ALIGHT

SUSTAINABLE AVIATION

Detailed report on smart energy solutions transferred and tailored in fellow and other airports

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Abbreviation	Extended name
ADR	Aeroporti di Roma
AMS	Amsterdam Schiphol Airport
ASTM	American Society for Testing and Materials
CPH	Copenhagen Airport
CPK	Warsaw Airport
DEL	Indira Gandhi International Airport
ETS	Emissions Trading System
FCO	Rome Fiumicino ''Leonardo da Vinci'' Airport
GHG	Greenhouse Gas
HRS	Hydrant Refueling System
HVO	Hydrotreated Vegetable Oil
LCAF	Lower Carbon Aviation Fuels
LHR	London Heathrow Airport
LTOU	Lithuanian Airports
OOL	Gold Coast Airport
NZE	Net Zero Emissions
SAF	Sustainable Aviation Fuel
VNO	Vilnius International Airport

Executive summary

This document aims to broadly illustrate the initiatives taken by airport authorities in the field of energy and sustainability. It is composed of four chapters, each focusing on a key aspect of airport energy, mobility and sustainability management. An additional conclusive chapter shall illustrate briefly valuable and innovative solutions implemented in the fields of concern as regards other airports worldwide.

Chapter 1: data on energy and thermal consumption for the baseline year (2019) is presented, along with explanations of the methodologies for sourcing thermal energy, fuels, and electricity according to the necessary requirements. Existing methodologies for conducting control and monitoring activities of energy data and airport site utilities, as well as supervision systems and standards followed to date, are also disclosed. Moreover, using the data provided regarding decarbonization strategies and plans for the following years, the targets set by each airport and the roadmaps to achieve them are shown focusing on the methods that can be adopted, those previously adopted, and the results achieved in recent times, where roadmaps had been previously drafted. This section, in detail, provides a very accurate overview of each airport's dedication to the mission of achieving the net-zero goal, adopting concrete, well-defined measures within realistic and decisive timeframes, in line with the market maturity of the latest available technologies

Chapter 2: focuses on sustainable mobility, one of the three pillars supporting decarbonization strategies, together with energy efficiency and renewable energy systems (RES). Firstly, an overview of the interventions carried out is elaborated, considering effects and, where applicable, budget and economic-financial data. Subsequently, the planned situation for the following years is illustrated.

Chapter 3: analyzes the energy efficiency projects, as in chapter 2, focusing firstly on the latest innovations to decrease the overall energy demand for each airport; moving on to the upcoming projects planned consistent with decarbonization roadmaps and airport development plans. Where applicable, budget and economic-financial data are included.

Chapter 4: illustrates the RES solutions implemented and planned for each airport, to decarbonize the remaining part of the overall energy consumption after energy efficiency and sustainable mobility solutions are applied.

Chapter 5: presents a quick overview of smart energy solutions appropriately contextualized within the relevant field for airport authorities located in other countries worldwide. The aim is to provide insights and updates on the latest technological innovations implemented, potentially usable as additional key points to achieve the set decarbonization goals.

Introduction

Airports are infrastructures characterized by a large use of energy due to their continuous operations, diverse systems, and integration of thermal, electrical, and transportation networks. This wide use of energy leads airports to find innovative approaches to optimize energy use, reduce environmental impacts, and enhance economic benefits.

A key step is to define a solid baseline, to adapt and customize innovative energy solutions to the different needs of each airport, in order to apply by a technical, operational, and economic feasibility all these smart energy solutions in the airport context.

The optimization of energy systems takes center stage, with a focus on smart grid technologies that integrate thermal and electrical networks. This includes leveraging waste heat recovery, energy storage, and renewable energy sources to enhance overall efficiency. Collaboration with local Energy Service Companies (ESCOs) further amplifies the impact of these initiatives, accelerating their energy, environmental, and economic benefits.

To support these advancements, tools for infrastructure management and planning are being upgraded to facilitate integration of data from multiple sources, optimizing energy performance in all the operations.

Electro-mobility also plays a significant role, with an important impact on both energy and transport systems. Wherever feasible, innovative strategies such as vehicle-to-grid (V2G) and demand response are being explored to maximize energy efficiency and grid stability.

In order to establish a clear framework for the evaluation of implemented smart energy solutions, it is crucial to analyze benchmarks, comparing the initiatives implemented by partner airports with those of other international airports. This benchmarking process will help identify best practices and ensure the adoption of the most effective technologies in the sector.

The implementation of these activities is critical to achieving the goals of energy efficiency and sustainability in the aviation sector. Through these solutions, airports can significantly reduce their carbon footprint while ensuring economic viability. The involvement of local stakeholders, including ESCOs, further ensures that the solutions are not only effective but also aligned with the regional context and needs.

The information related to future Warsaw Airport pertains to a facility that is not yet operational and is still under construction, awaiting completion before it can commence activities.

1 Energy Baseline

The definition of an energy baseline that accounts for thermal and electrical consumption is an important step to understand how smart solutions can be effectively integrated into the airport's energy perimeter. This baseline provides an overview of the airport's total energy demand and consumption for the year 2019, selected as the reference year as it represents the pre-COVID period most comparable to the current operational scenario. The analysis helps identify key areas for improvement and opportunities for optimization in energy efficiency and management. Moreover, an accurate energy baseline allows stakeholders to evaluate the impact of smart solutions on energy efficiency, cost savings, and environmental performance. It also enables a more informed decision-making process by highlighting synergies between thermal and electrical systems, such as the potential for waste heat recovery or the integration of renewable energy sources. This approach supports the seamless adoption of innovative technologies while maximizing their benefits within the airport's unique operational context.

1.1 Baseline energy assets, consumption and monitoring

This paragraph shows the baseline consumption in the reference year 2019 for each airport, highlighting which are the main sources of energy and the energy vectors involved.

1.1.1 Copenhagen Airport (CPH)

Copenhagen Airport in 2019 consumed approximately 102,026,000 kWh of electricity and 246,077 GJ of thermal energy annually. The airport's thermal energy consumption primarily relies on district heating, which accounts for 201,987 GJ. Additionally, 33,910 GJ of heat is generated from natural gas, while heat pumps contribute 4,106 GJ, further supporting the airport's heating needs.

Power purchase since 2025 has been through PPA, based on off-site wind power generation, which covers 100% of the airport's electricity needs, while the airport's primary heating comes from a publicly owned district heating system, which ensures a stable and efficient energy source. Currently, purchased energy accounts for more than 80% of its operational (scope 1 and 2) emissions.

On the electricity side, the Transmission System Operator (TSO) is responsible for providing auxiliary services. However, at present, Battery Energy Storage Systems (BESS) have not yet submitted any bids to participate in these services.

On the monitoring side, thermal and electrical energy are managed with integrated systems such as Power Factory and other BMSs. The Power Factory is used to monitor and control high-voltage systems. Almost all technical systems, such as ventilation, chillers, heating, etc., are controlled by a single BMS.

The energy management department ensures that everything works properly and records the correct data through the energy management system certificate (DS/EN ISO 50001:2018). The overall energy performance of the airport is reviewed, and deviations or changes are discussed in weekly meetings and is based on the automatic reading of about 3,800 energy and water meters.

The development of energy Key Performance Indicators (eKPIs) for Significant Energy Users (SEUs) is currently in progress at the airport. For newly installed SEUs, energy performance assessment is conducted during the commissioning phase and continuously monitored through energy metering systems to ensure compliance with the specified operational and efficiency requirements.

The supply of thermal energy is also happening by means of a water-to-water heat pump in Maglebylille, taking recycled wastewater in its secondary circuit. Secondary water, which may come from untreated groundwater, collected rainwater, or reused water from activities such as firefighting training, is used for cooling server rooms and flushing toilets. This practice helps Copenhagen Airport reduce its potable water consumption by approximately 120,000 m^3.

The ongoing expansion of Terminal 3 in combination with an extensive electrification of vehicle and equipment fleet, installation of electric heat pumps, and increased passenger vehicle charging will cause electricity consumption at the airport to rise steadily towards 2030 and beyond.

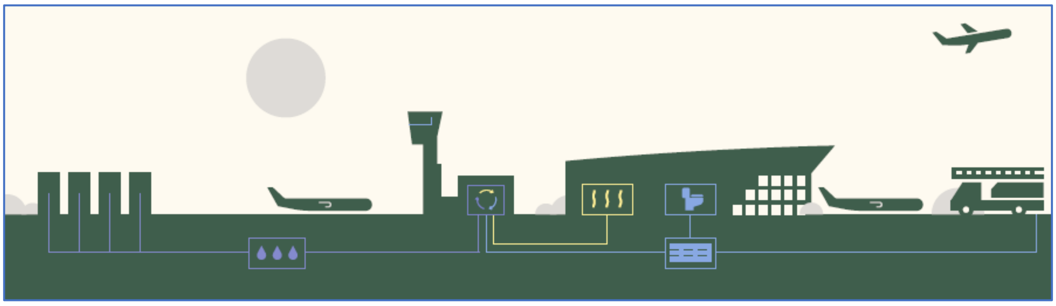

Figure 1 - Secondary water's journey through the airport - Annual Report CPH

1.1.2 Fiumicino Airport (FCO)

In 2019, FCO recorded an electrical consumption of 150,526,165 kWh and a thermal consumption of 80,648,280 kWh, reflecting the overall energy demand required to support its operations.

Fiumicino airport is equipped with a cogeneration system for the simultaneous production of thermal and electrical energy, and it is fueled to date by gas taken from the grid and a bypass thermal power plant consisting of methane boilers, serves as a backup to the cogeneration for heat production. Electricity consumption is also met by drawing from the national grid and thanks to self-generated electricity by means of installed photovoltaic panels.

Terminals are the most energy-consuming areas, from a series of assessments based on monitored cabins it is estimated that HVAC systems are responsible for the highest consumption.

According to the standards of the ISO 50001 Energy Management System, the energy consumption of Fiumicino airport is monitored in a standardized way, integrating all "Aeroporti di Roma"

(ADR – controlling FCO and Roma Ciampino airports) activities that contribute to energy consumption to ensure they are monitored within the EMS. Since the introduction of ISO 50001 standard, FCO Airport has experienced a significant decrease in its energy performance indicator, resulting in an improvement of its energy efficiency performance.

In the table below the main KPI's adopted from FCO to monitor energy efficiency and reduction of CO_2 emissions:

KPI	Description, methodology and assumptions	Impact [20]
REDUCTION OF ELECTRICITY CONSUMPTION	Energy consumption of the FCO Terminals (Kwh) / (#passengers) * (total net area of the Terminals in square meters).	2019: -28% 2023: -42%
REDUCTION OF CO2 EMISSIONS	CO2 equivalent emissions of the FCO Terminals (Kg) / (#passengers) * (total net area of the Terminals in Sq m). • CO2 emissions calculated according to the location-based methodology, generated by the electricity purchased for the FCO Terminals; • the emission factor per kWh calculated according to Italian ISPRA standards [21]; • electricity consumption does not include in-house production and the purchase of renewable energy (approximately 8% and 24% of the total electricity consumed in the terminals in 2019 and 2023, respectively).	2019: -42% 2023: -67%

CERTIFICATIONS AND SUSTAINABLE LABELS FOR GREEN BUILDINGS	Certification of eligible buildings according to international environmental protocols, such as:
	• LEED® [22] Gold;
	• BREEAM® [23] Very Good;
	• EPBD [24] A.
		ADR's Sustainable Certification Agenda
		• >60% of terminals built or renovated in line with LEED or BREEAM certifications by 2030 (reaching 30% in 2024);
		• >80% by the expiry of the concession in 2046 (LEED, BREEAM or ENVISION).
		LEED "Gold" certifications achieved
		• Ciampino General Aviation Terminal (completed);
		• "Baby gate" company nursery (obtained on 10/18/2022);
		• New Pier A (obtained on 05/23/2023).
		BREEAM certifications obtained:
		• Pier E and Front Building of Terminal 3: "Excellent" level achieved on 3/9/2022 (better than the previous "Very Good" target);
		• Terminal 1, T1 Extension, T1 Front Building: BREEAM certification "Very Good" level obtained on 01/4/2024.
		Future projects:
		• LEED certification "Gold" target on:
		  • restructuring of Pier B in progress (submission on 10/5/2023, Design Review phase in progress);
		  • restructuring of Pier D, objective to finalise design in 2024, target entry into operation and obtaining certification 2027.
		• BREEAM certification on Satellite expected in 2024.

Table 1 - FCO KPI's for energy efficiency - Annual Integrated Report (AIR) 2023

1.1.3 Vilnius Airport (VNO)

Vilnius Airport reported electricity consumption in the reference year of 14,516,455 kWh and thermal energy consumption equal to 6,679,910 kWh.

The airport did not produce any self-consumed energy in 2019, taking all the energy needed to cover its needs from the grid. It subsequently installed photovoltaic systems to produce renewable energy used to cover part of the airport's electricity needs.

The main energy sources are conventional fuels like diesel and gasoline for ground handling vehicles, and electricity taken from the national grid. Thermal energy is either taken from natural gas combustion or supplied by Vilnius district heating network.

The main areas within the airport with the highest energy consumption are the following:

- Indoor ventilation devices (2019 m) – 23.8% of the total electricity used
- Hot water preparation systems – 21.4% of the total electricity used
- Room heating systems – 18.4% of the total electricity used.

LTOU (Lithuanian Airports, owner of VNO) is part of the ESO Progressive Energy Club which unites companies, investing into a greener tomorrow by using energy efficiently and sharing know-how with other players in the market.

1.1.4 Planned new Warsaw Airport (CPK)

The future Warsaw Airport expects to consume approximately 300 GWh/year of electrical energy and approximately 576 GWh/year of thermal energy at the airport, of which 470 GWh/year for heating and 106 GWh/year for cooling.

Energy data monitoring within the airport will be done by means of BMS and smart meters and a Supervisory Control and Data Acquisition (SCADA) system will be used to monitor the heat and cold utilization and distribution in the district.

The electric energy distribution system at CPK will be managed by a dedicated operator within the CPK capital group. This entity will oversee the operation and maintenance of the electrical grid to ensure a stable and efficient power supply. Responsibilities include balancing electricity supply and demand to prevent outages, continuously monitoring the grid for anomalies, and implementing corrective actions as needed. The operator will also coordinate maintenance activities to minimize disruptions and uphold system integrity. In case of power failures or emergencies, they will act swiftly to restore service. Additionally, compliance with energy regulations and standards will be a key priority. Through this energy system operator, CPK will procure green energy via Power Purchase Agreements (PPAs), reinforcing its commitment to sustainable and environmentally responsible operations.

Objective	Target	KPI			
		Metrics	Development phase	1st year of operations	5th year of operations
1.1 Minimizing energy consumption	1.1.1 Total energy consumption per passenger	kWh/pax	N/A	Target to be set up during the design process	Initial KPI will be kept or slightly lower
1.2 Providing energy supplies from renewable resources	1.2.1 Share of renewable energy consumption	% of total energy consumed	Maximise %	Target to be set up for opening day	According to the business decision considering airport/airlines needs decision
	1.2.2 Share of on-site renewable energy generation	% of total energy consumed	Maximise %	At least 30% Advisable: 40% To be specified by designers	Initial KPI will be kept or slightly lower environmental/weather conditions

Table 2 - Main KPIs targets and overview at CPK

1.2 Decarbonization target

Based on the pathways for decarbonization that each airport intends to follow, the main targets to be reached are outlined below, possibly dwelling on estimated emission values to be achieved.

1.2.1 Copenhagen Airport (CPH)

CPH is certified under the airport's carbon accreditation scheme as "Transition Level 4+," which commits it to setting long-term climate go als, including in aviation.

The Net Zero Plan 2050 for CPH Airports outlines differents strategies for reducing Scope 1, 2, and 3 CO_2 emissions. The main reduction targest are represented in figure 2.

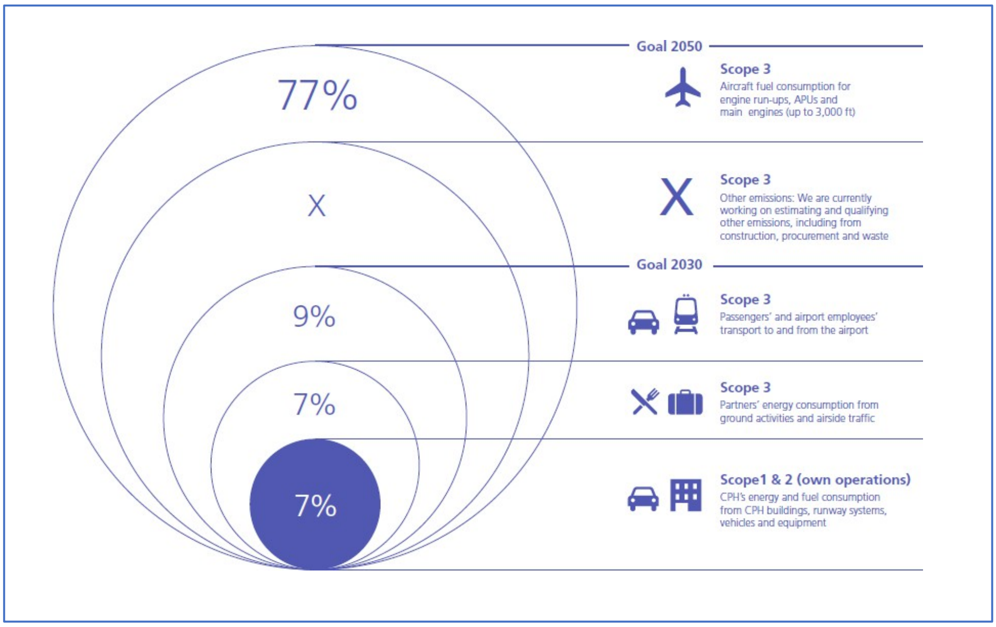

Figure 2- CPH Airport's Net-Zero 2050 plan and emissions breakdown[1].

CPH Airports' carbon footprint is calculated based on the principles of the GreenHouse Gases (GHG) Protocol. These calculations are highly complex due to the variety of emission sources, necessitating a thorough understanding of the activities performed for accurate monitoring and reporting. The airport's role as a landlord for various stakeholders, including cargo companies, retail shops, operational handlers, and associated businesses, adds to the complexity of the dataset.

The main measures to reach the airport's Net-Zero **Scope 1** strategy are the decommission of gas-fired boilers, along with the decarbonization of the public district heating network, and the decarbonization of its vehicle fleet, by gradually elecrtrifing conventional fuel-powered vehicles. An exception will be made for the 1% of consumption related to food cooking activities, for which phase-out plans will be developed. The target is to replace over 80% of them by 2027, keeping in mind that there's a variety of vehicles that cannot be substituted due to their complexity and lack of better available technologies (e.g. tractors, fire trucks, other trucks). However, the development of new technologies for these vehicles is kept monitored for the following years.

Regarding **Scope 2** emissions, CPH is committed to significantly reducing electricity consumption to counter the forecasted increase due to the electrification of the vehicle fleet and airport expansion. The airport's total electricity consumption is projected to increase by nearly 50% toward 2030. To mitigate this rise, a range of projects are being conducted to improve the operational efficiency of the airport's buildings, including investments in energy-efficient ventilation systems and LED lighting, that are the areas with highest consumption. The goal is to save around 24 GWh of the 100 GWh electricity requirement by the end of 2030. This will be achieved through the replacement and optimization of current assets, such as lighting systems, ventilation systems, and distribution infrastructure. In 2023, over 3 GWh of electricity savings were achieved, mainly through lighting projects where over 5,000 luminaires were replaced with associated lighting controls. The energy efficiency plan for the coming years, finalized in 2024, aims to realize the remaining 21 GWh savings. Electricity consumption is expected to rise significantly beyond 2030, so efforts will continue beyond this deadline. Renewable energy systems (RES) will be installed to cover the increasing and significant part of the demand over time, combined with investments in RES area of concern through Power Purchase Agreements (PPA) with external already existing renewable power production plants. Thus, the residual electricity demand beyond energy efficiency intervention will be met by new renewable energy power plants installed on the airport premises and supply of green power.

Scope 3 emissions are mitigated by considering transition both for the aviation sector and for the airport, also combining effort with external partners. On the aviation sector side, CPH considers relying on drop-in SAF utilization, and on the introduction of green hydrogen as a fuel and electric aircrafts development. About the airport, smart energy usage, sustainable mobility plans and circular economy are the key aspects to improve the carbon footprint.

In addition, in year 2023, CPH and the airlines entered into a four-year agreement, 2024-2027, regarding the prices airlines must pay for the use of airport infrastructure. As part of this agreement, the airport introduced a CO_2 tax. The idea behind this tax is to focus on the CO_2 emissions of different aircraft. This instrument was formed by the airport authority in such a way as to provide a small financial reward for airlines that emit less CO_2 during a calendar year.

This is somewhat of an experimental initiative, as experiences with a CO_2 tax by other airports are extremely limited. After 2027, CPH will reconsider the CO_2 tax in relation to whether it was properly constructed, whether it had the desired effect of pushing the technological development of more fuel-efficient aircraft, and whether the financial incentive should be more comprehensive.

1.2.2 Fiumicino Airport (FCO)

Fiumicino Airport calculated its carbon footprint in accordance with the rules set out by the ACA program for Level 4+, as defined by ACI Europe, following the guidelines provided by the ISO 14064-1 certification. In 2019, Fiumicino Airport emitted a total of 59,173 tons of CO_2, of which 4,413 tons were attributed to Scope 1 and 54,760 tons to Scope 2.

Starting in 2023, the year following ADR's acquisition of 100% of Leonardo Energia, an additional calculation was carried out to define a new baseline that includes Leonardo Energia in Scope 1. According to this new baseline, Scope 1 emissions in 2023 amount to 68,911 tCO_2, while Scope 2 emissions are equal to 0 tCO_2. The Action Plan included in the Sustainability-Linked Financing Framework for the reduction of Scope 1 and Scope 2 emissions remains suitable for achieving the target set for 2027 and 2030.

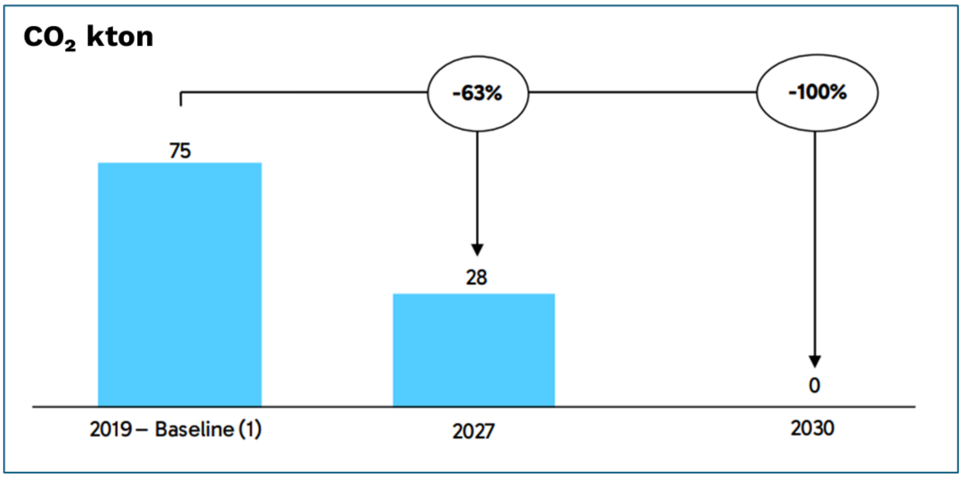

Figure 3 - Scope 1 and 2 emission reduction target for FCO[2]

As can be seen, the main objective for ADR considering FCO airport is to reach the Net Zero Carbon target by 2030, working on different areas of action, starting from the use of renewables and storage systems to the reduction of transport-related emissions.

Considering Scope 1 emissions, the use of HVO is planned, having a gradual transition of operating fleets (e.g. service cars, operating vehicles) to low-emission vehicles. This intervention would be accompanied by the installation of several charging stations for electric vehicles.

For the calculation of Scope 3 emissions, the following are the **Scope 3 emission sources** identified up to and including **2023**:

1. LTO (Landing and Take-Off) cycle
2. APU (Auxiliary Power Unit) & Engine Run-up
3. Aircraft cruise emissions
4. Ground Support Equipment (GSE) and handlers' vehicle fleet
5. Passenger accessibility
6. Staff accessibility (excluding ADR employees)
7. Mobility management (ADR employees)
8. Goods accessibility (estimated)
9. Waste management
10. Business travel
11. Third-party fixed and mobile sources
12. Aircraft deicing
13. Electric and thermal energy purchased from third parties.

Starting in 2024, the list of Scope 3 emission sources has been updated to include Purchased Goods & Services, Capital Goods, and Energy Well-to-Tank (WTT - Fera).

Additionally, the following Scope 3 emission sources fall under the Sustainability-Linked Bond (SLB) framework:

1. Ground Support Equipment (GSE) and handlers' vehicles
2. Passenger accessibility
3. Other staff accessibility (third parties)
4. Goods accessibility (estimated)
5. Waste management
6. Business trips of ADR staff

7. Third-party fixed sources
8. Aircraft deicing
9. Energy purchased from third parties.

In the figure below are reported the main targets for Scope 3 emissions for Fiumicino airport, related to a single passenger.

Figure 4 - Pro-capita FCO Airport CO_2 emission calculation since 2016, milestones and targets set for years 2027 and 2030.

Related to ground handling vehicles and aircraft emissions, "Eni," a major player in the Oil&Gas sector, entered in the year 2021 for the implementation and dissemination of SAF for aircraft and HVO (Hydrotreated Vegetable Oil). Moreover, FCO experimented trials in 2021 and 2022 to see if it was possible to bring SAF to FCO by truck and by ship. Activities are also planned to increase awareness and support initiatives in all stakeholders involved in activities that emit pollutants.

On the passenger side, improvements are planned in terms of accessibility, ensuring that travellers to and from the airport are incentivised to use alternatives to more polluting solutions. Related to this, strategic partnerships are envisaged with the "Ferrovie dello Stato" group, Italy's main railway company, to encourage the use of alternative means to private cars for land mobility to and from the airport. Still on the subject of accessibility, improvements are planned for airport personnel, including third parties, and for all cargo. In addition, business trips for ADR staff will be studied in more detail to limit relative emissions. Scope 3 emissions will also be reduced by acting on waste management, treatment and disposal of solid and liquid waste generated in airport operations, as well as by taking into account purchased energy and third-party stationary sources (emissions from on-site generators and installations).

Other activities to be considered include emissions from de-icing activities that currently use conventional fuels will be offset by specific projects.

As part of its ESG strategy, Aeroporti di Roma successfully completed the placement of its first 300 million euros Green Bond, attracting demand more than 12 times the offer from institutional and Socially Responsible Investors (SRI). Issued under the "Euro Medium Term Note" programme and aligned with ICMA's Green Bond Principles, the proceeds will finance environmental projects contributing to the UN Sustainable Development Goals, including the development of multi-MW photovoltaic plants, low-emission mobility infrastructure, and LEED Gold-certified buildings. The transaction is part of ADR's decarbonization roadmap, which targets Net Zero emissions by 2030, and is supported by a Green Financing Framework validated by a second party opinion and overseen by a dedicated Green Finance Committee. This initiative reinforces ADR's position as one of the few global airport operators capable of combining sustainable financial instruments with a structured approach to the ecological transition of the aviation sector.

1.2.3 Vilnius Airport (VNO)

VNO Airport's main environmental impact document management is the internal Environmental Strategy 2018-2028, which focuses on the globally recognized International Air globally agreed Sustainability Strategy of the Airports Council International (ACI). The Environmental strategy includes 4 activities from the ACI Sustainability Strategy, the declared "balanced performance model" for environmental protection (climate change, resources, Water and Biodiversity) impact strands.

From 2019 onwards, VNO is tracking and reporting on sustainability, publishing information on environmental indicators in the sustainability reports, in line with the ACI Sustainability Strategy indicators. The LTOU environmental KPIs used corresponds to ACI Sustainability Strategy KPIs. In detail, are kept monitored the tons of CO_2 emitted and the kilos of CO_2 equivalent per passenger, together with the percentage of green electricity over the total electricity consumption. The latter has become 100% starting from year 2021, while from the point of view of kilograms of CO_2 equivalent emitted per passenger, the results over time are promising, except for emissions assessed to the year 2021 for which there has been a sudden increase: they've reached 1.89 kg_{CO2e} per passenger in 2021 having fixed the target at 1.5 kg_{CO2e} per passenger. In year 2023 has been registered a value of 0.35 kg_{CO2e} per passenger, being also the best result among other LTOU-controlled airports.

In 2019 Vilnius Airport upgraded from the ACA Level 1 ''Mapping'' to the Level 2 ''Reducing''. In 2022 Level 3 has been reached, aiming at Level 3+ by 2023 and 4+ Transition by 2050. The Carbon management plan was prepared, according to the ACA requirements and it's continuously implemented. In the process of setting the CO_2 reduction target, year 2022 has been taken as a baseline year, because it is the last one in which Carbon footprint report has been verified by ACA verifier.

By the 1st of March and each year by 2023, the previous year's emissions are calculated based on the GHG Protocol methodology and three documents are prepared and reviewed:

- GHG protocol calculations report (prepared);
- The CO_2 reduction plan (reviewed and updated);
- The Stakeholder Engagement Plan (reviewed and updated).

The CO_2 emission reduction plan reports will list the CO_2 reduction measures implemented during each year and their actual contribution to CO_2 reduction, describing main activities involved, detailing the main measures and projects to be implemented in the following years and the deviations and changes with respect to the previous versions.

Based on the CO_2 footprint calculations, the residual emissions in 2027 will be forecasted, the scope of off-setting and the criteria for selecting funds will be determined. Procurement of CO_2 off-setting will be carried out by 1st of March 2028 and the balance of the CO_2 residual emissions will be off-setted annually starting from 2027. By 2029 new CO_2 emission sources are going to be considered as regards Scope 3 calculation: aircraft refrigerants (Freons), construction vehicles, cruise flight aircraft emission (so that full flight emissions are considered) and treatment of waste and sewage. Eventually, by 2030, to achieve Level 4+ by 2050, there will be formal commitment to reduce absolute CO_2 footprint, which will be calculated taking into account all the sources identified so far. A target for the reduction of absolute CO_2 footprint will be formulated (90% as of 2010 for the first year of calculation) and a plan for further emissions reduction will be updated to meet the set target.

LTOU has undertaken several initiatives for Vilnius Airport, broken down by Scope in the decarbonization roadmap.

Regarding **Scope 1 and 2** emissions reduction, initiatives for the future mainly involve supply of energy from RES, vehicle fleet renewal, installation of photovoltaic systems, implementation of energy efficient systems (LED light systems, green and high-performance buildings, etc.), energy audits and BMS. The graph below reports the actual Scope 1 and 2 emissions, measured in year 2023 and divided by area of interest.

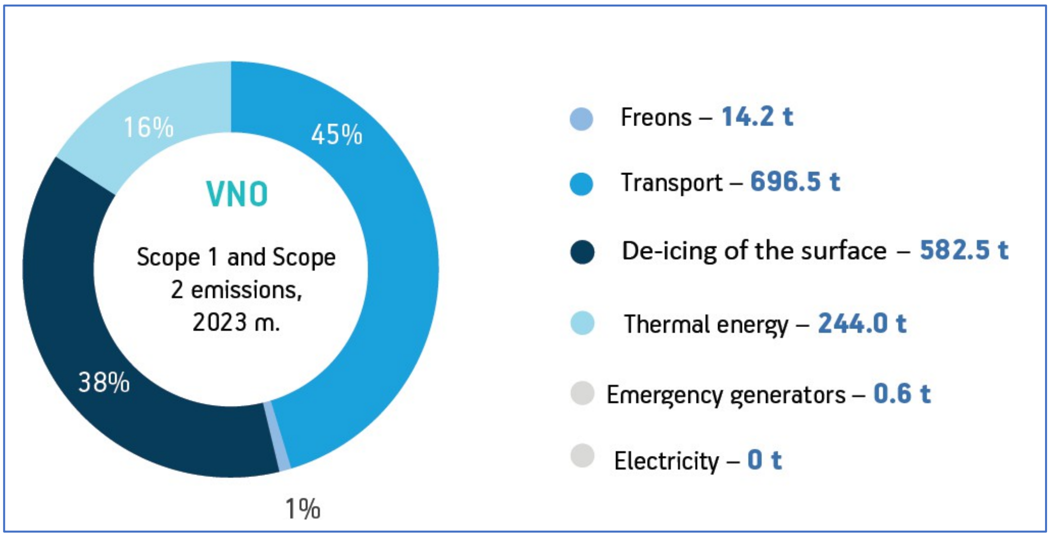

Figure 5 - VNO Scope 1 and 2 emissions, 2023

Lastly, **Scope 3** emissions reduction awareness among partners is promoted by a campaign run by LTOU, showing the net zero targets and discussing the involvement of each party in reaching the common targets. Measures to reduce CO_2 corresponding to the activities and contributions of a specific partner shall be included in the renewed contracts. A mandatory requirement to calculate CO_2 emissions annually will be set, together with a list of mandatory measures for the design and construction of new buildings, such as solar PV plants, passive buildings and high energy efficiency infrastructure.

The initiatives to reduce Scope 3 emissions mainly regard:

- Electrified aircraft stands
- Deicing runoff collection and treatment
- SAF implementation
- Expansion of EV charging net;
- Electric and bio-fuel powered ground handling equipment/vehicles (by 2030)
- Sustainable ground-access transportation.

The decarbonization strategy outlined below depicts how and when the milestones should be achieved, clearly identifying which areas of concern should be acted upon for all of the three Scopes.

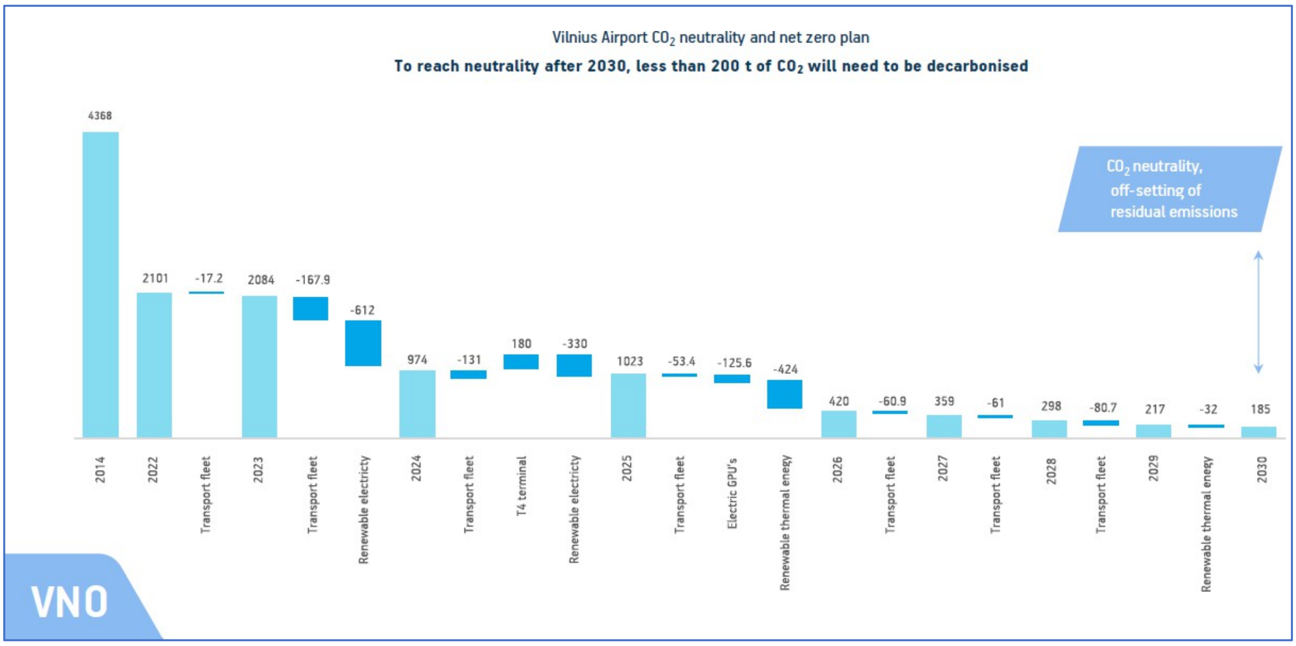

Figure 6 - VNO airport carbon strategy, 2023[3]

1.2.4 Planned new Warsaw Airport (CPK)

The future CPK airport aims to achieve Net Zero Ready at the start of operations through the exclusion of fossil fuel solutions. The path also includes electrification of heat and investment in on-site and off-site renewable energy sources (through so-called PPA power purchase agreements). The entire process began with careful consideration of the technical potential to achieve readiness for a zero-emission airport. These considerations will be applied in the planning and design of energy-efficient buildings and carbon-neutral infrastructure and transport at the airport.

The Strategic Goals of sustainability have been defined within two main areas: environmental and socio-economic. The environmental goals align with the six principles of the EU Taxonomy, which categorize major environmental issues, with particular attention to airport noise, for which a specific goal has been established. Other types of pollution have been integrated into broader goals, with air pollution included in SG 1 "Combating Climate Change" and water pollution in SG 2 "Sustainable Water Resource Management." On the other hand, socio-economic goals have been developed based on the needs of key stakeholders, such as future passengers, local and national businesses, employees, and local communities.

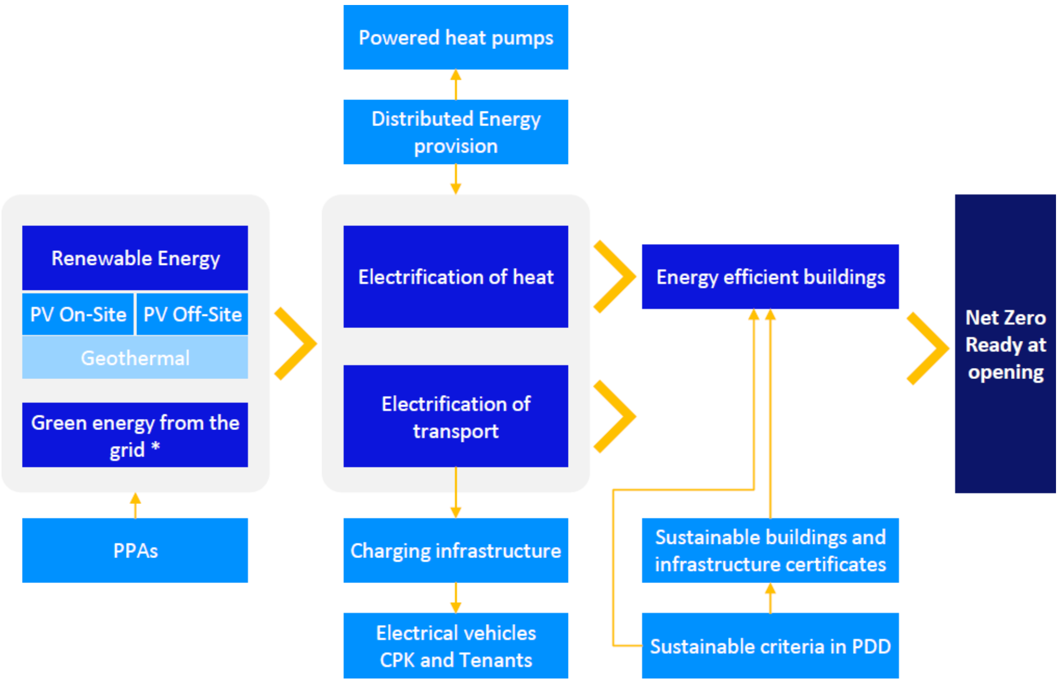

Figure 7 - CPK Net Zero plan flow chart

1.3 Key conclusions

What has been forementioned provides a clear overview of both the energy scenario and the carbon footprint of the airports. Each airport has a decarbonization plan aimed at meeting European requirements and common targets, with a view to achieving a “Net Zero” carbon footprint, minimizing energy needs and meeting them using renewable energy sources, either produced on-site or through purchasing contracts. It is important for this to unpack and analyze emissions, keeping them monitored and broken down into the three “scopes,” so as to understand where there is always the greatest room for improvement.

2 Sustainable Mobility Solutions

This chapter outlines the main sustainable mobility projects, already implemented or programmed for each airport. Promoting sustainable transportation solutions for passengers, employees, and commodities aims to reduce carbon emissions and integrate innovative technologies to support a more sustainable transportation system, aligning with global sustainability goals.

2.1 Sustainable mobility projects and actual context

Projects implemented and planned in the short-term regarding sustainable mobility within airports are discussed below, shifting the focus exclusively to the efficiency of the fleet of vehicles under the jurisdiction of the airport authority for moving cargo and passengers to decrease their carbon footprint.

Regarding the airports in Copenhagen, Rome, and Vilnius, numerous initiatives have been implemented to optimize transport systems in terms of both energy and mobility efficiency. As for Warsaw CPK, its ongoing construction prevents the collection of a history of mobility solutions to describe the current situation. However, looking ahead, Grodzisk Mazowiecki is committed to enhancing the public transportation system for Warsaw airport to meet the growing demand for efficient and accessible mobility.

2.1.1 Copenhagen Airport (CPH)

Currently, most of the vehicles in CPH's fleet are primarily BESS-electrified equipment and not fuel cells. CPH is exploring the possibility of enabling and prioritizing HVO for equipment for which alternatives cannot yet be obtained. Ways to push this process, first internally and then for third-party operators, are being explored, but it is noted that CPH stakeholders are already converting some of their equipment.

At the present time, all the transportation units are powered by different energy sources: one portion burns diesel, another portion, represented by the baggage trucks, has been electrified and operates on lead-acid batteries, and yet another portion operates on lithium-ion batteries. Of these converted vehicles, mainly these are standard Ground Handling (GH) units, push backs, and stationary Ground Power Units (hereinafter referred to as GPUs) that use charging points with power greater than 11 kW. Passenger stairs have also been electrified.

In total, it is estimated that about 33% of the airport equipment has already been electrified. To add to this, there are also 3 additional buses operating during peak hours for passenger mobility within the airport.

In December 2023 CPH, in collaboration with the energy company EWII, built a new charging station with 16 superchargers (360 kW chargers), serving passengers to and from CPH and the Øresund region. Since the beginning of 2022, CPH has opened a total of 444 charging points (420 AC and 22 superchargers) across the airport site. In 2023, CPH facilitated 40,500 charging processes, equivalent to 744,000 kWh. This represents an increase of 150% compared to 2022 and reflects the higher demand for more climate-friendly transportation options.

In 2025 the main project for sustainable mobility solutions in CPH Airport is the purchase of electrical buses. The project aims to improve landside passenger transportation by introducing two electric buses, that are estimated to cover 40% of mobility needs. The initiative involves multiple departments, including Sustainability, Aeronautical Field and Equipment, Procurement, Operators, and Project Management, and is integrated with efforts to develop charging infrastructure. The buses will use CCS charging technology, with one charging point featuring two outlets of up to 350 kW, powered by the nearest grid supply. The project is currently awaiting asset delivery and budget finalization, with expected environmental benefits such as reduced overall fuel consumption, abatement of CO_2 emissions, and reduction in maintenance costs. KPIs for success include fuel savings and electricity consumption metrics.

To pursue the goal of fostering the transition to sustainable mobility also for passengers and employees of the airport outside its boundaries, there are several initiatives to offer different alternatives to private transportation or to encourage the use of electric cars.

In 2023, Copenhagen Airport became the first airport in Scandinavia to be certified as a Bicycle Friendly Workplace. CPH achieved a silver certification and now, after implementing new initiatives and further improving the facilities, has been awarded a gold certification. In addition to promoting the use of bicycles, CPH encourages employees to travel by public transport by offering discounts on public transport through a commercial agreement with DSB, the Danish railway service.

2.1.2 Fiumicino Airport (FCO)

Sustainable mobility is one of the many activities that ADR manages through the subsidiary ADR Mobility. It plays a major role as it ensures and develops services and transport infrastructure between the airport and other destinations. The main intervention areas focus on fleet conversion and electric vehicle charging, including the development of parking areas for passengers, companions, and airport staff, along with the installation of a high number of EV charging stations to support sustainable mobility.

In 2024 ADR inaugurated ADR e-Move, a parking facility exclusively dedicated to electric and plug-in hybrid vehicles. It features 74 covered parking spaces, each equipped with a 22-kW charging station, and is conveniently located on the first floor of the Terminal B multi-level parking garage, near Terminals 1 and 3 via a moving walkway. The goal for Fiumicino airport is to reach around several charging stations by the end of 2025 for passengers and airport operators.

ADR, which has been implementing a comprehensive sustainability program for years, has recently introduced electric shuttles at FCO and CIA airports. The landside shuttle fleet has been converted with 11 fully electric buses, charged via 240 kW DC chargers, starting from August 2024.

2.1.3 Vilnius Airport (VNO)

By 2026, the eight diesel-powered Ground Power Units (GPUs) currently in use at Vilnius will be replaced with electric versions. The vehicle fleet upgrade will follow a renewal program focused on energy efficiency and advanced environmental standards. The goal for light vehicles is to achieve 100% electrification by 2030. As for heavy-duty vehicles, given the limited availability of electric alternatives, a gradual transition to biofuels will be implemented, with a target of 30% biofuel usage by 2024 and 50% by 2026. These initiatives align with LTOU's broader strategy to reduce CO_2 emissions and achieve climate neutrality by 2030. Plans for sustainable mobility initiatives for Vilnius Airport involved the implementation of charging stations and integration of electric vehicles into the fleet. This latter started in year 2019 with the introduction of 1 electric car in the fleet out of 218 to be converted.

The central parking area in front of the VNO terminals was reconstructed, including the installation of 10 charging points for electric vehicles in the project, cables and power supply were brought in to allow a total of 34 charging points for electric vehicles to be installed both in landside and airside areas in the future according to demand.

This project of integrating electric vehicles into the airport fleet may have several advantages, including the possibility of optimizing energy flows by obtaining cost-free energy supply by connecting the charging stations to an on-site photovoltaic system. Additionally, providing electric vehicles for high-ranking executives would significantly reduce time lost in traffic, as they would be allowed to use dedicated lanes for electric vehicle transit. This transition would also strengthen the company's image as a leader in green energy and sustainability. Vilnius Airport does not provide directly GH services (buses, pushbacks, cargo lifts, PRM etc.), but use equipment and machinery for the airfield maintenance (snowploughs, tractors, cars, firefighting cars, lawnmowers etc.). For these categories of equipment, the Transport program was initiated to renew all the vehicles and equipment in order to reduce the cost of maintenance and CO_2 emissions. At the current time, the process of fleet electrification has significantly advanced, having additional 2 electric and 2 hybrid cars, 6 hybrid and 4 diesel SUVs, and electric minibus and a cargo van for VNO.

Vilnius Airport intends to undertake more projects apart from this. Firstly, there is an ongoing CEF-funded project, to include the installation in VNO of several electric vehicle charging stations. "Connecting Europe Facility for Energy" (CEF Energy) is a portfolio of European projects aiming to support the synchronization of Baltic countries with the rest of Europe in terms of electrical grid connections and other infrastructures. Specifically, this project is running since 2023 and is going to be concluded in 2025 and intends to provide the necessary infrastructure for electric charging stations, involving also GH companies and airport operators. It was initiated to provide an opportunity to purchase new electric vehicles, since there were few charging points in the Airside area. The project includes the installation of a Battery Energy Storage System (BESS) with storage capacity of up to 560 kWh electric, as well as charging stations with 1.08 MW total capacity (6 charging points of 360 kW) for charging electric passenger buses; 5 dual charging points (60 kW) and 5 three-phase outlets (12 kW) with a total capacity of 0.36 MW for charging the airfield's special vehicles, equipment, and mobile GPUs; 4 dual charging points (also 60 kW) with a total capacity of 0.24 MW will be installed for transporting ground service companies and other partners. The total allocated budget is 1.3 million euros, and the payback period is estimated to be over 10 years, with a Net Present Value (NPV) of 2.4 million euros and Internal Rate of Return (IRR) of 73.80%. The environmental benefits are mainly reduced CO_2 emissions and reduced gasoline and diesel consumption. The KPI used to measure the success of the project is the reduction of CO_2 emissions generated by diesel vehicles by at least 33 tons of CO_2 per year.

Runways were also built and renovated, decommissioning Alpha, renovating Bravo and extending Foxtrot, and building Zulu. The result was to reduce the length of operations in each runway by 2 minutes while avoiding CO_2 emissions by up to about 626 tons per year.

Another project regards the electrification of diesel-fueled GPUs and MGPUs. Between 2021 and 2022, 9 new GPUs have been installed to power stationary aircraft using electricity to replace those GPUs previously powered by diesel, thus reducing CO_2 emissions in Scope 3 and other pollutants. The project involved airport management and the EU CINEA (CEF) and it aimed to reduce consumption of diesel fuel in transport and equipment. The diesel Mobile GPUs (MGPUs) are replaced with electric GPU with rated frequency 400 Hz, voltage 115V and apparent power 90kVA. The total budget allocated to this project is 1.03 million euros with an NPV of 1.14 million euros and a 47.96% IRR, with a payback period of 3 years, financed at 50% by CINEA CEF-T-2021-AFIFCOEN. Main reduction for this project were CO_2 emissions and fuel consumption. The project was aimed for BREEAM - GOOD, after opening it the airport expecting BREEM - VERY GOOD in 2026.

Another very important project regards the construction of T4 departure terminal featuring green and sustainable solutions and has occurred in the years 2023-2025. The new terminal, as a result of the installation of innovative technologies within it, would allow it to serve a frequency of about 2,400 flights/hour (on departure). This project involved Vilnius Airport management and included the installation of solar photovoltaic systems and additional new electric vehicle charging stations. With this expansion, in fact, charging stations are also provided for the adjacent new short-term parking lot, amounting to 17 dual charging columns of 2x22 kW each, up to a total of 374 kW, also fed from the national power grid. The total project budget was around 46.8 million euros, with an NPV of 1.8 million euros and an IRR of 8.90%. What is remarkable is that the expansion of the airport infrastructure would cause a significative increase in energy demand, that would eventually be minimized by the introduction of energy efficient technologies and thanks to the guidelines of green building design. In fact, in accordance with green building practices, the new terminal has scope to achieve BREEAM - GOOD certification, but a BREEAM - VERY GOOD certification will be expected in 2026, following the inauguration. For this project the airport received incentives from Lithuanian government, which supports around 4 million euros in the total budget.

Additionally, the remaining part of the demand might be satisfied by RES-produced energy, resulting in a carbon-neutral project.

2.2 Planned Mobility Solutions

After discussing already implemented and short-term planned projects concerning the internal side of airport mobility, the focus below is shifted to future projects and targets, including involving external partners.

2.2.1 Copenhagen Airport (CPH)

Currently, the airport's main focus is to plan for the conversion of internal fleet equipment in the short term and ensure that all other stakeholders operating at the airport fulfill aligned goals. The plan is to replace approximately 70% of the fleet vehicles and motorized equipment with electric alternatives by 2030.

To improve mobility solutions, Copenhagen Airport is investing in conversion of equipment, especially the landside terminal buses will be the main focus to get electrified. All 21 diesel buses providing landside transportation are to be replaced by 2027.

Figure 8 - CPH Zero Emission vehicle

The target of CPH Airport is to achieve Net Zero emissions by 2030 from both Ground Support Equipment (GSE) and surface assess transport to and from the airport. The GSE group continuously works on raising the percentage of electric vehicles inside the fleet. Aims to both handling the internal equipment rates as well as the collaboration with all the stakeholders operating within the airport. Every stakeholder has the responsibility to report on the progress and the ambitious timeline is 2030.

2.2.2 Fiumicino Airport (FCO)

Among all the mobility projects on which ADR is involved, there is the Commuting Work Travel Plan (CWTP) for FCO Airport to optimize mobility and people transport options. It includes several initiatives currently under in-depth study and development, such as integrated public transport subscription together with Local Trasport Companies, with micromobility partners and with local Railway Manager Company. Also, the plan will include more facilities for private electric vehicle charging stations and the implementation.

ADR is also working to make a gradual transition of the operational fleet from internal combustion engines to electric and HVO.

2.2.3 Vilnius Airport (VNO)

The airport has begun implementing sustainable mobility initiatives, which are set to continue until their planned completion in 2027.

One is the transport renewal program (equipment and vehicles), that is, an ongoing initiative started in 2022 that will end in 2028. The aim of the project is the renewal of airport vehicles and equipment through purchases and leases. The vehicles in scope are cars for operational lease, tractor implements, lawnmowers, tractors, snowploughs, dump trucks, snow blowers, firefighting trucks. More specifically, the number of vehicles involved are the following, all in the EURO 6 emission standard, except for fire trucks, which are EURO 5, and mainly fuelled with diesel and gasoline: 40 cars (50% of them is actually HEV), 8 snow removal vehicles,1 chemical reagent spreader, 2 snow removal rotors, 2 sweeping and suction vehicles, 3 tractors, 2 bobcats, 4 fire trucks and 2 dump trucks. Also, three-year long-term rental plans have been made for several operational vehicles in the domestic fleet. In detail, 2 electric cars, 2 hybrid cars, and 6 hybrid SUVs have been leased since 2023; while 4 diesel SUVs, a minibus, and a truck have been completely replaced with new, more efficient vehicles. In 2023, thanks also to the replacement between 2019 and 2021 of 3 combustion engines, one tractor, and two airfield sweepers, CO_2 emissions were reduced by 5.8 tons.

In total, this program covers 95% of the airport's committed mobility resources, with an employed budget of 15.1 million euros, a payback period of more than 10 years, and an NPV of 10 million euros. The main environmental benefits refer to lower maintenance-related overhead costs and reduced emissions of CO_2 and other pollutants such as CO (carbon monoxide), HC (hydrocarbons), NOx (nitrogen oxides), PM (particulate matter). The KPIs used to measure the progress of project goals are kilograms of pollutants emitted measured through analysis of critical equipment exhaust gas emissions. It is predicted that the average annual amount of pollutants emitted in the period 2027 - 2030 will be less than 800 kilograms for CO, 60 kilograms for HC, 400 kilograms of NOx, and 5 kilograms of PM and about 380,000 kilograms of CO_2.

Furthermore, there is a project about the purchase of new electric buses, starting in 2024 and concluding in 2027, and the main actors involved are Airport management and the companies providing ground handling services that operate buses. The project aims to purchase passenger-friendly and nature-friendly passenger buses to ensure uninterrupted passenger service and airport operations of VNO. The current bus fleet is operated by companies that provide ground services in the airport area. It is technologically obsolete, polluting, and does not meet the airport's obligations in terms of reducing CO_2 emissions. With polluting ground transportation, the commitment to become a zero-emission airport under the Airport Carbon Accreditation cannot be achieved. In addition, outdated technology reduces passenger satisfaction with airport services. The project involves the purchase of 12 electric buses (3 more will be purchased in the 5 years following the project), with charging stations powered by the city power grid. The total project budget is about 8.3 million euros, with a payback period of more than 10 years and an NPV of -0.6 million euros and an IRR of 5.96%. The environmental benefits are mainly the reduction of CO_2 emissions, monitoring as a KPI the reduction of CO_2 emissions generated by the diesel buses used by the partners by at least 58,000 kg of CO_2 per year.

Additionally, Vilnius Airport is promoting sustainable mobility with the installation of 17 new electric vehicle charging stations, each equipped with two 22 kW plugs, in a short-term parking area. In the long term, the airport plans to expand its electric bus fleet between 2026 and 2027.

Looking ahead to 2030, Vilnius Airport aims to develop a hydrogen infrastructure for both aircraft and ground transport, while simultaneously adapting aircraft stands to accommodate hydrogen and electric aircraft.

The ground fleet (airfield maintenance vehicles and other light vehicles) is planned to be completely electrified by the year 2030, possibly including hydrogen fuel cell vehicles as an alternative solution to common Battery Electric Vehicles (BEVs). Within the framework of the INTERREG project, by 2029 a dedicated working group will collaborate with the heavy vehicle manufacturer to modify and test a hydrogen-powered snow plowing machine. It will also analyse and test the infrastructure changes needed for such fuels. If the project is successful, consideration will be given to installing a hydrogen supply infrastructure and gradually upgrading heavy-duty vehicles to vehicles running on hydrogen.

2.2.4 Planned new Warsaw Airport (CPK)

CPK has developed a strategic plan for the transport system, which is divided into several initiatives by time intervals.

In the period from **2025 to 2028** CPK is going to develop the following initiatives related to the transport system:

- Cooperation with existing Transport Organizations
- Providing transportation services for the construction workers and early employees
- Preparing a running bus network for the opening day
- Promoting sustainable travel methods for employees
- One ticketing system for buses in the region.

One of the projects in the short term is developing the regional bus network, that is a solution with lower cost, bigger flexibility and a better impact on the Region. CPK should develop a sustained approach to funding local bus services that correspond to key staff and passenger catchment areas.

CPK will introduce an on-demand bus service for employees that will be complementary to regional bus network. The service can be either provided by CPK or bought as a service, and it will be dedicated to the users from smaller villages in the region that are not in the catchment area of the regional bus lanes. Small buses should allow 10-15 people to commute with each ride. The buses can be used as an Airport Shuttle or Parking Shuttle outside of employee peak hours.

The initiatives planned from **2029 to 2034** are reported below:

- Rail access for both passengers and employees
- Cooperation with Railway operators
- Continuous cooperation within Regional Transportation Forum
- Inclusion of the Airport City into the Surface Access Strategy
- Introducing parking and kerbside policies.

At this stage, the first step involves the development of rail connections in cooperation with the rail operator to ensure a convenient, accessible and reliable service for employees and passengers, through future cooperation within the regional transport forum should be further developed.

Car sharing will also develop more during this period. Consideration should be given to whether there should be only one authorized operator with designated parking spaces or an open market with the same rules for all operators. Whether to promote Zero Emission Vehicles and whether to provide additional charging spaces for car sharing, especially considering the fact that no more gas-powered cars will be sold in the EU from 2035 onwards.

Finally, for the period from **2035 to 2044**, CPK planned the following initiatives:

- WKD regional railway line extension
- Further cooperation with Railway operators
- Continuous cooperation within Regional Transportation Forum
- Additional support of the Airport City into the Surface Access Strategy.

The most important initiative on this time horizon will be the planning and construction of the extension of the WKD regional railway line, a fast and frequent rail transport service that currently connects Warsaw and Grodzisk. The project will enable the development of the aerotropolis in the vicinity of the airport and create many living spaces for airport employees. It will also open new areas along the WKD line where employers in CPK or the airport city can look for more specialized employees. It will analyze whether it is necessary to create a surface transport brand similar to other airports and create new regional bus lines for employees and passengers[4].

2.3 Key conclusions

Sustainable mobility is a key issue for airports as they seek to ensure efficiency in the transportation of cargo and passengers, facilitating their transit both within the airport's boundaries and for reaching the airport from different areas of the surrounding region.

There appears to be a great deal of commitment on the part of airports, which create detailed and well-implemented sustainable mobility plans, increasing the efficacy of the solutions already in place while possibly incorporating new ones, either through self-funded investments or through agreements with third parties and public agencies.

3 Energy Efficiency Projects

This chapter provides an overview of energy efficiency projects undertaken at airports, highlighting measures taken to reduce energy consumption, optimize operations and support sustainability goals, with the aim of achieving measurable improvements in energy performance through advanced technologies and innovative solutions.

3.1 Current Energy Efficiency Projects

This first part introduces an overview of the energy efficiency projects undertaken, placing them within each airport's decarbonization roadmap. In particular, projects of both expansion and integration and replacement of energy-intensive equipment with competitive, energy-forward performance design will be illustrated. Where possible, they will be related to targets where they are clearly set.

Regarding the airports in Copenhagen, Rome, and Vilnius, numerous initiatives have been implemented to optimize energy systems and reduce overall energy consumption. In contrast, Warsaw CPK, which is still under construction, is being designed to meet the highest standards of energy efficiency, and therefore, no projects have been implemented today.

3.1.1 Copenhagen Airport (CPH)

Copenhagen Airport has started testing new and advanced solutions to further investigate the potential to operate as a smart energy hub. By producing and smartly distributing electricity, CPH Airport can significantly reduce energy consumption during peak times, improving reliability and operational efficiency.

As regards Copenhagen Airport, most of the heating power needed is satisfied by district heating. The airport continuously strives to optimize the systems to reach higher efficiency rates, with some waste heat recovery options to be analyzed. Central to the efforts of the past 3-4 years has been the involvement of the Commissioning department in all projects to ensure that the energy performance of the facilities can be tracked. Previously, the challenge was mainly addressed through the in-house Energy Management department, but with the latest collaboration, there has been greater success in the improvements brought forward, precisely because of the ability to unify the engagement of both in the commissioning phase of each project, in line with the requirements of the departments involved that keep track of the system.

In 2023, the airport completed a project related to the replacement and management of airport indoor lighting and aircraft stand lighting. The old light sources were replaced, implementing a more energy-efficient LED solution also throughout the airport, including intelligent light control systems that also allowed more branched control of faults and inefficiencies. In detail, the intervention involved all aircraft stand lighting and more than 5,000 lights in passenger areas, illuminated outdoor areas and along runways and taxi lanes, yielding considerable savings. Moreover, to save more energy related to lighting systems, CPH has started to turn off lights in passenger areas during night hours when there is no activity. The stakeholders involved in the project included the internal airside operations departments, as mentioned earlier for the internal project, as well as the energy management department. Additionally, the component supplier, the installation contractor, and the BMS provider were involved. The areas and systems affected by the interventions included apron lighting, the BMS, and the energy management system, with the replacement of LED lighting and the setting of BMS colors. The energy savings amounted to approximately 835 MWh. This type of project is not scalable at this airport, but it will be for its expansion or another airport facility. The major environmental benefit was the reduction of emissions by about 45 tons of CO_2 per year. The main KPI used to measure the success of the project is the kWh/year consumed.

3.1.2 Fiumicino Airport (FCO)

Several energy efficiency projects have been undertaken at Fiumicino airport, including air conditioning system upgrades, lighting systems revamping through LED systems installation, optimization of mechanical systems, expansion of the measurement system and other-nature initiatives.

Some projects have also been evaluated by Green Building Council's LEED certification, achieving "LEED GOLD" as building design as for the "Baby Gate", the airport Kindergarden dedicated to airport employes' kids, or the Pier A and B.

Figure 9 - Airport Kindergarten

Figure 10 - New Pier A

This is a remarkable achievement, because it highlights the attention given to occupants' comfort, starting from the chosen materials, indoor air quality and energy efficiency at its highest level.

One of the KPI that ADR uses to monitor the effect of the actions taken to reduce its consumption is the kWh/pax*m² KPI that monitors the energy efficiency in relation to the number of passengers and the airport area. The trend of this KPI is illustrated in the graph below:

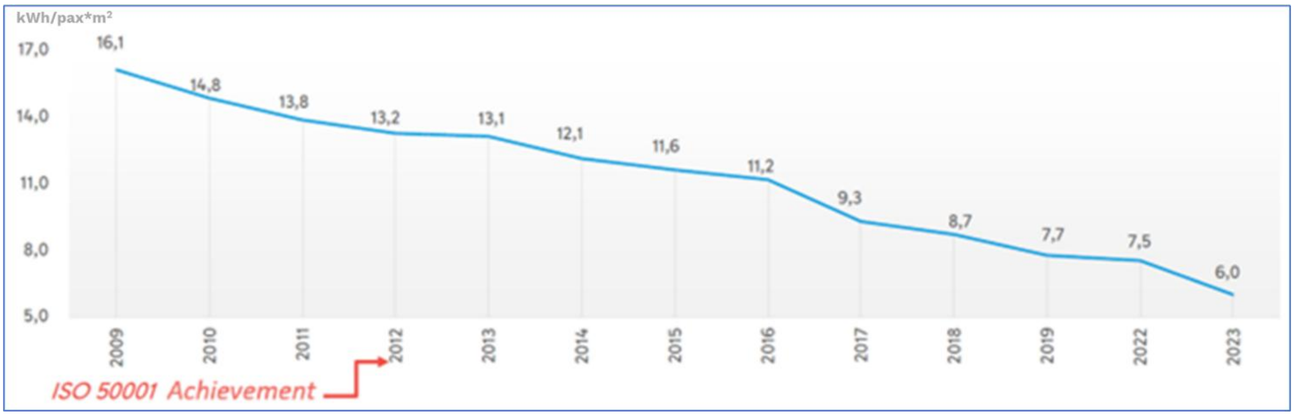

Figure 11 - Energy performance indicator - FCO. Period 2009-2019.

The kWh/(Mpax*m²) indicator was approximately 6.0 kWh/(Mpax*m²) in Fiumicino in 2023, 22% lower than in 2019, thanks to the numerous energy- saving actions implemented at plants and in systems. Fiumicino airport was also the first airport in the world to have joined The Climate Group's EP100 initiative, a global energy efficiency initiative that brings together over 125 ambitious companies committed to improving their energy efficiency.

3.1.3 Vilnius Airport (VNO)

In 2023, electric consumption decreased by 70.6 MWh to thermal consumption by 1,755 MWh, for a total Scope 2 emission reduction equal to 190.9 tons of CO_2. All this was made possible by the implementation of a BMS in 2020, subject to continuous upgrades and adjustments, gradually connecting the various parts of expanded airport infrastructure as Terminal T4 will be. In addition, energy audits are carried out every 4 years to keep track of the energy KPIs and overall consumption inside its boundary. No use of waste heat recovery and energy storage systems is currently planned, and HVAC systems are subjected to periodic technical inspections every three years to ensure proper operation and monitor component aging also to prevent energy leaks. In addition, energy audits help to quickly identify inefficiencies and target interventions to be implemented.

The lighting system efficiency program, initiated in 2017, led to the replacement of all lamps at VNO with new LED devices between 2020 and 2021, and along the runway during its reconstruction in 2017. This program resulted in annual savings of approximately 92 MWh of electricity and the avoidance of 35 tons of CO_2 emissions. During the reconstruction of the passenger terminal, the airport updated the lighting devices and their control systems as well. LED lamps (236 units with a consumption of 227.41 MWh) were installed instead of halogen lamps (total consumption of 640.58 MWh), controlled by a pre-arranged operating schedule and motion sensors. Energy savings amounted to around 413.17 MWh, with a CO_2 reduction of approximately 256.14 tons per year. The total budget was around € 78,876, with a payback period of 2 years. The main KPI used to measure the project's success was lighting energy efficiency.

One other project in the net zero strategy implementation plan is the construction and installation of the new T4 departure terminal, started in 2023 and estimated to serve on average 2,400 flights per hour in the departure direction, involving the only airport management and incentivized by the government, that provided 4 million euros out of 46.8 million euros of allocated budget. This initiative aims obtaining Green Building BREEAM "GOOD" Certification, which is also a performance indicator as regards project success and overall performance. However, given that it is overperforming the expectations, it is candidate for the BREEAM "VERY GOOD" Certification to be obtained in year 2026, after the opening of the new departure terminal. This is also thanks to the combination of the decarbonization initiatives together with energy efficient design that has been studied for the new construction. More specifically, the T4 departure terminal completion will be accompanied by a solar power plant installation on the rooftop, to generate renewable electricity (having a rated peak active power of 488 kW_e), together with the installation of multiple electric vehicles charging stations. Additional areas targeted within the project's scope include heating, ventilation, and air conditioning (HVAC) systems, as well as lighting systems. These have been meticulously designed to incorporate the most advanced technologies, prioritizing energy efficiency. In particular, the heating system is expected to be automatically controlled based on the data from an outdoor climate sensor, adjusting the indoor set-point in response to external air conditions. As for the lighting system, it will be controlled using a timed on/off regulation, designed according to flight frequency and occupancy levels.

The expected energy savings for the T4 terminal are projected to be nearly 33% compared to the baseline, which is 2 GWh/year (approximately 666.67 MWh/year less than the benchmark). The NPV for the VNO program is 1.8 million euros, with an IRR of 8.90%.

Also addressing aircraft mobility within the airport, tons of CO_2 emitted for de-icing operations are reduced by installing dedicated stations and recycling wastewater (intervention completed in 2023).

3.2 Planned Energy Efficiency Solutions

Now the projects planned for the medium to long term will be outlined, aiming to accomplish the targets set by each airport and to complement and continue what has already been achieved or is in progress, as enunciated in the previous paragraph.

3.2.1 Copenhagen Airport (CPH)

CPH Energy Management department has set goals of reducing 3 GWh every year to 2030 on electricity consumption. On other levels, the airport is currently working on separate goals.

The Copenhagen district heating systems aims to become carbon neutral by 2025, while CPH plans to gradually decommission its gas-fired boilers, starting with the largest one by the end of 2026. This initial action is expected to eliminate 55% of the airport's natural gas consumption, benefiting the surrounding community.

3.2.2 Fiumicino Airport (FCO)

The renovation of the boarding area A1-10 (Pier D), part of the broader Fiumicino Sud completion plan and planned for the 2025-2027 period, represents a significant step towards optimizing the service level of the boarding system. The objective is to fully comply with current regulations, with a particular focus on fire prevention, seismic improvements, and decarbonization goals, thereby upgrading the infrastructure to the highest safety and sustainability standards.

Additionally, the project aims to enhance operational capacity, improve the passenger experience by expanding spaces dedicated to commercial services, and elevate overall perceived quality, making the boarding area more welcoming and functional. This project involves the replacement of facade fixtures, installation of external shading devices, reduction of energy consumption and the improvement of indoor comfort, opening of skylight and installing rooftop solar panels.

3.2.3 Vilnius Airport (VNO)

VNO reports that as the number of passengers increases, the energy demand will also increase. The Vilnius airport Building Management System (BMS) is undergoing a continuous upgrade process, aimed at improving efficiency, automation, and overall energy performance. This ongoing enhancement involves the progressive integration of new facilities into the system, ensuring seamless monitoring and control of airport infrastructure.

3.2.4 Planned new Warsaw Airport (CPK)

Energy generation continues to be a significant driver of global greenhouse gas emissions. While the airport's entire operational energy demand is planned to be supplied by renewable energy sources in the long term, maximizing energy efficiency remains a critical design and operational priority. To this end, CPK will implement advanced energy and emissions monitoring frameworks, enabling the continuous collection, analysis, and reporting of performance data. These systems will support the identification of inefficiencies and the definition of corrective measures on an annual basis, ensuring the airport maintains optimal energy performance. This data-driven approach will allow for adaptive energy management strategies over time, aligned with best practices in low-carbon infrastructure operation.

The airport's approach to energy efficiency is integrated with a broader sustainable resource management strategy, with a focus on water use and treatment systems. Efficient water management strategies include the implementation of an advanced drainage system to collect and control rainwater, with the goal of minimizing runoff and encouraging natural infiltration. To further reduce potable water consumption and improve the development's sustainability performance, graywater will be reused in selected buildings and facilities, particularly for non-potable applications. During winter operations, a deicing management system will be in place to monitor and control the use and discharge of deicing agents, minimizing associated environmental risks through real-time monitoring and containment measures. These combined systems will contribute to both operational efficiency and environmental protection.

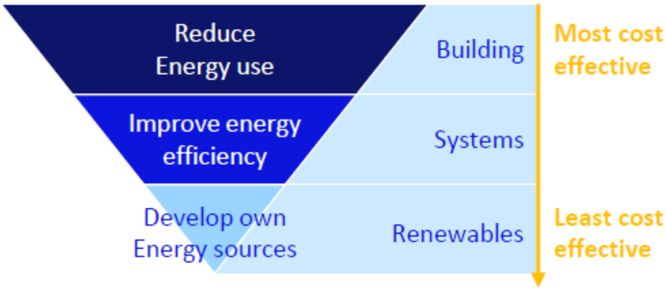

Figure 12 - CPK energy strategy insight

3.3 Key Conclusions

In terms of energy efficiency, the partner airports have already implemented a range of initiatives and have planned further actions aimed at reducing energy consumption. These efforts reflect a strong commitment to improving operational performance and minimizing environmental impact through more sustainable energy practices.

The airport terminals are the primary areas involved in the implementation efforts, given their high energy demand and central role in airport operations.

4 Renewable Energy Solutions

4.1 Current Renewable Energy Solutions

This chapter provides an overview of renewable energy solutions already implemented in the fellow airports, in order to reduce emissions and energy consumption from the grid. RES play a key role in achieving the net-zero goal, as they are implemented to self-generate energy to meet the residual total needs that could not be cut by implementing energy efficiency and sustainable mobility solutions in the airport perimeter.

Regarding the airports in Copenhagen, Rome, and Vilnius, numerous initiatives have been implemented to promote energy self-production and consumption. As Warsaw CPK is still under construction, it is not possible to collect a history of RES implementation. However, there are plans for new systems to be installed upon the airport's completion.

4.1.1 Copenhagen Airport (CPH)

Copenhagen airport has installed mainly roof-based PV plants on the parking houses with power installed around 4.5 MW_P and is establishing a PPA to improve the share of renewable electricity that will contain both PV and Wind energy to cover the airport's consumption levels. The share of renewable energy for CPH Airport increased from 0.2% in 2019 to 2.7% in 2023.

One of the main energy renewable projects is the Roof-based PV plant installation in P1. This is the first installation where the system has not been angled because of the height limit, therefore they are flat mounted. The project involves supplier, contractor, fire and safety management, project management and sustainability SME's. The plant has 760 kW_P of power installed and all the production, around 750,000 kWh, is self-consumed, covering less than 1% of energy demand and it was meant to supply the charging points installed in the very same building. It is not dependent on production of electricity which means charge units can deliver always but adds to the nearest power station when production is available. When there is over production, it will just go to the loop and be used for other consumption needs.

CPH therefore installed a specially built battery of 900 kW power and 1,200 kWh production, resembling 15 refrigerators. The battery can cover around 1% of CPH's daily energy consumption. The idea is to test different scenarios and find the best solution for energy storage that can be replicated and scaled up at the airport[5].

4.1.2 Fiumicino Airport (FCO)

As explained in the previous paragraphs, FCO airport produces its own energy with a cogeneration plant and photovoltaic plant, but it also purchases electricity from the grid. In agreement with its decarbonization targets, the suppling contracts with the external providers do include Guarantees of Origin Certificates for the whole amount of energy purchased.

In the table below are reported the energy consumption from renewable energy sources in 2023 and in the baseline year 2019 for FCO:

ADR GROUP	UoM	2023	2022	2021	2019
Energy consumed within the organisation for the two airports [49]	GJ	852,041	822,419	719,195	902,323
From renewable energy sources [50]	GJ	131,935	71,437	67,859	29,729
Electricity	GJ	601,588	551,984	468,640	596,205
Natural gas and heat from co-generation [51]	GJ	250,453	270,435	249,390	303,062
of which for heating	GJ	163,516	172,717	177,513	167,308
of which for cooling	GJ	-	-	-	-
Diesel fuel for emergency generators	GJ	3,862	3,756	1,165	3,055

Table 3 - FCO energy consumption by sources - AIR 2023

In 2019, energy from renewable sources was 29,729 GJ, increasing to 131,935 GJ in 2023, an increase of 343.79%.

In January 2025 ADR inaugurated a new solar farm near track 3. The plant has an installed capacity of 21.9 MW, characterized by 54,816 modules of 400W each, 164 inverters and 2,340 substructures, 10 MV/LV transformer substations, 1 collection cabin, 4 clusters and 10 subfields.

4.1.3 Vilnius Airport (VNO)

VNO is mainly supplied thermal energy by the Vilnius district heating network controlled by the company JSC. The company is aiming at reaching a share of RES-generated thermal power of 93% by 2026, mainly coming from biomass plants, as a result of their long-term decarbonization strategy until 2040. This has as a direct consequence the almost total decarbonization of thermal energy used by the airport site. Moreover, in accordance with the long-term strategy, plans to increase the share of energy generated by RES from 93% to 100% by the year 2040.

In 2025 the airport finalized the installation of a 488-kW solar power plant on the roof of the new T4 terminal. The plant has a yearly production between 450,000 kWh and 550,000 kWh, all of them in self-consumption and covers the 30% of T4 terminal energy need. The total budget of the project is around 46.8 million euros (4 million euros of them were financed by the LT government support) with a payback of 9 years. The project was aiming for BREEAM - GOOD, and after the opening the airport is expecting BREEM – VERY GOOD in 2026.

In 2020, the VIP terminal and conference center project, which started in 2018, was completed. This project aims to increase revenue, ensure the satisfaction of VIP clients and delegations, and create spaces for conferences and events. It was combined with the installation of solar power plants on the roof of the VNO VIP terminal, with a capacity of 25 kW and an annual production of 22,000 kWh, all self-consumed, covering 14% of the VIP terminal's energy needs. Although power consumption did not decrease, costs were reduced as there was no need to purchase electricity from the grid. Additionally, it saves 0.6 tons of CO_2 emissions every year. The total budget is 3.9 million euros, with a net present value of 0.3 million euros and an IRR of

11.50%. The calculated payback period is 8 years. The key performance indicators used to measure the project's success are the tons of CO_2 equivalent emitted, amounting to 0.6 t_{CO2e}.

4.2 Planned Renewable Energy Solutions and target

This chapter describes the renewable energy solutions that each connecting airport has planned for the medium and long term and the associated targets.

4.2.1 Copenhagen Airport (CPH)

CPH set a goal to achieve a net zero electricity supply by 2030 and is developing a plan to achieve this goal.

This is crucial that the electricity consumed at Copenhagen Airport comes from renewable energy sources to ensure that the current energy-related CO_{2e} emissions are eliminated.

Copenhagen Airport has installed approximately 5 MW_P of solar capacity covering just under 5% of the current consumption and is exploring options to expand our CPH production and acknowledging the need for investments outside of the properties, potentially through a Power Purchase Agreement (PPA). A combination of solar and wind energy, therefore, fits well with the consumption patterns, and by finding the right balance, production can be maximized when needed most.

4.2.2 Fiumicino Airport (FCO)

ADR plans to develop renewable energy production through the construction of multi MW photovoltaic systems, up to 60 MW_P by 2030, also with electrical storage solutions composed of batteries previously installed on vehicles and reused to store the energy produced by ADR's photovoltaic systems.

Another project that recently went to a tender related to RED in FCO airport is the installation of approximately 7.2 MW photovoltaic plant near runway 1, which will incorporate advanced solar trackers to optimize energy production. These trackers allow the solar panels to follow the movement of the sun throughout the day, maximising efficiency and ensuring a higher energy yield.

ADR is also partner of the EU funded project “PIONEER”, that together with Enel X and Fraunhofer Institute, consists in the study and the implementation od the of second-life batteries from various automotive manufacturers into a single power system and applying it to time shifting-use[6].

The aim of this technology is to store excess energy generated during the day by the solar PV system and release it when most needed to cover the airport’s peak energy demand in the evening, when solar energy is no longer available.

This project that includes a total amount of storage capacity of 10,7 MWh, will serve as a proof of concept for using second-life batteries as a cost-effective and efficient energy storage solution.

4.2.3 Vilnius Airport (VNO)

In 2026 Vilnius airport will install a Battery Energy Storage System (BESS) to operate together with the 488 kW_P solar PV plant. The installed BESS power will be 4.5 MW, and a remote wind power plant is also being acquired to connect with this system. In the first year of operation, about 50% of the electricity demand is covered, in the following years it will cover 100% of the VNO and tenants' demand. This project is in combination with the installation of electric vehicle charging stations and is estimated and yearly production of 5,326,967 kWh all of it in self-consumption, that will cover the 35% energy demand, with an associate emission reduction of 2,238 t_{CO2e}. The total budget of the project is 6 million euros and a payback period of 5 years and NPV (for VNO, KUN, PLQ) of -2 million euros and an 6,12% IRR.

The EU Solar Strategy foresees an obligation to install solar power plants on the roofs of all new buildings by 2026 and on the roofs of all existing commercial and public buildings with a usable area of more than 250 m² by 2027.

Starting in year 2025, VNO plans to meet 100% of its energy needs (excluding tenants) by purchasing energy generated from renewable energy sources (RES) and supported by guarantees of origin (GO).

4.2.4 Planned new Warsaw Airport (CPK)

Warsaw Airport will generate approximately 200 MW of photovoltaic energy, which will be complemented by geothermal energy, ensuring a fully renewable and sustainable energy supply without relying on fossil fuels. To maximize efficiency and further reduce environmental impact, the airport will utilize heat pumps powered entirely by domestically produced electricity, optimizing energy consumption.

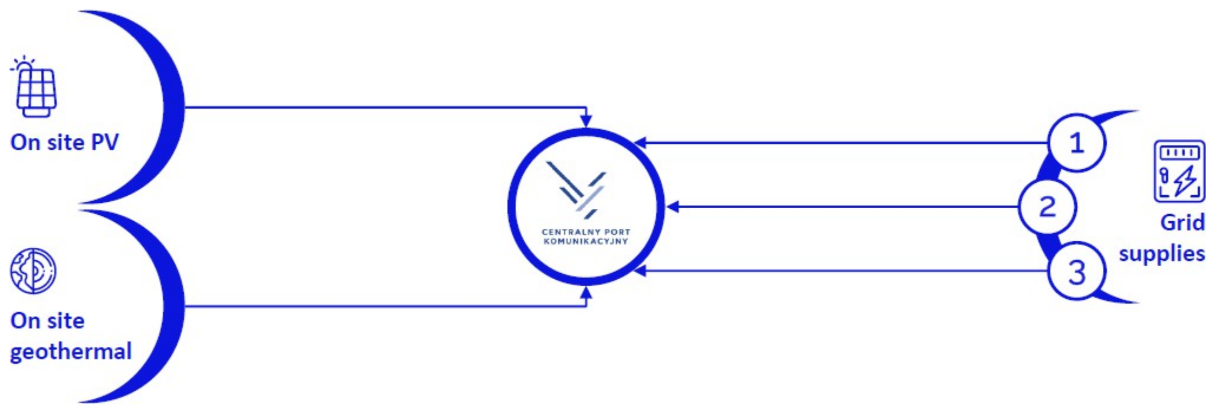

Figure 13 - RES connection, control and management at Warsaw CPK

4.3 Key conclusions

There is a lot of focus and commitment in implementing new technological solutions, and just as much to upgrade equipment to make it less energy-intensive and less CO_2 emitting. Energy management activities prove to be critical to the implementation of projects to achieve the common and individual goals set by each airport authority, and the willingness to stay up to date on new technologies is key to maintaining continuity in innovation. In addition, the implementation of renewable energy systems such as air-to-water heat pumps and photovoltaic systems helps decarbonize the remaining share of consumption downstream of the technological conversion to more energy-efficient solutions. Recalled in this regard are typical interventions to convert ground (and possibly air) vehicle fleets toward the purchase of electric vehicles, for example. On the plant side, on the other hand, we often return to interventions in lighting system replacement, heat generator replacement, monitoring, control and minimization of consumption, virtuous energy practices and circular economy.

5 Examples of Other Airports

This chapter presents the key initiatives undertaken by other airports in the areas of renewables, sustainable mobility, and energy efficiency, providing a benchmark for comparison with the initiatives implemented in collaboration with partner airports.

5.1 Renewable Energy Solutions

Gold Coast and Townsville Airports (OOL)

Gold Coast and Townsville airports, Australia, since 2025 are supplied by 100% renewable energy. Their main consumption is related to airport operations, including lighting, air conditioning, escalators and charging stations amounting to approximately 30 MWh.

The transition is part of a wider strategic plan to achieve net zero emissions by 2030. By using renewable energy, the airports will reduce nearly 90% of their Scope 1 and 2 emissions, based on their 2023 carbon footprint

Indira Gandhi International Airport (DEL)

Delhi Airport becomes the first airport in the nation to run exclusively on hydro and solar power with the goal of achieving Net Zero by 2030. Through a 7.84 MW solar plant located in the airside area and an additional 5.3 MW plant, an estimated 200,000 tons of carbon emissions will be reduced. The airport also signed a long-term power purchase agreement (PPA) with an hydropower company for the supply of hydropower to the airport until 2036.

5.2 Mobility Solutions

Amsterdam Schipol Airport (AMS)

In 2014, Schiphol became the world's first airport to introduce an electric taxi fleet, marking a significant step toward sustainable mobility. Since then, the number of electric vehicles has steadily increased, with nearly 700 electric passenger cars and over 100 electric vans now in operation. Sustainability requirements extend beyond the official Schiphol taxis, also applying to other taxi companies operating from the airport's designated stands. By eliminating CO_2, ultrafine particle, and nitrogen emissions during operation, electric taxis contribute to improved air quality in and around the airport.

Toulouse-Blagnac Airport (TLS)

In December 2023, Toulouse-Blagnac Airport inaugurated the first European station for the production, storage, and distribution of green hydrogen located within an airport area. This project, developed by HYPORT (a joint venture between ENGIE Solutions and AREC Occitanie), includes an electrolyzer, two refueling stations, one airside and one land side.

The infrastructure is designed to fuel up to 20 buses or 200 light vehicles per day using only renewable energy from local networks.

Currently, five hydrogen-powered buses operated by Transdev are in service four dedicated to the airport and one used for Airbus employee transport.

5.3 Energy Efficiency Solutions

Louisville Muhammad Ali International Airport (SDF)

The airport in Kentucky, USA, has officially inaugurated the country's largest geothermal heating and cooling system, harnessing underground energy to enhance sustainability. Developed over two years with an investment of nearly $22 million, the system is expected to save $400,000 annually in utility costs while significantly reducing carbon emissions. The geothermal field, covering 7 acres between the runway and terminal, comprises 648 wells drilled to a depth of 500 feet (~152 meters). Once drilled, the wells were capped, grouted, and filled with sand and gravel before being sealed with 17 inches of concrete and asphalt, ensuring a level surface suitable for future aircraft parking. By utilizing stable underground temperatures, the system provides efficient, low-emission heating and cooling throughout the year, optimizing energy use across all seasons.

San Diego Airport (SAN)

In 2022, the San Diego County Regional Airport Authority captured, treated, and reused 812,500 gallons of stormwater to heat and cool buildings at San Diego International Airport, reducing the use of potable water for these operations. The stormwater reuse treatment system collects runoff from the Terminal 2 Parking Plaza and stores it in underground pipes with a capacity of approximately 100,000 gallons. The captured water undergoes treatment through high-rate media filters and ultraviolet light before being pumped to a central utility plant, where it is used in cooling towers to regulate the temperature of terminals and jet bridges. Since its inception in 2018, the system has processed and reused over five million gallons of stormwater, contributing to the airport's long-term sustainability efforts.

6 Conclusions

The paper outlined the highlights of the airports involved in the project from the perspective of the efforts made and planned to implement smart energy solutions. After an overview of the energy situations used as baselines, as well as the energy supply methods (sources and carriers involved), the decarbonization targets set were observed and analyzed from the perspective of the ACA score obtained and the three Scopes. A key role is taken by airport decarbonization strategies and roadmaps, official documents containing information on past, present and future situations and dedicated effort in various airport sectors. In particular, it was observed that Fiumicino and Copenhagen airports have achieved already excellent levels of decarbonization, pointing them more easily on the path to net-zero. Downstream of these considerations and the implementation of energy-efficient solutions, partnerships with stakeholders in the world of transportation, entering into PPAs and installing RES systems enables decarbonization of the remainder of energy consumption. The strategies used also aim to find alternative solutions in the hard-to-abate sectors, choosing green district heating systems and heat pumps instead of conventional thermal power generation methods based on conventional fuels.

Once the targets are defined, the focus is shifted to the means of reaching them. In this regard, the sustainable mobility solutions implemented and planned for each airport in their strategies are discussed at length. The focus is on electrification and the search for alternative and sustainable fuels for vehicles on both the landside and airside, installing charging stations for electric vehicles, directing passengers and staff to choose alternatives to the private car for travel to and from the airport, and mitigating internal consumption by using GPUs and units for newer and possibly electrically powered GH operations.

Regarding energy efficiency, both implemented and planned solutions were discussed, outlining a strong commitment from all airport authorities to address current inefficiencies and ensure that any new infrastructure and renovations comply with the highest energy efficiency standards, implementing Best Available Technologies (BAT) where possible. The main interventions carried out include the replacement of obsolete lighting systems and improvements in HVAC systems. Future considerations include efficiency interventions and advanced, comprehensive monitoring and control solutions through Building Management Systems (BMS) to optimize energy flows within airport boundaries, minimizing external inputs. The energy needs will be supplied by renewable energy systems (mainly photovoltaic), in some cases already implemented in other still in the design and planning stages, potentially integrable with storage systems such as Battery Energy Storage Systems (BESS), electrolysers, and fuel cells. Some airports are also considering entering into Power Purchase Agreements (PPAs) with external renewable energy producers to fully decarbonize energy needs.

In conclusion, examples from other airports worldwide were reported, showcasing unique interventions, strategies, and innovations to provide insights and successful, innovative strategies to improve already achieved results and guide future strategies towards new, successful, and already vetted solutions, reducing risks associated with uncertainty.

7 References

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