PV plants, energy storage systems, or EV charging stations, the primary constraints are determined by budgetary considerations and the scope of innovative possibilities.

13.3.1 **Renewable energy sources**

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 (with a significant distance the airport to avoid interference etc.), 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 CPK team has made an estimate of its own - we are waiting for the designer to confirm it 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. Should the decision to construct wind turbines be approved, the size of the PV plant will be adjusted accordingly to optimize the energy mix.

13.3.2 **Electric vehicles and charging infrastructure**

CPK has started the planning for integration of EVs and eGSEs in the future airport. CPK has conducted initial assessments to estimate the demand for charging infrastructure which resulted in a charging power span of 20–40 MW for eGSEs at airside and 30–70 MW for chargers in parking areas landside, which will be available to passengers and airport employees. CPK plans to prioritise chargers with a minimum capacity of 22 kW for charging on EVs and fast chargers with capacity above 100 kW for eGSEs to meet operational needs. The final scale of implementation is depending on the adoption of the EU directive (EPBD) on the Polish car fleet. The current planning is done in collaboration with Polish companies making the chargers.

The business model for the charging infrastructure is under consideration, where CPK is evaluating if an investor or external operator should operate and manage the charging facilities. The decision on ownership for the charging infrastructure is depending on the influence on the EU directive in Poland.

13.3.3 **Energy storage**

The main concerns regarding batteries are if return of investment can be held at a feasible level if there is no EU funding available.

The main purpose of installing a BESS would be to store surplus energy from local RES, and to do energy arbitrage by selling and buying electricity when the spot prices are attractive. Further, stabilising and supporting the electricity network near EV and transformer stations could be an advantage from the BESS.

At this stage, CPK has been in touch with BESS suppliers to collect information for further investigations.

13.3.4 Energy management system

The entire energy system of the airport will be connected into one common management system. For electricity this include networks at both high, medium, and low voltage, as well as energy storages, PV plants, and chargers for EVs and eGSEs. The EMS will be designed to offer full remote access from the Energy Centre, which are facilities housing heat pumps and other equipment for heating and cooling generation. For reference, please see London/Islington Energy Centre.

13.4 Lithuanian Airports (LTOU)

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.

LTOU has invested in renewable energy projects to enhance sustainability. This includes roof-mounted solar panels covering an area of 5 000 m².

In 2019, VNO had an annual energy demand of around 19 GWh/year.

	Amount	Comment
Roof-mounted PV	526 kWp	Implemented
Ground-mounted PV	4.5 MWp	Planned
EV chargers (AC 11-22 kW)	5	For GPUs
EV chargers (DC 50-400 kW)	6	For buses - Planning/ Procurement
	18	For cars airside
Public EV chargers (AC 11-22 kW)	14	Implemented
	34	Planned
Public EV chargers (DC 50-400 kW)	4	Implemented
BESS capacity	>100 kW/100 kWh	
	2 x 2.5 MW/5 MWh	Planned

Table 13 – Overview of installed or planned solar power, EV chargers and electrical energy storage in Lithuanian Airports per March 2025.

13.4.1 PV Plant and batteries

LTOU has PV panels on one terminal roof with a total capacity of 526 kWp. They are planning to install another PV plant which will also include a BESS. Currently there are no BESS at LTOU. Moreover, they are planning to install a BESS in combination with their EV charging stations.

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.

Even though the electricity prices have now normalised, and the payback time therefore has increased significantly, the underlying objectives for LTOU have also changed: The focus is now on the volatile geopolitical situation with the neighbours to the east (Russia and Belarus). The airport is a strategic facility, both civilly and militarily, which needs to have a 24/7 power supply in case of disruptions in the city's central infrastructure.

The preliminary capacity of the PV plant is 4.5 MW, and for the two storages a capacity of 2.5 MW/ 5 MWh each. The exact sizes and capacities will be determined in the design phase. The design phase will also include technical documentation for the location of the PV plant including cable layout, transformers, protection equipment etc. The plant is planned to be commissioned in end of 2026. In the first year of operation, the plant should cover around 50% of the electricity demand and in the following years cover 100% of the electricity demand for both LTOU and tenants. When the demand is completely covered by energy from renewable sources, the main impact will be on scope 3 electricity emissions[23], as the airport supply electricity to the tenants operating in the airport (e.g., ground handlers, commercial, etc.). Currently, LTOU achieves zero Scope 2 emissions by purchasing electricity with guarantees of origin. When VNO supplies 100% of its and its partners' electricity needs from renewables, both Scope 2 and electricity related Scope 3 emissions will be reduced to zero.

Planning phase

This phase consists of selection of area for the PV plant and BESS, stakeholder identification and engagement together with technical analyses, requirement specification and design.

During the design phase the recommendations and/or requirements described by IATA and ICAO that directly or indirectly relate to airport infrastructure and solar power plants will be used. The design solutions shall be subject to coordination with relevant stakeholders.

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[23] The purpose of the three scopes is to identify where in a company's value chain the emissions originate. Scope 1 are direct emissions that occur from sources that are owned or controlled by the company. Scope 2 are indirect emissions from the consumption of purchased energy. Scope 3 are all other indirect emissions that occur in the value chain of the company. Scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company. [22]

Some of the relevant Stakeholders are:

- Transport Competence Agency – Lithuanian public body contributing to development of the public transport system. [21]
- Air Navigation JC
- Relevant internal airport departments
- DSO and TSO for connection approval
- Technology providers

Location is selected, based on:

- Master plan and available lots in airfield
- Evaluating and minimising electricity transmission losses
- Flight safety zones

Detailed analyses and design have been performed in the planning phase:

1. Glint and glare analysis to assess impact on aviation.
2. Requirements to physical site and a site plan including foundation elements, protective fence and surrounding areas and infrastructure e.g. to ensure proper access roads to the plant.
3. Electric infrastructure study, requirements and design.
4. Requirements for and design of data communication and networks.
5. Requirements and impact on existing building management system (which is expected to monitor and control the PV and BESS) shall be clearly described.
6. Identify fire safety requirements for PV plants and BESS.
7. Construction plan to ensure that the airport operation is not being disturbed during construction.
8. Signing a letter of intent with the national energy distribution operator, by which LTOU would commit to implementing this project.
9. Obtain construction permit.
10. Selection of technology provider and procurement of plant.

13.4.2 **Smart charging and V2G**

EV chargers are only implemented on landside, consisting of four short term chargers and four long-term chargers. Within the coming 5 years it is expected that buses, light vehicles, GPUs and electric vehicles can be charged at air side, and that the number of EV chargers at landside will increase to 17 stations (34 chargers). The first 5 have already been installed.

For buses at airside, the planned charging stations will consist of ultra-fast charging stations with a rated power of 240 kW to 360 kW DC, where one station can provide power to two charging points. The charging connection will be identified by analysing the market for electrical buses and considering the stakeholders planned solutions. Depending on the network load, a buffer battery with a capacity of 100 kW/100 kWh may be installed.

For cars and GPUs at airside, 9 fast-charging stations with a capacity of 60 kW each for cars and four 60 kW charging stations for GPUs are planned. As for buses, a buffer battery will be installed accordingly, depending on network load. The capacity should be at least 50 kW/50 kWh.

The landside EV chargers will be operated by private companies, and chargers at airside will be owned and operated by LTOU.

Planning and integration of chargers

The installation of chargers at LTOU consisted of several stages from assessment of potential to procurement of chargers. The stages are:

- Analysis of the need and potential.
- Identification of number of needed chargers and their position.
- Analysis of needed power and specifications with the electricity network provider, until our own production and storage of electricity is secured.
- Analysis of the electrical network airside and landside.
- Procurement (including technical specification)

For high level implementation planning of chargers on airside, a 12-year project program was prepared. The plan includes three phases containing the following objectives:

Phase 1 (5-year timeframe):	Installation of 3 charging stations for buses, 5 charging stations for cars and 4 charging stations for GPUs, resulting in a total of 24 chargers. In this phase, all cabling work will be completed while considering the planned future expansions in the next two phases. The installation if chargers in this phase is funded by Connecting Europe Facility
Phase 2 (8-year timeframe):	Installation of 2 charging stations for buses, 3 stations for cars and 3 stations for GPUs, resulting in additional 16 chargers.

Phase 3 (12-year timeframe): Installation of additional 4 charging stations for buses, 2 stations for cars and 2 charging stations for GPUs, resulting in additional 16 chargers.

As the number of passengers are expected to grow in the coming years, the fleet of vehicles is also expected to increase, and the infrastructure needed to support the fleet must be implemented accordingly. LTOU is expecting the fleet to grow in three steps:

Time period	Year 1-5	Year 6-8	Year 9-12	Total
Phase	**1**	**2**	**3**	
Cars	25	42	65	**132**
Buses	8	11	20	**39**
Minibuses	3	4	8	**15**

Table 14 – Expected increase in operational vehicles at VNO.

During the charger project some valuable learnings are obtained. Firstly, collaboration with the master planners is important especially to avoid misunderstandings and thereby ensuring a better process. Choosing suitable locations for installations, such as EV chargers, was identified as a critical factor. This requires careful planning and consideration of practical and strategic factors to ensure optimal placement. Therefore, close communication with both internal and external stakeholders played a pivotal role in overcoming barriers. Engaging stakeholders early and consistently helps in addressing their needs and aligning efforts toward project goals. Secondly, assigning a project owner who has an interest and strong commitment to the project to achieve a continuous progress is a recommended strategy. This also ensures a driving force behind the project, leading to more focused and efficient implementation.

The planning process for chargers is expected to include the following steps:

1) Analysis of the needs and potential
2) Identification of number of needed chargers and their position
3) Discussions and conditions from electricity network provider, until our own production and storage of electricity is not secured
4) Analysis of the electricity network airside/landside
5) Procurement (including technical specification)

13.4.3 **Energy management system**

Currently, VNO's main energy systems management is carried out through the BMS system.

With the help of the BMS, consumption is regulated, managed, maintained and monitored of electricity, climate, water and lighting systems. BMS is also used to monitor consumption (of VNO itself and operating partners in VNO), if large increases in quantities occur, the systems and their operation are assessed, whether any failures have occurred, so they can be promptly eliminated.

Newly expanded areas are connected to the main system, such as the new departure terminal T4. PV was installed on T4 a little later (it was not in the original design solutions) therefore their maintenance and management is with a separate system.

VNO and old terminals are also being reconstructed in stages, during the reconstructions new heating, ventilation and other systems are installed, so they are being reconnected from the old BMS to the new BMS.

Newly implemented projects are also planned to be connected to the BMS system (all newly implemented projects are connected to the BMS). Solar power plants and BESS will also have monitoring (solar power plants themselves, inverters, BESS capacity etc.). In the electric charging station project, it is important to mention that not only will the system also be operated via BMS, but the BMS will also control the electricity balancing between the stations to avoid large spikes.

14 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 green transition in energy supply and infrastructure offers airports a pathway to sustainable, resilient, and efficient operations. By investigating and implementing smart energy solutions, airports can reduce their environmental impact, enhance energy security, and align with global climate goals. While challenges remain, proactive planning, stakeholder engagement, and leveraging support schemes will enable airports to overcome barriers and achieve long-term sustainability.

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.

To successfully transition the energy supply and infrastructure, airports can follow these steps:

1. Assess current energy consumption and renewable potential
2. Develop renewable energy strategy aligned with RED II requirements
3. Plan infrastructure upgrades integrating renewable solutions
4. Implement smart energy management systems
5. Ensure compliance with sustainability criteria and reporting requirements
6. Consider support schemes and financing options
7. Monitor and verify renewable energy performance

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.

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16 Appendices

16.1 Introduction to demonstration site: Maglebylille, Copenhagen Airport

The demonstration site in Maglebylille, part of the airside area in CPH, is located in the western part of the airport. This area supports several of the internal operations regarding service, maintenance, and storage of airport equipment. For demonstration, this area is suitable due to its remote location less affected by the flight traffic.

Figure 34 – The Maglebylille service area at Copenhagen airport.

The Maglebylille area allows to demonstrate energy supply and more efficient use for a range of different energy streams. Besides operational activities linked to service and maintenance, office buildings, canteen etc., Maglebylille has its own district heating system. Energy for the district heating system is generated from natural gas boilers and heat pumps (that run on reclaimed water, outdoor air, and residual heat from the exhaust gas) as well as photovoltaic system and emergency power supplies (diesel gensets and UPS systems). By now, the percentage of the ground service vehicle fleet operating within Maglebylille has been converted into electrical vehicles, and conventional charging points are established throughout the site. The site also offers gas stations for petrol, diesel, and natural gas that in time could be repurposed for fast charging points. Table 15 lists relevant installations at Maglebylille.

Unit	Size/number of units
Natural gas boilers	4.9 MW
Heat pumps	1.1 MW
Photovoltaics	375 kW (peak power)
E-vehicle charging points (conventional)	10 units
Diesel gensets	5 units

Table 15 – Installations at Maglebylille.

16.2 Stakeholder analysis tool

The stakeholder analysis can be structured in several ways and can contain different parameters. Some of the most common parameters to assign to each stakeholder are:

1. Name of the stakeholder
2. The stakeholder's role in the project
3. Defining the impact and influence the stakeholder might have on the project
4. Ideas on how to the impact and influence can be mitigated
5. How to communicate with the stakeholder and how often

Stakeholder	Role	Impact	Influence	Mitigation	Communication

Table 16 – Stakeholder analysis table.

When all relevant stakeholders have been mapped, the stakeholder analysis can be expanded to include preparation before engaging, typical barriers which the stakeholder will see in the project, opportunities for mitigation and expected outcome for the coming project planning process. An example of such a table is presented in Table 17. In Appendix 16.3 a stakeholder engagement analysis for the above-mentioned risks and barriers have been initiated for replication matters.

Stakeholder	Preparation	Typical barriers	Mitigation	Outcome

Table 17 – Stakeholder engagement table.

16.3 Example of stakeholder engagement for PV projects

Stakeholder	Preparation	Typical barriers	Mitigation	Outcome
Master Planning	Potential areas for PV	Conflict with future plans for the areas	Combine new buildings, parking lots etc. with PV	Reduced potential areas for PV
				Initiate alternative projects with PV on buildings etc.
Operation and maintenance	Physical design options for PV plant	Lawnmowing	Increased height of stands	Requirements to e.g., solar panel stands and underlay
			Lawnmowing robots	
			Maintenance free underlay	
	Physical design options of ground	Wildlife management	Non-natural underlay	
			Design of stands to avoid unwanted birds	
		Rainwater drainage	Drainage and underlay design	
Security		Patrolling along airport fence shall be possible and give good sight	Keep security distance to airport perimeter	Requirements to distances to perimeter of the airport

		Risk of overlooking someone behind panels	Add surveillance together with PV	
Rescue and firefighting		Increased risk in case of crash	Include fire prevention, fire detection and fire-fighting in design	Requirements to monitoring of systems
		Firefighting accessibility	Allocate a larger area to the PV plant to allow for access roads	Requirements to emergency roads
Communication, navigation and surveillance		Electrical interference		
		Radar reflections		
Air safety and compliance		Glint and glare		
Legal and planning		Restrictions on land usage, setbacks, height limitations, and aesthetic considerations		

Master planning: The Master Planning department plays a vital role in the long-term development and growth of an airport. This department is responsible for developing and maintaining the airport's comprehensive master plan, which serves as a roadmap for the airport's future development and expansion over a period of several years or decades. The master plan department conducts extensive research and analyses to identify the airport's current and future needs and works closely with other departments within the airport and external stakeholders to ensure that the airport's strategic goals and priorities are aligned with the master plan. By developing a robust and well-executed master plan, the department helps to ensure that the airport can continue to operate safely and efficiently while meeting the evolving needs of its passengers, airlines, and other stakeholders. The department is therefore a vital stakeholder to include early in the process since they might have strategic development plans for several possible PV installation sites.

Security concerns: As the security level in airports is of high importance, it will in many cases be necessary to assess whether solar power plants will affect security. For ground-based systems it can be necessary to ensure that security personnel can keep patrolling along the fence and that the panels do not increase the risk of overlooking someone in the airport area. According to National Aviation Safety Plans (NASP) it is required that solar panels are placed a minimum of three meters from the perimeter fence.

Air safety and compliance: Initial safety evaluations are essential for planning large PV installations in airports. Discussions should involve experts in airside placement, radar, and aerodrome engineering, focusing on safety zones around and at the end of runways. PV plants cannot be located within these zones as defined by the International Civil Aviation Organization (ICAO)[24]. Assessments needed for plant approval:

- Flight safety zones areas
- Wind/turbulence and noise impact studies
- Final safety risk assessment

Additionally, glint and glare analyses are crucial to prevent safety hazards from light reflections, which could distract pilots or ground personnel.

Operation and maintenance: One of the primary concerns is the integration of PV systems with the existing operations and maintenance (O&M) procedures. Lawn mowing to mitigate birds and other wildlife is a crucial part of O&M, especially around airport runways. The presence of solar panels can complicate these activities, as it is essential to maintain the grass beneath and around the panels. Adjusting the height of solar panel stands and choosing appropriate underlay materials, such as artificial grass or concrete, can help facilitate maintenance. However, these choices must also consider their impact on wildlife and drainage, particularly near runways.

Rescue and firefighting risks: The introduction of PV systems increases the risk of fire, particularly from electric sparks, which could ignite fuel from a crashed airplane. A risk

[24] ICAO document 9137 *Airport Service Manual*

assessment should be made to ensure that the risk is not too high. Presumably, both rescue/firefighters in the airport and airside safety and compliance personnel should be included in this risk assessment and documentation of rescue plans regarding accidents including the PV plant or close to the plant.

The design of the power plant shall include:

1) Fire prevention e.g., by using non-flammable materials
2) Fire detection e.g., monitor systems
3) Firefighting e.g., accessibility for fire fighters

After installation of solar power plants, the response time for firefighters and rescuers still needs to comply with defined limits for response time.

Wildlife management: Airports must address the potential impact of PV installations on wildlife management, particularly concerning bird strikes, which can have catastrophic consequences for aircraft operations. PV arrays may create habitats and attract certain bird species, requiring careful habitat management and active bird control measures. For instance, grass cultivation and mowing policies must ensure that some grass types are unattractive to birds. Additionally, the physical presence of solar panels may restrict the view and movement of bird controllers, posing further challenges.

Communication, navigations and surveillance (CNS) interference: CNS systems are critical to airport operations, facilitating communication, navigation, and surveillance. PV installations can interfere with these systems, potentially causing issues like ghost echoes (the signals would bounce back and forth, causing radar plots to display false locations) on radar displays or interference with the Instrument Landing System. For systems that provide positioning and identification of aircraft and vehicles with Vehicle Locator Transponder, the occurrence of harmonic frequencies can affect the interrogator equipment and potentially disrupt services and transmitters.

Detailed planning and documentation are required to assess and mitigate any potential disruptions to CNS systems, ensuring that the PV installations do not compromise air traffic management and safety.

Legal and planning considerations: Prior to the installation of solar panels, it is crucial for the airport to thoroughly assess and ensure compliance with local and municipality planning regulations. This process involves obtaining necessary permits and approvals, including potential land zone permits, to ensure the project aligns with the designated land usage requirements in the area.

Complying with local planning regulations is essential to ensure that the installation of solar panels is permitted within the specific zoning laws of the region. These regulations may vary depending on the municipality and can include restrictions on land usage, setbacks, height limitations, and aesthetic considerations. By adhering to these regulations, the airport can mitigate potential conflicts and legal issues and ensure that the solar panel project proceeds smoothly and in accordance with the local authorities' requirements.

Engaging with local experts or consultants familiar with the local planning processes and regulations can be greatly assist in navigating through the necessary compliance procedures and ensuring the solar panel project is in full accordance with the established rules and guidelines.

16.4 Communication, Navigation and Surveillance

In an analysis of a potential roll-out of major PV plants, identification of concerns (interference, reflections etc.) have been investigated for the flight safety critical CNS equipment.

To enhance a previous conducted analysis by CPH and applying the gained knowledge, a decision was made to engage with four system providers of the equipment to gather their input on the challenges associated with installing a larger PV plant in close proximity to their equipment. As this was still part of a preliminary study, the specific details of the PV installation equipment (such as size, heights, angles etc.) were not yet specified, which limited the level of detail in the analysis. The PV plant's influence on the following systems have been assessed:

- Surface Movement Radar (SMR)
- Instrument Landing System (ILS)
- Multilateration (MLAT)
- Bird Radar

Surface Movement Radar (SMR)

SMR is used by air traffic controllers to detect and visualise aircraft and vehicles on airport surface grounds.

Equipment suppliers have raised awareness warning PV installations in the vicinity of an airport could represent the risk of generating multi path/ghost echoes. A ghost echo would allow signals to bounce back and forth between rows resulting a radar plot to be presented for a false location, representing safety issues. An impact assessment needs to be made.

Instrument Landing System (ILS)

Precision radio navigation system providing short-range aircraft guidance for allowing them to approach a runway, e.g., in reduced weather conditions such as night times or lowered visibility situations.

An issue could arise if PV plant is located too near to the ILS, hereof: glide path (GP), localizer (LOC), Distance Measurement Equipment (DME), Computer Aided Design (CAD).

Multilateration System (MLAT)

Multilateration is a surveillance tool used to precisely determine the location of transmissions. It efficiently matches any identification data contained within the transmission, such as octal code, aircraft address, or flight identification, and promptly sends this information to the Air Traffic Management system.

The conducted analysis suggested that the threat posed by the proximity of PV installations to interrogators placement in CPH was minimal. However, it is crucial to address this issue by avoiding the installation of PV systems in close proximity to interrogators.

Bird Radar

Bird radars have the capability to detect and forecast the presence of bird units within a specific radius. This proactive approach helps mitigate potential risks associated with birds unknowingly entering an area, as it allows for timely action to be taken.

If the radar emits signals towards the rear side of the solar panels, there is a possibility of reflections bouncing back. This can result in the radar detecting not only the panels themselves but also the metal mounting structure, leading to an increase in clutter levels and a decrease in sensitivity. It is challenging to accurately predict the extent of these effects. Generally, the impact of solar panels on radar signals diminishes as the distance between the radar and the panels increases.

In certain cases, it may be necessary to establish "no-tracking" zones. However, it is important to note that implementing such zones would block all signals originating from the ground upward. This solution may not be advisable in the vicinity of runways due to potential disruptions.

Further discussions and assessments should take place, taking into account the number of radars involved and their proposed locations. This will help determine the best course of action to mitigate any potential interference caused by the presence of solar panels.