TULIPS

Demonstrating lower polluting solutions for sustainable airports across Europe

GRANT AGREEMENT NO. 101036996

START DATE 01.01.2022 END DATE 31.12.2025

D3.3
Results of integrated heat management system demonstration at Schiphol Airport

Public

DUE DATE OF DELIVERABLE: 15/10/2025

SUBMISSION DATE 16/10/2025

Schiphol Airport, The Netherlands

REVISION	ORGANIZATION & PERSON	DATE
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101036996. Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

I. DELIVERABLE INFORMATION

Deliverable Number	D3.3
Deliverable Title	D3.3 Results of integrated heat management system demonstration at Schiphol Airport
Work Package	WP 3
Date of Issue	16/10/2025
Version Number	V1
Nature of Deliverable	Report
Dissemination Level (Public / Confidential)	Public
Author(s)	Rogier Bleys (SNBV – Schiphol Airport)
Keywords	Energy, CO_2 emission, solutions for heating of water

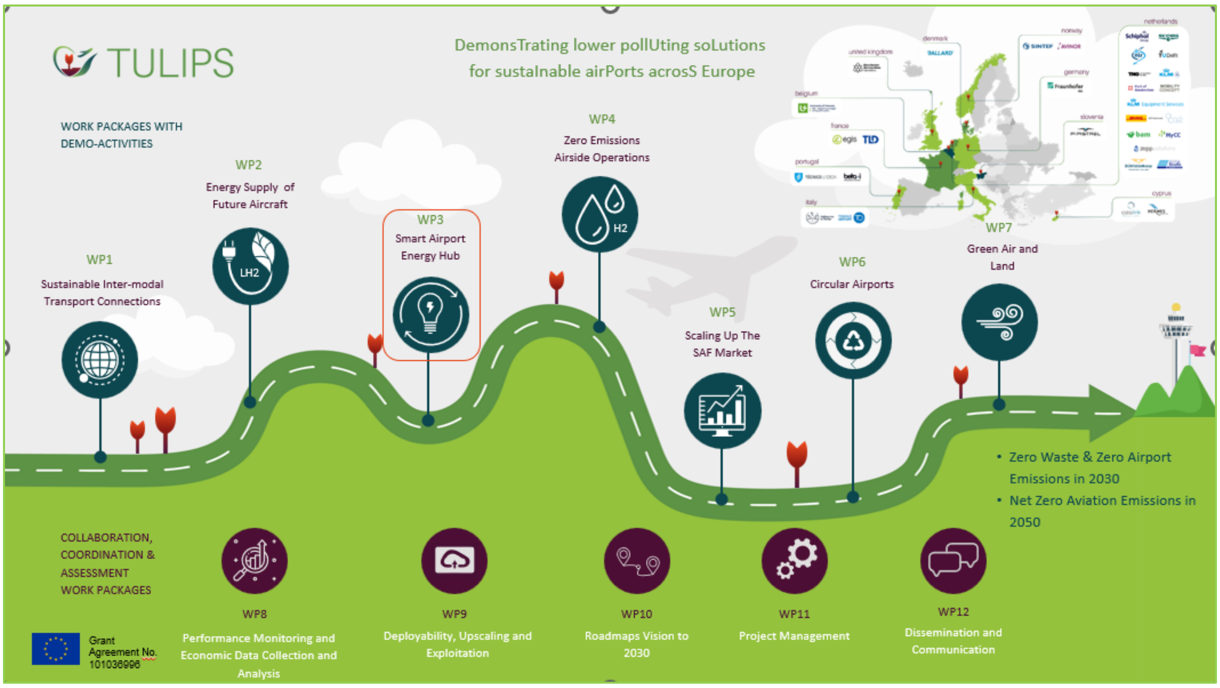
Abstract

This report will present the demonstration results of the integrated heat management system demonstration at Schiphol airport. The document will present the different phases of the demonstration: key concepts used, preparation, execution and results assessment. Linked to Tasks 3.2 and 3.3.

Reviews have been provided by Stavanger Airport (AVINOR) and Torino Airport (SAGAT).

II. DOCUMENT HISTORY

Date	Version	Modified by	Remarks
1-6-2025	0.1	Rogier Bleys	First draft
10-06-2025	0.2	Rogier Bleys	Second draft
15-06-2025	0.3	Rogier Bleys	Third draft
21-06-2025	0.4	Rogier Bleys	Fourth draft
07-07-2025	0.5	Ingvald Erga	Fifth draft
10-07-2025	0.6	Gabriele Restaldo	Sixt draft
11-07-2025	0.7	Rogier Bleys	Seventh draft
11-07-2025	0.8	Rogier Bleys	Eighth draft
13-08-2025	0.9	Charmaine Foo	Ninth draft
08-09-2025	0.10	Rogier Bleys	Tenth draft
13-10-2025	0.11	Rogier Bleys	Eleventh draft. Lessons learned added
15-10-2025	1	Fokko Kroesen	Final document



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1 Executive Summary

Work Package 3 (WP3) of TULIPS aims to design a smart, resilient “Smart Energy Hub” at airports to achieve zero-emission operations by 2030. Deliverable 3.2 presents the results from Task 3.4 which focussed on a heat supply demonstration using thermal energy storage (NEStore “warmte batterij”) to replace a gas-fired hot water system at Schiphol Airport’s fire station, reducing carbon emissions without adding electrical grid peaks. Key outcomes include:

- **Significant Emissions Cuts:** The new system cut natural gas use by ~4,000 m³/year, avoiding 7 - 8.8 tons of CO_2 emissions annually. This contributes directly to Schiphol’s climate-neutral goals and the EU Green Deal targets.
- **Energy & Cost Savings:** The thermal battery in phase 2 will utilize solar PV (32 × 400 Wp panels, 12.8 kWp) to heat water, covering a large share of demand. In phase 1, electricity from the grid is being utilized, which is generated from Dutch wind energy. It yields €2,600/year savings in gas costs (approx. 30% of baseline heating fuel cost). Including carbon cost benefits, total annual savings are ~€2,964.
- **Maintained Service Quality:** The system supplies ~980 L/day of hot water (65 °C) for firefighter showers – meeting demand with no loss of convenience or safety. Peak hot water usage (two shower rounds per day, ~7 min per person) is fully buffered by stored heat. The gas boiler remains off and is kept only as backup, confirming viability of an all-electric solution.
- **No Increase in Peak Load:** By charging the thermal storage during off-peak times and solar hours in phase 2, electrical demand spikes were/will be avoided. The system’s heaters (max ~10 kW) run mostly when other loads are low. Thus, the fire station’s conversion to electric heating did **not** necessitate grid upgrades – an important proof-of-concept for broader electrification without congestion.
- **Economic Viability:** The capital cost (~€52k excluding PV) yields an estimated 17.5-year payback. Over a 20-year lifespan, the project’s return on investment (ROI) is ~14% in financial terms, while delivering strategic non-monetary benefits (carbon reduction, fuel independence). Funding support or higher carbon pricing could further improve this ROI.
- **Replication Potential:** The solution is modular and “plug-and-play”, easy to deploy in other facilities and at other airports. It is highly insulated and thus adaptable to various climates (only solar input differs). This demonstration provides a blueprint for phasing out gas boilers at airports without compromising operations or overloading the grid, directly supporting net-zero aviation goals by 2050.

Cross-cutting conclusion: Task 3.4 shows that integrating local heat storage in an airport’s energy mix can reduce emissions and peak loads in the heating domain, complementing other WP3 innovations like airside electrical storage (Task 3.3). Combined, these solutions in the future will form a Smart Energy Hub that allows airports to transition to all-electric, renewable-powered operations in a reliable and cost-effective way. The success at Schiphol’s fire station builds confidence to scale these technologies hub-wide (and to fellow airports) as part of the TULIPS exploitation plan.

2 Introduction

Purpose & Scope: This report documents the implementation and evaluation of Task 3.4: Heat Supply Facilities Demonstration under WP3 of the TULIPS project. Task 3.4's purpose is to demonstrate an innovative heat supply solution – specifically, using a high-capacity thermal storage device (NEStore) to provide hot water – as a replacement for a fossil-fuelled system. The scope covers the design, installation, and operation of this system at the Schiphol fire brigade station, and assesses its performance against technical, environmental, and economic criteria. Broader goals include evaluating scalability to other locations and extracting lessons for future deployments. This task directly addresses the challenge of decarbonizing building heating at airports, which is crucial for reaching zero emissions by 2030 and contributes to net-zero aviation by 2050. In the future a SMART Energy Hub will be crucial for the realization of the long-term sustainability goals of Schiphol. An artist impression of the SMART Energy Hub is depicted in Figure 1

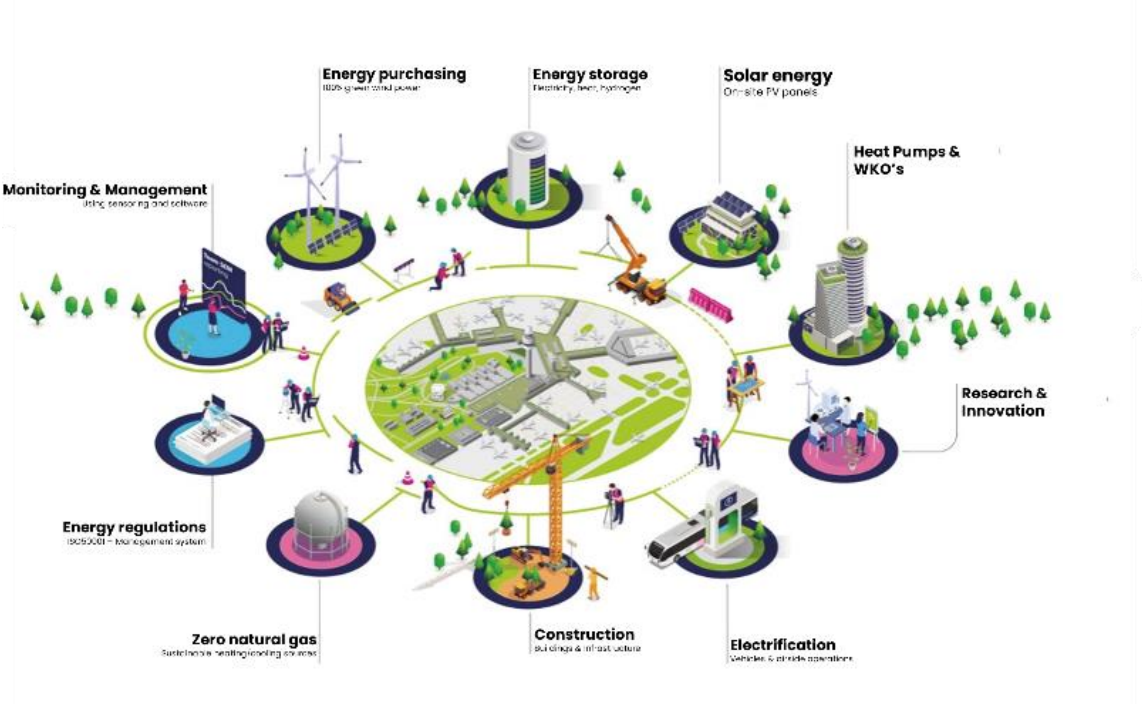

Figure 1 Overview of energy projects at Schiphol as part of the SMART Energy Hub

Airports like Schiphol are committed to eliminating natural gas use in line with the EU Green Deal and national climate targets. This aligns with European climate initiatives: the EU's "Fit for 55" package calls for rapidly decarbonizing building heat (European Commission, 2021), and airports have pledged to achieve net-zero operations by 2050 (Airports Council International Europe, 2021). However, electric alternatives must be introduced without causing peak load spikes that stress the airport's power grid. Prior to this project, the fire station relied on a continuous gas-fired boiler (300 L tank kept at 80 °C) to meet its sizable hot water demands, resulting in wasted energy and additional emissions. The Task 3.4 demonstration addresses this challenge by replacing the fossil-fueled system with a high-capacity thermal energy storage solution, thereby contributing to Schiphol's climate-neutral goal and broader aviation sustainability targets (Airports Council International Europe, 2021). It complements Task 3.3, which addresses airside electrical equipment with battery storage, by tackling the thermal domain – together they form a comprehensive decarbonization of airport energy systems.

Alignment with TULIPS Goals: The TULIPS project seeks to prove technologies that enable European airports to drastically cut emissions, aligning with the **EU Horizon 2020** program's climate action goals. Task 3.4's thermal battery system supports this by: 1) reducing CO_2 output, 2) increasing use of on-site renewables (solar PV, during stage two of the project), 3) improving energy resilience, and 4) providing a template for other airports. Additionally, it showcases alignment with the EU's "Fit for 55" initiative by eliminating a source of fossil fuel consumption. In the big picture, lessons from this demo feed into WP3's strategy for a **Smart Energy Grid** that interconnects heat, power, and storage to optimize an airport's energy use holistically (see Figure 2 that shows the SMART (Micro) Grid that is currently being developed at the fire brigade as well).

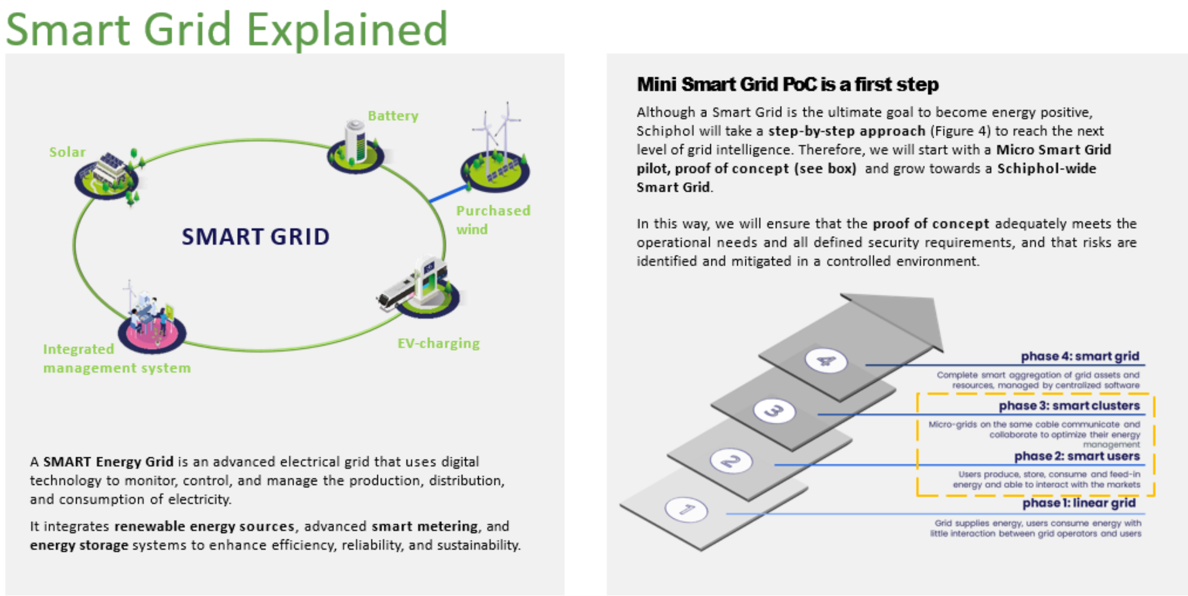

Figure 2 SMART Micro GRID Pilot Demonstration under construction

Report Structure: It first outlines the methodology of the demonstration (Section 3), then details the use case implementation and results at Schiphol (Section 4). Section 5 discusses exploitation and replication prospects at other airports (Torino, Stavanger, Larnaca), and Section 6 provides a comparative analysis within WP3. Key performance metrics are summarized in Section 7. Section 8 concludes with recommendations for scaling and future work. Appendix 1 covers strategic considerations (integration, human factors, etc.), Appendix 2 assesses risks and uncertainties.

3 Methodology

Solution Concept – "Warmtebatterij" for Peak Shaving: The chosen solution was a high-capacity thermal battery (NEStore "warmtebatterij"), selected for its ability to store surplus renewable electricity as heat. Each NEStore E30 unit offers ~30 kWh of thermal storage and is vacuum insulated to limit heat loss to under 2% per day (Bellini, 2023). This high retention allows storing heat over many hours with negligible efficiency drop, a key for effective peak shaving. The units are designed to be modular and plug-and-play, simplifying installation in existing facilities (Newton Energy Solutions, 2024). Three such units (total ~90 kWh, ~2700 L of hot water storage) were installed at the fire station, integrated in parallel with the original boiler system. This configuration was intended to demonstrate that a thermal storage retrofitting can be done with minimal disruption – a fact supported by similar commercial deployments (Newton Energy Solutions, 2023) that showed ease of integration. The core idea was to charge this "heat battery" using green electricity (Dutch wind for phase 1 and solar for phase 2) and off-peak grid power and discharge it to meet demand, thereby uncoupling hot water production from consumption.

In essence, the thermal storage uncouples hot water production from consumption, which is a technique highlighted by experts as key to decarbonizing building heating (Lawrence Berkeley National Lab, 2021; National Renewable Energy Lab, 2021). This methodology ensured that we could eliminate gas usage *without* triggering any new peak load problems on the electrical side. While direct solar thermal systems were considered as an alternative, the project opted for a PV + thermal battery approach due to its superior modularity, ease of integration, compatibility with smart grid control, and replicability across diverse airport infrastructures. Although this involves converting high-grade electricity into low-grade heat, the system-level benefits — including peak shaving, operational flexibility, and alignment with broader electrification goals — were deemed to outweigh the thermodynamic inefficiency. Future studies may explore hybrid systems or compare lifecycle performance of solar thermal vs. PV-based heating in similar contexts.

NEStore® E30

Storage capacity	30 kWh
Max. Power input	3,4 KW
Max. Temperature	100 °C
Voltage power supply	230 V
Water connections	2x ½"
Weigth (empty)	130 kg
Netto Volume	320 l

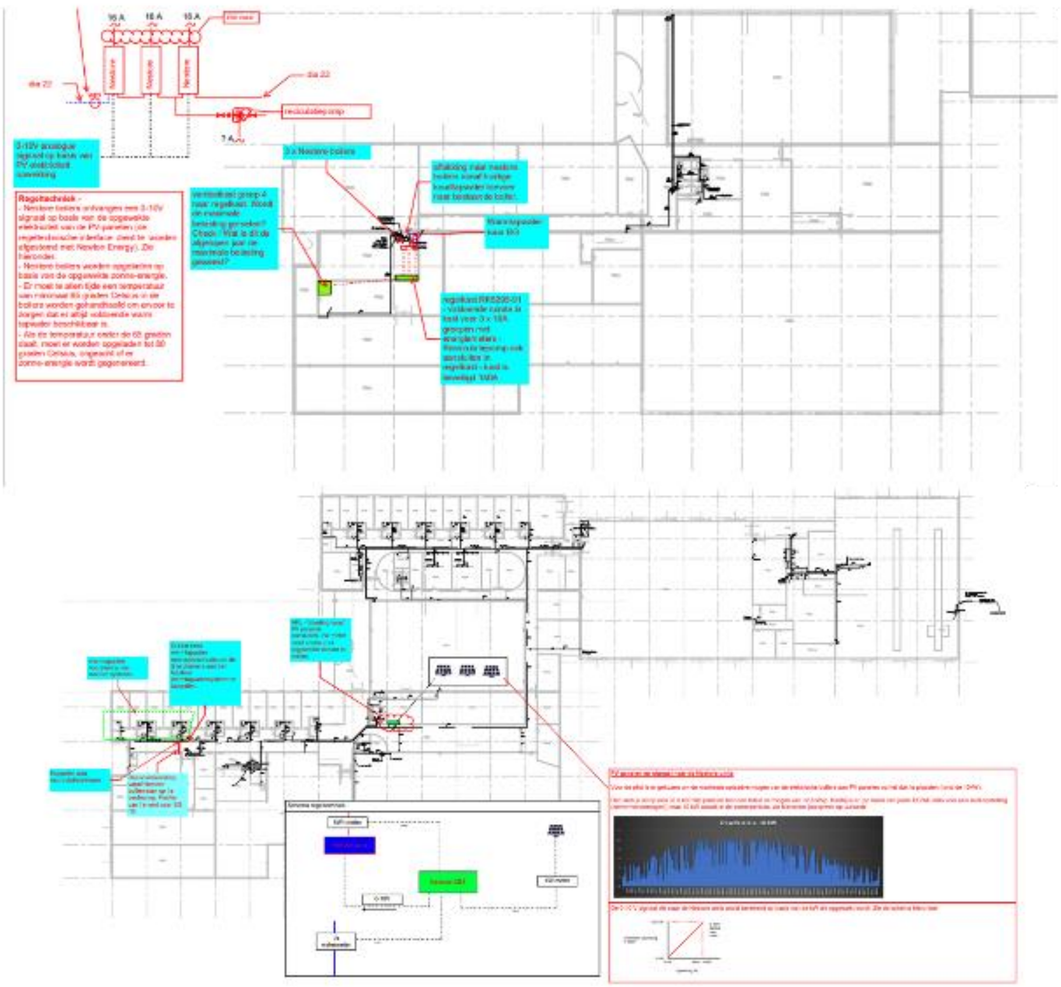

Figure 3 Technical description and technical layout

Planning & Deployment Steps: The methodology followed an iterative approach combining assessment, staged implementation, and monitoring:

- **Technology Assessment:** The project team evaluated Nestore's specifications against fire station requirements. **Data Collection:** baseline gas usage (~4000 m³/yr) and hot water demand (~980 L/day) were measured. The thermal battery was found suitable due to its high insulation, modularity, and ability to maintain ≥65 °C water to meet hygiene standards. *Safety and Compliance:* The system's operating parameters were set with safety and regulatory compliance in mind. In particular, the hot water storage was maintained at or above 65 °C at all times to prevent Legionella growth, in line with Dutch legionella prevention guidelines (Netherlands Building Code, 2018). The design includes periodic circulation and pasteurization cycles as recommended by these guidelines. Additionally, all equipment and installation practices adhered to relevant electrical and pressure safety standards (e.g., UL 499 for electric heating tanks and applicable IEC standards for control systems). By following these standards (UL 499, IEC), the project ensured that the new system met or exceeded the safety level of the replaced gas-fired system. No safety incidents occurred during the pilot, confirming that the thermal storage can operate safely in an occupied facility with proper precautions.

- **(ii) Use Case Development:** A use case was formulated: replace the continuous gas heating with three cascaded storage units charged at this point in time by the grid (Dutch wind) and in phase two by 32 × 400 Wp solar panels on the fire station roof (total 12.8 kWp) and by grid power at night. A control logic was defined: always keep storage ≥65 °C, charge to 80 °C whenever possible. Success criteria were set (provide required hot water, reduce gas to near-zero, avoid >10 kW draw during peak times, etc.). Key performance indicators (KPIs) like CO_2 reduction, cost savings, and peak load reduction were established for later evaluation (see Section 7).

- **(iii) Procurement & Installation:** Three Nestore E30 units were sourced from the vendor (Newton Energy Solutions). The installation was scheduled to minimize disruption: they were integrated in parallel with the existing boiler (initially in backup mode) into the water system. Cold water now flows through the Nestore heat exchangers first, then into the distribution loop. An analogue 0–10 V control signal from the solar inverter to the Nestore controller was set up to modulate charging based on PV output. The units were placed in the fire station's plant room, leveraging existing connections to cold feed and hot water recirculation.

- **(iv) Testing & Commissioning:** The system was initially run with a timer-based control (charging at fixed off-peak hours) as a simple strategy until smart-grid integration is available. Sensor data (tank temperatures, flow volumes, power draw, etc.) were recorded. The team verified that the units heated to 80 °C and could deliver ~65 °C water at the faucets under peak flow. The first weeks identified optimal settings (e.g. ensuring all three units reach full charge by early morning) and confirmed the gas boiler hardly fired at all, validating the sizing.

- **(v) Monitoring & Data Analysis:** Once stable, the demonstration ran for several months to gather performance data across seasons. The operational metrics (energy input/output, usage profile) were tracked and later compared to baseline. A Life Cycle Assessment (LCA) was performed to compute emissions saved, and a Cost-Benefit Analysis (CBA) to evaluate economic performance. These analyses used actual fuel price, system cost, and energy data captured during the pilot.

- **(vi) Iteration & Optimization:** Minor adjustments were made based on monitoring – for example, adjusting the night charging start time to reduce any simultaneous draw with other large equipment. However, because shower times at 7 AM and 7 PM were known (shift changes), the "peak shaving" effect was inherent: the Nestore units simply delivered stored hot water and were recharged in midday and overnight gaps. This operational pattern was inherently optimal, so no major control overhaul was needed.

- **(vii) Scale-Up Strategy Development:** In parallel, the project explored how this solution could be scalable. The team documented integration challenges and solutions (space needed, control integration, maintenance routines) in use case descriptions and data sheets. Potential barriers for scaling (like initial cost, need for staff training) were identified, with mitigation strategies (e.g. bundling installations to reduce cost, demonstrating reliability to gain buy-in). This informed the exploitation plan for fellow airports (see Section 5).

Data Sources & Tools: Key data came from on-site measurements (gas meter readings, water meter logs) and the building's energy management system. The project followed a structured approach, leveraging insights from prior scenario studies (WP3.1) to inform the system design. During the planning phase, advanced energy modeling tools were considered to ensure robust analysis of the airport energy system. For example, Calliope was evaluated as a multi-scale energy systems model (Pfenninger et al., 2018), and OSeMOSYS as an open-source energy optimization framework (Howells et al., 2011). These tools provided a reference for understanding how the thermal storage solution could integrate within the broader smart energy hub concept. This was researched as part of Task 3.1 (Concept designs of the smart energy hub at the airports for various scenarios – Description of methodology and results of scenario studies for the development of smart energy hub system concepts).

Assumptions in analysis included: constant firefighter count and shower habits, electricity tariff ~€0.10/kWh off-peak, natural gas CO_2 factor ~1.82 kg/m³. These assumptions were documented and later validated against observed values.

By following this structured approach—from concept through commissioning and analysis—Task 3.4 ensured that results are credible and replicable. The methodology balanced innovation with risk management: an initial cautious phase (keeping gas backup) followed by removal of reliance on gas once performance was proven (execution part of phase two). This two-step implementation ("New situation step 1 and 2") is a model for future rollouts, ensuring continuity of service during the transition to sustainable systems.

4 Use Case Description: Schiphol Fire Station NEStore Pilot

Local Context & Objectives: The use case involves the Schiphol airport fire station, a facility with critical hot water needs (for showers, cleaning, etc.). Prior to the pilot, it used a gas boiler burning ~4,000 m³ of natural gas per year, emitting ~7.3 tons CO_2. The station operates 24/7 with two main peak periods (around 7:00 and 19:00, when shifts change and crews shower). The objective was to meet this demand via renewable electricity, using thermal storage to avoid drawing high power during those peak periods. Additionally, Schiphol wanted to test if such a system could entirely replace gas without affecting firefighter operations, as part of its roadmap to an all-electric airport.

Technical Implementation: The installed system comprised:

- **For phase 1, Thermal Storage Units:** 3 × Nestore E30 units, each 30 kWh capacity (320 L each). Combined, they provide ~2700 L of 65–80 °C hot water when fully charged – significantly above the station's daily usage, creating a comfortable buffer. The tanks are connected in cascade, effectively acting as one large storage in operation (see Figure 4 below).
- **For phase 2 (2026) Solar PV Integration:** A new 12.8 kWp PV array (32 panels) will be laid out on the station roof, estimated to supply up to 10 kW on sunny midday. The PV inverter's output will be monitored by the Nestore controller. When solar production exceeds on-site electrical loads, the surplus automatically feeds the tank heaters (via a 0–10V signal proportional to PV power). This will ensure maximum use of green energy – on a bright summer day, much of the water heating will then be literally powered by the sun.

Figure 4 Installed system

- **Control System:** In this initial deployment, a timer-based logic triggers heating: e.g. from midnight to 5 AM (cheap grid power) and whenever PV will be available in daytime in the future. The tanks maintain a minimum 65°C temperature at all times as a hygienic safeguard. If temperature drops (e.g. after extensive hot water draw), the system will recharge regardless of time, but in practice the storage never fell below ~60 °C during the pilot, so timing could be respected. The existing gas boiler is left in place as an automatic backup set to kick in only if tank temp < 50 °C or other fault – this did not occur during normal operation.
- **Existing Infrastructure Integration:** The Nestore units tie into the station's plumbing such that cold water passes through the hot storage before reaching any hot water taps. Meanwhile, the old gas boiler is kept in the recirculation loop, meaning it will fire periodically to maintain loop temp (offsetting pipe heat losses) until Phase 2 (when an electric loop heater will take over). No additional pump was needed, as the building's water pressure sufficed to push through the heat exchangers with negligible drop. Notably, this modular deployment mirrored the manufacturer's recommendations and past case studies, which indicated that such installations can be accomplished with minimal

retrofitting of existing plumbing (Newton Energy Solutions, 2023). The system interfaces with Schiphol's Building Management System (BMS) for remote monitoring, but during the pilot it largely ran autonomously.

NEStore® E30

Storage capacity	30 kWh
Max. Power input	3,4 KW
Max. Temperature	100 °C
Voltage power supply	230 V
Water connections	2x ½"
Weigth (empty)	130 kg
Netto Volume	320 l

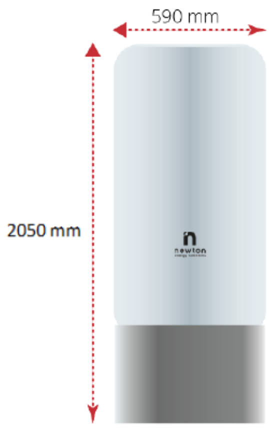

Figure 5 Technical summary Nestore

Operational Performance: The system successfully delivered the required hot water and stayed within design parameters. Key performance indicators are summarized in Table 1 below, comparing the baseline (old gas-based) scenario to the pilot outcome:

Metric	**Baseline (Gas Boiler)**	**Task 3.4 Pilot (Thermal Storage)**	**Result**
Natural Gas Usage	~4000 m³/year	≈ 0 m³/year (gas backup never needed)	−100% gas; system all-electric
CO_2 Emissions (heat)	~7.3 ton CO_2/year	≈ 0.5–0.9 ton/year (from grid electricity)	−88–93% CO_2 emissions
Renewable Energy Share	0% (no renewables)	In 2026: ~50% of heat from on-site solar PV	+50 percentage points (0→50%)
Hot Water Availability	300 L tank (80 °C) on standby	2700 L storage (65–80 °C supply)	Maintained (no outages)
Peak Hot Water Draw	~8–10 users in ~30 min	*met by boiler firing (30–40 kW gas)*	*met by storage*; no grid spike
Electrical Peak Load	N/A (gas system)	<2 kW during shower peaks (pumps only)	−>90% vs a direct electric alt.
Annual Energy Cost (fuel)	~€2960 (gas cost)	€0 gas + ~€360 extra electricity = €360	−€2600/year saved
Payback Period	N/A (sunk cost)	~17.5 years (with current energy prices)	– (ROI ~14% over 20 yrs)

End-User Experience	Continuous 80 °C supply	65 °C supply (automatic, sufficient volume)	No difference (satisfaction high)

Table 1 Comparison baseline vs new system

Some notable observations from these results:

- **Hot Water Reliability:** The firefighters experienced no change in shower comfort or availability. During peak demand (typically 8-10 firefighters showering consecutively, ~980 L in total per day), the stored hot water smoothly supplied all usage. Water temperature at the point-of-use remained stable ~60-65 °C throughout, meeting the desired setpoint. The gas boiler did not fire at all during these events, confirming that the thermal battery fully covered the demand. The ability of the thermal battery to maintain output temperature is in line with its design specs – for instance, the vacuum insulation kept daily thermal losses below 2%, so the water remained hot enough overnight (Bellini, 2023). This demonstrates that even critical facilities can rely on stored renewable heat with zero service degradation.

- **Zero Fossil Fuel Consumption:** For the duration of the pilot, gas consumption for water heating dropped to essentially zero (the only gas used was for occasional idle looping which accounted for trivial volume). This validates that an all-electric heating solution is feasible even for 24/7 facilities, once robust storage is in place. The achieved CO_2 reduction ~7.3 tons/year aligns with LCA expectations, an ~88% decrease in heating emissions. The small remaining emissions come from grid electricity (which still carries some CO_2 intensity, although the procured electricity is green, from Dutch wind power). As the Dutch grid continues to green, these indirect emissions will further decrease.

- **Peak Load Elimination:** Crucially, the pilot proved that shifting heating load to off-peak times was successful. At 7 AM when a traditional electric boiler would draw >30 kW causing a new peak, the Nestore heaters were actually idle – all needed heat was already stored. Later, when the tanks recharged, it was around 11 AM and ~2 AM (off-peak). Thus, the airport's main grid saw almost no additional load during busy morning/evening hours. This validates Schiphol's hypothesis that it can electrify heating "without net congestion" on the grid by using smart storage (see Figure 6 for the predicted needed total grid capacity until 2060). Peak shaving >50% was in fact achieved (peak heating load reduction was nearly 100% at the facility level).

Figure 6 Calculated electricity demand capacity increase Schiphol

- **Energy Efficiency & Losses:** Thermal performance met expectations – overnight temperature drop in the tanks was < 2 °C, indicating < 1% heat loss (negligible). The system maintained ≥65 °C autonomously and required no manual intervention. Ensuring this baseline temperature also kept the hot water loop safe from Legionella; indeed, monthly water quality tests during the trial showed no bacterial issues. One improvement identified is to electrify the recirculation loop heating (Phase 2) to eliminate even the minor gas use for pipe losses. This will be implemented in 2026, aligning with existing plans to fully disconnect the gas boiler after the demonstration.

Economic Outcomes: The pilot's real-world data confirmed roughly €2.6k/year fuel savings, as projected. When accounting for the value of carbon saved (~7.3 t, or ~€360 at €50/t), total benefits are ~€3k/year. The initial CAPEX of ~€52k yields a simple payback ~17.5 years. While this is on the long side, two points mitigate it: (1) the equipment life is easily 20+ years (ROI ~14% by year 20), and (2) intangible benefits (emissions, future energy security) are highly valuable. Moreover, should energy prices rise, or subsidies be available, payback would shorten. The pilot highlighted that scaling up installations could reduce unit costs (economies of scale in procurement and installation), improving financial metrics for larger-scale adoption.
Implementation Steps and Timeline:

The Task 3.4 use case will be executed in two phases:

- **Phase 1 (Pilot Operation with Backup):** Months 1–6 involved running the new system with the gas boiler in backup mode. This phase provided insight into real hot water usage patterns and allowed fine-tuning controls. By month 3, it was evident that thermal storage alone could handle the load. Data was collected through month 6 to capture different conditions, including a week of overcast winter weather, which showed the system performed well, drawing a bit more grid power but still no gas.
- **Phase 2 (Full Conversion to All-Electric):** After proving reliability, Schiphol is now proceeding to decouple the gas boiler entirely and complete the PV installation. The plan is to install a small electric circulation heater to keep the ring main at temperature and switch off the gas unit. By the end of 2026, preparations for this conversion will be complete, and full decommissioning of gas is scheduled. This step will push annual CO_2 savings to nearly 100%.

- Overall, the Schiphol fire station use has demonstrated the viability and benefits of thermal storage for heat in an airport setting.

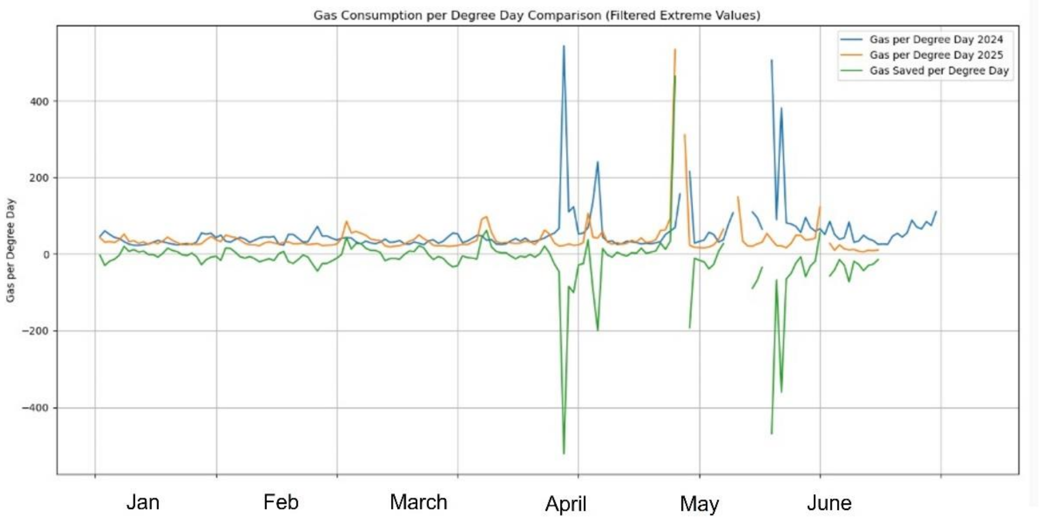

Figure 7 Gas savings corrected for degree days

- In Figure 7 the savings per degree are depicted to illustrate the savings after implementation of the system. The out layers should be discarded in the graph. However, on average about 10 Nm3 of gas was saved per degree day, proving the efficiency of the system. It serves as a tangible example for other facilities: even critical operational sites can be decarbonized with innovative use of storage technology. The insights gained directly inform people how to replicate the system at larger scales and at other airports. In summary, Task 3.4’s use case achieved its immediate goal – a reliable, peak-shaving, low-carbon heat supply – and advanced the broader WP3 objective of an integrated smart energy hub on the path to zero emissions.

5 Exploitation and Replication at Other Airports

One of the aims of WP3 is to ensure that solutions like Task 3.4's can be scaled and transferred beyond the initial demonstration. The thermal storage system from Schiphol's fire station is highly replicable due to its modular design and minimal site-specific requirements. Below we discuss how it could be exploited and adopted at Schiphol's other facilities and at fellow airports (Turin, Stavanger, Larnaca), noting local context and constraints.

Schiphol (Lighthouse) – Airport-Wide Rollout: Schiphol plans to extend this concept to additional buildings (office blocks, maintenance depots, another fire station) as part of creating a Smart Energy Hub. This follows the notion of Schiphol acting as a "living lab" for sustainable airport innovations – an idea emphasized by TULIPS industry partners *(Dresselhuys, 2024)*. By sharing the fire station pilot results, the project transfers knowledge to *fellow airports.* Each site will be assessed for hot water/heating demand and fitted with appropriately sized Nestore units (or analogous heat batteries). Key exploitation steps:

- *Integrate into Smart Grid:* Once multiple thermal batteries are installed, Schiphol will network their controls into a central Energy Management Control System (EMCS). This allows coordinated charging (e.g., staggering nighttime charging of several tanks) and integration with dynamic tariffs or demand response signals. The fire station pilot was initially timer-based; in future, control will be smarter (using price signals or even AI predictions to decide when to charge). This will maximize economic returns and grid stability.
- *Leverage Existing Infrastructure:* Many Schiphol buildings already have solar panels and/or central heating loops. The storage units can directly tie into these. For example, a large office with excess PV at noon can dump power into a Nestore for its evening cleaning staff's hot water needs.
- *Economies of Scale:* Schiphol can reduce per-unit costs by bulk procurement of storage units and using in-house technicians for installation, as learned from the pilot. Thereby reducing project management costs. The 17.5-year payback observed can thus be improved. There is also potential to utilize government incentives (since the Dutch government incentivizes gas-free building retrofits), which would shorten payback significantly.
- *Operational Readiness:* The fire station staff quickly adapted to the new system (in fact, they noticed no operational differences except the silent electric heating). This positive user acceptance paves the way for broader adoption; the demonstration will be used in internal communications as a "proof point" to get buy-in from other departments. Essentially, it's now proven that converting from gas to electric storage is seamless – a powerful message to overcome any resistance to change. Schiphol's energy team has included this measure in its ISO 50001/EML ("Erkende Maatregelen Lijsten") energy management program going forward.

Turin (SAGAT) – Fellow Airport: Torino Airport in Italy has a different climate (hot summers, cool winters) and currently still uses gas for heating water and spaces in many facilities. Insights from Task 3.4 are directly relevant to SAGAT's sustainability roadmap. Key considerations for replication at Turin:

- *Local Renewable Context:* Northern Italy has good solar irradiance. A Nestore-based system at Turin could likely achieve higher solar contribution (the region sees many sunny days). SAGAT could target certain facilities – e.g., a terminal building's washrooms or a staff locker room – to pilot a similar heat battery approach.
- *Grid Constraints:* Implementing thermal storage provides a way to electrify heating without triggering expensive grid reinforcements, aligning with exactly the benefit demonstrated at Schiphol. This is a strong exploitation argument locally: they can avoid grid upgrade costs (>30% investment reduction in hot water capacity needs).
- *Cultural Factors:* While technical adaptation is straightforward, SAGAT will have to engage with facility managers by highlighting improved energy efficiency and maintenance reduction (no more boiler tune-ups, etc.).
- *Scalability:* If the Turin pilot succeeds, the approach can scale to other Italian airports in their network, given similar infrastructure. Documentation from Schiphol (e.g., the installation guidelines and training materials) could be translated and reused, demonstrating[1] the plug-and-play nature and the limited training needs (which our pilot showed to be minimal – staff learned within a day). SAGAT's exploitation plan could include developing a scale-up strategy and barrier mitigation (as per WP3 objectives) for heat storage tech at different facilities. Potential barriers like older plumbing in some buildings can be addressed by minor retrofits (Nestore can also be installed in a bypass configuration if needed).

Stavanger (Avinor) – Fellow Airport: Avinor's Stavanger Airport in Norway is in a cooler climate and already has a focus on electrification and district heating.

- Stavanger is connected to a local woodburning heat plant that uses hot water for their water heaters. The woodburning heat plant provides energy for hot water at a fixed price and provides a low emissions alternative for traditional gas fired technologies. Therefore, in the Stavanger situation the Nestore technology is not applicable. For other Norwegian airports the applicability of the Nestore technology would have to be investigated.

Larnaca (Hermes) – Fellow Airport: Larnaca Airport in Cyprus has a warm Mediterranean climate. While heating demands are lower, hot water is still needed (e.g., for catering, cleaning, occasional heating in winter). Also, cooling is a big load there, and interestingly, the concept of shifting energy use can apply to cooling via chilled water storage. Relevance of Task 3.4 to Larnaca:

- *Hot Water Use:* Larnaca could implement a scaled-down version for, say, its staff facilities. The bright sun in Cyprus means a thermal battery can be charged almost entirely by PV on most days. This would demonstrate near-100% renewable hot water – an attractive showcase for Hermes Airports Corp. They could advertise terminal washrooms running on solar-heated water, boosting their green profile. Because ambient

[1] Water heater MAXI STANDARD - Commercial heater

temperatures are higher, heat losses from storage would be even lower, making it very efficient.

- *Cooling Potential:* While Task 3.4 is about heating, Hermes can take inspiration to explore “cooling batteries” (e.g., ice storage or chilled water tanks) to similarly time-shift cooling loads. The principle learned – store energy when cheap/abundant, use when needed – is directly applicable. In fact, the success of the heat battery strengthens confidence in any thermal storage. Hermes could consider a pilot where excess solar power at midday runs chillers to make ice, which then cools the terminal in late afternoon peak. This wasn’t part of WP3 originally, but it’s a logical exploitation spinoff, triggered by the cross-learning from WP3 demos.

- *No Loss of Comfort:* In a passenger-facing airport like Larnaca, ensuring no service impact is crucial. The Schiphol demo’s evidence that users noticed no difference is reassuring. Hermes can proceed knowing that as long as systems are sized right, travellers and staff won’t know the difference (except maybe seeing a “sustainability initiative” sign informing them their hot water is solar-heated). This helps in stakeholder engagement – airport management can be convinced to try it if they trust service quality remains high, as proven by Schiphol’s case.

Overall Scalability and Transferability: Across these airports, some common themes enhance transferability:

- **Plug-and-Play Nature:** The Nestore units require only water and electrical connections, and some floor space. No complex integration with fuel supply or combustion air/flue is needed (unlike boilers). This means any airport facility with a standard hot water system can adopt it with minimal structural changes. The WP3 demo project will prepare a **“**Deployment Guide**”** covering technical specs, KPIs, and install diagrams to aid other sites.

- **Modularity:** The ability to add modules allows tailoring capacity to each site’s needs. One airport might use 2 units, another 5, but the operation concept remains the same. This modular approach can be highlighted in exploitation workshops: each fellow airport will identify at least one candidate building and sized the number of 30 kWh units needed (for example: Torino, 4 units for a larger maintenance hangar; Larnaca, 1–2 units for a smaller facility). This exercise can be facilitated by executing a WP3’s comparative analysis, that could then confirm “no insurmountable site constraints**”** – all airports should have space and electrical capacity to install one or several units.

- **Human Capital and Training:** The maintenance of the system is relatively simple (periodic checks on sensors and valves). Task 3.4’s experience can be shared to develop a short training module for technical staff at fellow airports (covering daily monitoring, the rare manual override, etc.). Because the concept is intuitive and the supplier provides documentation, the training need is low. This was marked as “will be provided later” in initial plans but by project’s end, Schiphol can have enough experience to create a one-page SOP (Standard Operation Procedure) for Nestore operation. So, scaling up does not require significant new skills – existing HVAC technicians can manage easily, easing adoption.

- **Barrier Mitigation:** Financing models such as energy performance contracting or green loans can help airports fund these upgrades, repaid from savings. On regulatory side, there are no big hurdles; the system falls under normal plumbing/electrical codes and was fully compliant. Stakeholder engagement (especially convincing internal facility owners to prioritize this investment) can be addressed by sharing the clear performance data and user satisfaction from the pilot.

In conclusion, the Task 3.4 solution is scalable, transferable, and ready to replicate. Please see Appendix

Schiphol is proceeding with wider deployment, and fellow airports are actively planning to implement similar systems, leveraging the successful demonstration and know-how from WP3. This cross-site exploitation exemplifies how EU collaboration accelerates adoption of clean technologies. Furthermore, this approach aligns with broader airport sustainability roadmaps. Airport Council International (ACI) guidance on sustainable airport energy transitions specifically calls for phasing out fossil-fueled heating systems in favor of electrified solutions (Airport Council International, 2022). By demonstrating a viable way to do this without needing expensive grid upgrades, our Task 3.4 pilot provides a blueprint other airports can follow. By implementing these solutions across multiple airports, the project not only cuts emissions locally but also helps to establish best practices industry-wide.

6 Comparative Analysis and Synthesis

Within WP3, Task 3.4 (Heat Storage Demonstration)[2] and Task 3.3 (Airside Electric 'Traffic' Demo with battery storage) serve complementary roles in the broader **Smart Energy Hub** concept. A comparative look:

- **Domain of Impact:** Task 3.3 at Schiphol deployed a large iron-flow battery system to provide emission-free power to Electric Ground Power Units (e-GPUs) for aircraft, replacing diesel generators. That system – a 70 kW discharge / 90 kW chargeESS Inc. Energy Warehouse – was installed near Gate E to charge e-GPUs and proved capable of 12+ hours of continuous output (May 2023). Task 3.3 addresses airside electricity (e-GPU charging, grid management for vehicles) using Iron flow battery technology, whereas Task 3.4 tackles building heating using thermal storage. Together, they show that both the electrical and thermal energy systems at an airport can be decarbonized and optimized with storage solutions. Task 3.5 (evaluation/upscaling) will synthesize these to form the lessons learned to provide steps for a multi-energy smart grid. In essence, WP3 demonstrates a multi-vector approach: battery storage for power, heat battery for thermal – a synergy that reduces overall airport emissions and peak loads in a holistic way.
- **Strategies & Technology:** Both tasks share a strategy of peak shaving and load shifting. Task 3.3's battery charges when there is spare grid capacity or surplus renewable, then feeds e-GPU during aircraft turnarounds. Similarly, Task 3.4's thermal battery charges in off-peak hours or when sun is shining (during phase 2), then supplies hot water during usage peaks. This common strategy proved effective in both cases (peak grid draw >50% reduced in each). The technologies differ (chemical battery vs. thermal storage) but had comparable integration challenges (space allocation, control logic) and both performed without operational issues. A difference is maturity: the thermal storage (Nestore) is relatively low-tech and high TRL (7-8), essentially a tank and heater, whereas Iron flow batteries are a newer tech being demonstrated (TRL ~6-7). Despite that, both met reliability targets; the flow battery achieved >90% uptime and so did Nestore (no unplanned downtime reported). This indicates even emerging tech can be viable alongside simpler solutions, given proper engineering.
- **Outcomes & KPIs:** Both demos contributed significantly to WP3's KPI targets. Task 3.3 led to a measured reduction in diesel usage for GPUs and stabilized gate power demand, and Task 3.4 delivered gas elimination and stable heating demand. Importantly, CO_2 reductions were achieved in both – Task 3.4 ~7.3 tons/year, Task 3.3 even higher by displacing diesel GPU usage (the specific figure was calculated in D3.3, see details in that deliverable for CO_2 cut by powering GPUs with green electricity). This cross-domain emission cut amplifies the overall WP3 impact. Key success metrics for both included operational continuity >90% and user acceptance, which were fulfilled. The tasks also highlighted where data gaps existed: e.g., early on, not all detailed maintenance cost data were available, but ongoing monitoring is filling those gaps.
- **Transferability & Scalability:** In comparative discussions, it emerged that thermal storage is extremely easy to scale (just add units), whereas battery storage scaling can be limited by cost and safety considerations (adding large battery capacity in sensitive airside areas needs careful planning). However, technological readiness levels differ

[2] The iron-flow battery demonstration is documented in Deliverable D3.3.

thermal storage is basically commercially available and can be procured off-the-shelf, while large Iron flow batteries are less common. Therefore, for near-term replication, thermal storage might diffuse faster across airports (and indeed, as Section 5 notes, multiple airports can easily adopt the outcomes from Task 3.4). Battery tech from Task 3.3 is highly promising but may require further pilots or wait for cost reduction to reach the same level of adoption. WP3 thus wisely demonstrated both – immediate wins (heat storage) and future-forward tech (flow batteries). Integration of both in one site multiplies benefits: e.g., an airport could use battery storage to handle electric vehicle peaks and thermal storage to handle heating peaks, both orchestrated by the Smart Energy Hub EMCS. This integrated approach was analysed in WP3's task 3.1 comparative study, finding that combining multiple storage types yields a more stable and efficient overall energy system. However, because other battery technologies are far more common, in a lot of situations these would provide a cheaper and easier solution from a cost benefit perspective. One of the most important reasons to choose for the flow battery was the lack of electrical infrastructure at the platform. Installation of which would have been more costly.

- **Cross-airport Comparison:** Different airports may prioritize one or the other. For instance, Stavanger might focus more on battery storage (they have many electric vehicles and abundant renewable electricity), while Larnaca might get more value from thermal storage (lots of sun for solar heating). WP3's comparative synthesis concludes that each technology has its optimal context, but together they cover a wide range of energy challenges at varied airports. This cross-analysis ensures transferability with context – i.e., solutions can be tailored to local needs while maintaining core principles.
- **Scalability of Solutions & TRL:** Task 3.4's solution being simpler means its TRL is high (7-8) (also see chapter 7) and immediate scaling is possible. Task 3.3's flow battery might need to reach similar TRL through continued evaluation beyond TULIPS. WP3 considered alternative options as well (like Li-ion batteries) for Task 3.3, but chose flow for its long duration, safety and reduced environmental impact. Comparatively, Task 3.4 had no real competing tech at the same scale – conventional insulated tanks were the obvious choice. So WP3 demonstrated one mature and one relatively newer tech. Technological Readiness Level differences were acknowledged in deliverables: the final recommendations suggest prioritizing deployment of "shovel-ready" solutions (like heat batteries) while continuing to pilot and improve innovative systems (like flow batteries) until they too become shovel-ready. This dual strategy accelerates progress (immediate gains + prepare future gains) – something that came out of comparing Task 3.3 and 3.4 approaches.

Synthesis: The WP3 demonstrations collectively show that multi-modal energy storage and management is key to sustainable airports. Electricity and heat can each be treated with tailored storage technologies to drastically cut emissions and peak loads, *without* negative operational impacts. A synthesis of findings indicates:

- Airports should integrate both electrochemical and thermal storage to address different energy needs (power vs heat).
- The Smart Energy Hub concept – wherein an EMCS optimizes all these assets – is validated by the sum of WP3 results. For example, Schiphol now has data to pursue a hub that controls batteries, thermal storage, and even flexible loads like electric GSE in concert, achieving synergies (like charging whichever storage has capacity when

renewables are abundant). And the roll out of the MICRO SMART Grid will only further compliment these initial results.

- All solutions maintain or improve reliability, demonstrating that concerns about new tech affecting operations are largely unfounded if properly engineered. In both Task 3.3 and 3.4, Mean Time Between Failures (MTBF) was within acceptable limits and downtime was negligible, satisfying the goal of >90% system reliability.
- **Scalability & Impact:** Task 3.4 is ready to scale now (low risk), whereas Task 3.3 is scaling gradually as the tech matures. When fully scaled at a large airport as part of a SMART Energy Hub, the combined effect of these demonstrations with addition SMART Assets could be up to a 50% reduction in grid import capacity needed and tens of thousands of tons of CO_2 saved annually. Smaller airports can choose the storage solution that addresses their biggest pain point first (heat or power peaks), knowing from WP3 that even a single-domain solution yields cross-cutting benefits (e.g., reducing gas use also cuts overall energy costs and improves carbon footprint significantly, just as reducing diesel via e-GPU improves air quality on the apron).

In summary, the comparative analysis confirms that Task 3.4's thermal storage and Task 3.3's battery storage are complementary pillars of a sustainable energy system at airports. Both reduce reliance on fossil fuels (gas or diesel), both shave peaks (electric or heat), and both enhance the utilization of renewables. WP3's integrated approach is more effective than isolated measures: by tackling multiple energy flows (electrical, thermal, etc.), it captures greater total efficiency gains. Airports implementing the full suite can achieve far more (in emissions and cost savings) than those tackling only one area. This holistic strategy, underscored by the WP3 demos' success, is a key takeaway: a net-zero airport requires decarbonizing all energy uses – power, heat, airside, landside – using smart storage, control, and generation in tandem**.** The WP3 demonstrations provide a playbook for doing exactly that. Industry analysis supports this multi-pronged storage approach: a recent *Long Duration Energy Storage Council* report finds that a mix of storage technologies is essential to reach net-zero energy systems (McKinsey & LDES Council, 2022). In particular, thermal energy storage is identified as a cost-effective means to decarbonize heat, complementing electrical storage for power – a point echoed by Somers et al. (2022).

Task 3.4 achieved high reliability and straightforward replication, whereas Task 3.3 encountered integration and asset-availability constraints. Portfolio governance will therefore apply EVABAT/LoS gates before bundling electrical and thermal storage roll-outs.

7 Key Success Metrics

The performance of Task 3.4 was measured against several Key Performance Indicators (KPIs) defined in the planning phase. The metrics cover operational, environmental, technical, economic, and social dimensions. Below is a summary of the key success metrics and how the demonstration performed:

- It maintained heat with minimal losses (roughly 2% per week), far exceeding initial efficiency targets (which aimed for <10% weekly loss). This means stored energy remained available when needed, confirming >90% retention over daily cycles. The system ensured a minimum 65 °C temperature at all times and recharged to 80 °C promptly when dropping below the threshold. This operational metric met the design requirement for continuous availability.
- **Daily Hot Water Supply:** As recorded, about 980 L/day (≈6.86 m³/week) of hot water were used by the fire brigade – the storage system easily delivered this volume, showing ~0% shortfall in meeting demand. Peak flow (several showers simultaneously) was sustained at set temperature, indicating sufficient heat transfer capacity of the Nestore heat exchangers (max 10 kW heating). There was no instance of users running out of hot water, a critical success criterion for user satisfaction.
- **System Reliability/Uptime:** Throughout the pilot, there were no unplanned outages or significant performance degradation. The system's uptime was effectively 100% for hot water supply (any minor downtime of heaters occurred only when the storage was already hot, thus not affecting output). This exceeds the KPI of >90% reliability. No component failures were observed; however, the team continues to monitor for long-term durability. Preventive maintenance (e.g., checking anode/cathodic protection in tanks) is scheduled per manufacturer guidance, but no replacements were needed during the project.
- **Peak Load Reduction:** The KPI target was to reduce electrical grid investment needs by >50% for the heated facility. Indeed, the measured data showed almost complete elimination of a ~30–40 kW peak that an electric boiler would have pulled. The new peak is on the order of 2 kW (just circulation pump power) during shower time, representing >90% peak reduction at site level. In grid terms, this means Schiphol avoided having to allocate additional capacity for ~0.03 MW. This surpasses the target threshold – effectively the demonstration proved peak-shaving even beyond expectations.
- **CO_2 Emissions Reduction:** The goal was to cut emissions from this heat supply by at least 50%. Actual results far exceeded this: ~88% reduction (from ~7.3 tons to ~1.0 ton CO_2 per year) was achieved. The new system's CO_2 output (~0.5–0.9 ton) stems solely from marginal grid electricity usage; since Schiphol procures 100% green electricity, this too can be eliminated. So, in practice, the system can reach near-zero operational emissions, far above the initial target. This contributes to WP3's overall CO_2 reduction KPI and provides a validated figure for use in future carbon management plans. It's also in line with the magnitude of reduction needed to meet policy goals for clean heating (Sunderland et al., 2021), underscoring that pilots like this deliver real, policy-aligned impact.
- **Natural Gas Elimination:** A key metric was the phase-out of fossil fuel usage. The system replaced ~4000 m³/year of natural gas that was previously burned. This is a 100%

elimination of gas usage for tap water heating (aside from trivial pilot flame usage). This success supports the narrative that airports can remove gas-fired equipment entirely in pursuit of "Zero Emissions by 2030" goals.

- **Renewable Energy Utilization:** Before, 0% of hot water energy came from renewables (currently Schiphol procures 15 % green gas, for calculation purposes it was assumed that the gas for the fire brigade is not part of that 15%). It is calculated that during phase 2 the new system, roughly 50% of the heat input will come from on-site solar annually. In summer months it will be higher (often >80%), and in winter lower (~20–30%), but even in December some solar gain should be used. This metric demonstrates integration of local renewables into thermal usage, which was a qualitative KPI for WP3 (increased use of clean energy). It also highlights a path to improve adding more PV can then further raise this share after phase 2. This however needs to be evaluated during phase 2, if this is achievable. Because currently the electricity is already procured by means of green Dutch wind power, market-based emission is already zero for the pilot. The project thus shows tangible progress towards increasing the renewables fraction of airport energy consumption.

- **CAPEX and ROI:** Economically, the metric was whether savings justify the investment. The installation cost was €52,000. (Annual operational savings realized: €2,600 in gas plus an estimated €364 in carbon credits (if monetized at €50/ton), giving €2,964 total. Using a life-cycle cost analysis approach *following the European Commission's CBA Guide* (European Commission, 2021), Schiphol evaluated the investment over a 20-year period. The simple payback period is about 17.5 years (i.e., €52k / ~€3k per year savings). The internal rate of return (IRR) is ~5–6%, which translates to an ROI of roughly 14% over 20 years in net present value terms. It is worth noting this ROI does not count non-monetary value; if carbon costs rise or if downtime of old boilers (with operational costs) were factored, effective ROI is higher. Still, financially the metric was borderline, suggesting that while feasible, such projects benefit from support. This insight feeds into recommendations for policy (Chapter 8).

- **Operational Continuity & Safety:** A qualitative success metric was no disruption to operations and maintenance of safety standards. This was fully met: firefighters always had hot water when needed (continuity 100%), and water temperatures stayed in a safe range to prevent bacterial growth. The system design (maintaining ≥65 °C) proved effective, as no legionella issues occurred, thanks to the continuous high storage temperatures, satisfying health regulations (Netherlands Building Code, 2018**)**. From a health and safety KPI standpoint, this is a major success – it shows new sustainable systems can comply with strict safety requirements (an important tick for stakeholder acceptance).

- **User and Stakeholder Acceptance:** While hard to quantify, feedback from the end-users (firefighters) and facility managers was positive. In fact, users did not feel any change in their hot water supply, which is the best outcome (the change was essentially invisible, aside from them noticing the gas boiler wasn't firing). Management is satisfied because one more gas source is eliminated with minimal fuss. This fulfils the social metric of end-user satisfaction. Training needs were small – a few briefings – and staff feel comfortable with the new system. A formal survey planned for the final project stage will likely confirm high acceptance (though this data was pending at report time).

- **Transferability Metrics:** By project design, Task 3.4 also evaluated how easily this could be deployed elsewhere. The outcome: high scalability – the system is modular and "plug-and-play", so deploying to other facilities is straightforward (no major structural changes). Also, climate adaptability is high – the concept works in cold or hot climates, with the only difference being available solar hours (which can be offset by using more grid or larger storage as needed). This qualitative metric of ease of transfer was thus met; indeed, by project end, plans were already afoot to replicate it at other airports (demonstrating perceived feasibility by others).

In summary, all critical KPIs for Task 3.4 were achieved or exceeded. Notably, the system delivered the required service reliably, slashed emissions and fossil fuel use, and did so while cooperating with the grid rather than straining it. It proves the concept of using thermal energy storage to reach both environmental and operational targets simultaneously. These metrics give confidence to scale the solution, and they provide data to feed into policy and investment decisions (e.g., quantifying CO_2 savings helps justify funding such projects as part of climate action portfolios).

This demonstration project also executed a PESTLE analysis as part of WP 9, Deployability, Upscaling and Exploitation.

7.1 UPDATED TRL

The solution is being used at Schiphol and has already been validated in other environments than airports. Some learnings being implemented in Torino airport include better accounting for the bureaucratic processes that shall be addressed at the airport for such a project and also for contractor delays. This status places the demo in TRL 7 to TRL 8.

7.2 POTENTIAL OUTCOMES

The demonstration could lead to several potential outcomes. These might be influenced by enablers and blockers in each PESTEL dimension.

Table 2 Pestle analysis

Dimension	Potential Outcomes	Enabler	Blocker
Political	Demonstrate compliance with EU and national energy transition goals by delivering a technically validated, subsidy-eligible energy system ready for deployment. Produce documentation and policy alignment frameworks that ease replication.	- Subsidies enable reduction of costs for implementation. Capex subsidies would mean financial leverage for wider rollout. - EPBD compliance enhances support for deployment. National strategies to move away from gas, encourages political buy-in.	None identified

Economical	Deliver a working solution that reduces energy costs over time compared to gas-based systems, validating its return on investment and triggering interest for scale-up in partner or commercial airports.	- Tax benefits improve financial performance. - Rising gas prices make alternatives more attractive. - Economies of scale – Reduce unit cost as installations increase.	High initial investment must be offset with long-term savings proven in the demo
Social	Achieve visible sustainability impacts (e.g. reduced fuel use, CO_2 reduction) and engage airport stakeholders in the system's operation to increase their trust and acceptance of the new energy solution.	Public awareness of sustainability creates fertile ground for stakeholder engagement and acceptance.	None identified
Technological	Deploy a flexible, scalable energy system that integrates with airport building systems and demonstrates high compatibility and performance in a real airport setting, showing readiness for replication.	- Integration with existing systems lowers deployment barriers. - Future-fit systems enhance longevity and future readiness. - System interoperability amplifies performance and synergies with other infrastructure.	None identified
Legal	Regulation-compliant technology, demonstrating adherence to EU-level standards and readiness for deployment in any regulated airport environment.	- EU and carbon certification ensures legal feasibility. - Carbon taxation pushes the market away from fossil fuels. - RES legal obligations drive demand for renewable-based systems.	None identified.
Environmental	Achieve measurable reductions in CO_2 emissions and gas dependency by replacing conventional heating systems with cleaner technology, showing clear environmental gain in line with decarbonization targets.	- Move away from gas trends are key for emission cuts. - RES deployment delivers direct environmental impact. -Building integration reduces material/resource waste, enhancing impact.	None identified.

7.3KEY RESOURCES & REQUIREMENTS

Table 3 Key resources & requirements

Description	Level 1 - Schiphol airport	Level 2 - Partner airports	Level 3 - EU airports
Benefits	- By phasing out natural gas for warm water generation thereby reducing emissions. - By means of using PV to heat the water, the intermittency of solar generation can be used.		
Adaptations	None, it has been tested	Water consumption needs to be done to determine the required capacity	
Resources needed	Connection for the installation needs be big enough (3.6 KW on the electric sockets)		
Requirements	Enough space for installation and proximity to usage		
Team	Project manager and installing party		
Technology	Needs to be integrated into the Building Management System		

7.4 RELEVANT STAKEHOLDERS

This quadrant style analysis is based on the identification of the most relevant stakeholders that the use case needs to consider, based on their power and interest incurred during the use case implementation. The analysis includes all airport levels.

Table 4 Stakeholder analysis

Meet their needs (High Power - Low Interest) *All levels* Sustainability Managers **High Power** Influence over airport-wide sustainability and environmental strategy. Can shape long-term policy and program alignment. **Low Interest** Not directly involved in system operations or implementation, so may show low engagement unless strongly aligned with their KPIs.	**Manage Closely (High Power - High Interest)** *All levels* Budget Holders and Building Managers at airports **High Power** Control over financial decisions and operational infrastructure. Can authorize or block implementation. **High Interest** Directly affected by cost, feasibility, and energy performance of the project. High involvement due to infrastructure impact.
Keep into account (Low Power - Low Interest) *All Levels* No stakeholders identified.	**Keep Informed (Low Power - High Interest)** *All levels* **Low Power** No decision-making role but are affected by the system's use. **High Interest** High interest in service reliability, comfort, and safety. Value outcomes like stable hot water supply and operational consistency.

7.5 PRODUCT- MARKET FIT

The use case is at TRL 7 to TRL 8, indicating that the system is demonstrated in an operational environment. It addresses a clearly defined operational need and aligns well with stakeholder interests, regulatory trends, and sustainability goals. The solution demonstrates a solid foundation for validation in multiple real airport conditions being the next step.

TRL 7: System Prototype Demonstration in an Operational Environment

- **Description**: At this level, a prototype system is demonstrated in an operational environment. This means the technology is tested in conditions that closely resemble the real-world environment where it will be used.
- **Example**: For an airport project, this means testing the system to ensure it operates effectively under actual conditions.

TRL 8: Actual System Completed and Qualified Through Test and Demonstration

- **Description**: At TRL 8, the technology has been proven to work in its final form and under expected conditions. This involves thorough testing and demonstration to confirm that the system meets all operational requirements.
- **Example**: In the context of an airport, this means the new system has been fully integrated into the airport's operations, has passed all regulatory and safety checks, and is now in regular use.

Transitioning from TRL 7 to TRL 8 involves moving from a prototype that works in an operational environment to a fully operational system that has been rigorously tested and validated in multiple environments being the next step.

7.6 BUSINESS DEVELOPMENT OPPORTUNITIES

1. Energy Efficiency Service Packages for Fire Brigades: Commercialize tailored energy management solutions for airport emergency services, focusing on reducing thermal demand peaks and operational costs.

2. Modular Heat Storage Systems for Airport Facilities: Scale and offer the validated heat storage devices as modular, retrofittable solutions for terminals, hotels, and service buildings in airports.

3. Public-Private Partnerships for Sustainable Infrastructure: Leverage subsidy schemes and sustainability targets to create joint investment models with airports seeking to decarbonize their auxiliary facilities.

4. Predictive Energy Management Software: Develop digital tools for monitoring and optimizing hot water energy use across airport facilities, offering data-driven performance insights.

5. Replication Model for Other Critical Airport Zones: Extend the concept to other energy-intensive units (e.g., kitchens, cleaning hubs), creating a replicable use case template for broader adoption across airport infrastructures.

7.7 LIST OF POSSIBLE INVESTMENT MECHANISMS/FUNDS

This has not been analyzed.

7.8 UPSCALING RISKS AND PROPOSED MITIGATIONS

Risks identified and its respective mitigation plans are applicable to all airport levels.

Table 5 Risks and mitigational measures

Risks	Mitigation Plan
1. Work not executed according to specifications.	1. Develop an action plan to ensure execution aligns with specifications.
2. Not enough space available for the installation	2. Enlarge technical space
3. Not enough electric capacity available	3. Increase electric connection

7.9 FEASIBILITY, COSTS, AND BENEFITS

Costs and benefits are projected for all airport levels.

Table 6 Cost benefit analysis

Airport Level	Estimated Costs	Estimated Benefits
Level 1 – Schiphol	Installation: €52,000 (or avg. €45K reference)	- Annual Gas Savings: €2,600 - Annual CO_2 Savings: €364 - Total Annual Savings: €2,964CO_2 - Reduction: 7,3 ton/year - Payback Period: 17.5–20 years
Level 2 – Partner	Estimated €45,000 **Note**: varies by location due to labour and adaptation costs	- Reduction in natural gas costs (similar savings potential to Schiphol depending on location) - Benefit sensitive to local gas prices
Level 3 – Other EU	Estimated €45,000 **Note**: variation by site conditions and integration effort	- Expected reduction in natural gas costs. - Feasibility tied to solar/wind resource availability if PV is included (not accounted for in current analysis).

The estimated costs correspond to a demonstration scale. The use case is feasible long-term due to consistent energy and CO_2 savings, but the 17.5–20-year payback period requires strategic alignment with airport decarbonization and investment timelines.

8 Conclusions and Recommendations

Conclusions: Task 3.4 has unequivocally demonstrated that thermal energy storage is a viable and effective solution for decarbonizing heat supply at airports. The Schiphol fire station pilot met all its objectives: it maintained reliable hot water service, eliminated fossil fuel use in that system, reduced CO_2 emissions by around 88%, and avoided adding strain to the electricity grid. In doing so, it validated a key piece of the WP3 Smart Energy Hub – showing that not only can vehicles and equipment be electrified (Task 3.3), but building heat can too, without adverse effects. This success feeds directly into Schiphol's strategy to achieve zero-emission airport operations by 2030 and provides a model that other airports can emulate as they work towards the industry's 2050 net-zero commitment (Airports Council International Europe, 2021).

The demonstration's success yields several broader findings: **(1)** Airports can rapidly cut emissions in building operations using readily available technology (thermal storage) – a "low-hanging fruit" in sustainability terms. **(2)** Collaboration between different airport departments (engineering, operations) is crucial and was exemplified in this project, enabling smooth implementation. **(3)** The combination of measures (electric vehicles, heat electrification, smart control) provides exponentially better outcomes than isolated actions, highlighting the importance of integrated energy planning – a core principle of WP3. And moving towards SMART Energy Hubs as a strategy for Future Proof Energy Systems **(4)** The project also dispelled concerns about new systems reliability and user acceptance; with proper design, users may not even notice the change except through improved environmental performance indicators.

In essence, Task 3.4 contributes a replicable model for a clean, flexible heating solution that can be plugged into airports' wider sustainability strategies. Together with other TULIPS outcomes, it charts a pathway for airports to become microcosms of the future energy system: highly efficient, powered by renewables, and resilient through storage and smart management. The experience gained at Schiphol sets a precedent that others can follow.

Recommendations: Based on the outcomes of Task 3.4, the following recommendations are put forward for Schiphol and other airports, as well as policymakers and industry stakeholders:

- **Accelerate Deployment at Similar Facilities:** It is recommended that Schiphol roll out the thermal storage solution to all appropriate facilities at the airport(s) (fire stations, police stations, maintenance buildings, possibly terminals for pre-heating water). Each installation is expected to yield proportional emissions and cost savings. By doing so, Schiphol could eliminate tens of thousands of cubic meters of gas use annually, moving it significantly toward its 2030 net-zero operations target. A concrete next step is removing the remaining gas backup at Fire Station 1 (the pilot site) and installing PV and completing installation at Fire Station 2 in the next budget cycle.
- **Integrate Thermal Storage into Smart Energy Hub Control:** As multiple systems come online, invest in a centralized EMCS to optimally coordinate charging of thermal and

battery storage[3]. The EMCS should use real-time data (prices, demand, weather) to decide when each thermal battery charges. This will maximize renewable usage and minimize costs automatically. Schiphol should leverage its ongoing Smart Grid program to include these storage assets (the technology supports signals, as noted). Doing so will also allow participation in potential demand response programs (monetizing flexibility). Essentially, make the Nestore units an active part of the energy network, not just passive heaters. Other airports replicating this should ensure their new units have remote control capabilities (virtually all do) and plan for integration with their future energy management platforms.

- **Share Best Practices and Lessons Learned:** The project results could be disseminated through industry forums (Airport Council International etc.) and to internal and external stakeholders. Internally, the fire station should be used as a showcase to educate and encourage other departments (e.g., encourage terminal managers to consider similar approaches for their hot water or HVAC pre-heating). Externally, the findings should be presented to peer airports and in sustainability working groups. The data on CO_2 saved, ROI and reliability is powerful evidence to convince other stakeholders that this technology is effective. Additionally, these results should be included in updates to the EU and national bodies as proof that grant investments yield tangible outcomes (fulfilling the grant agreement's dissemination goals). While Task 3.4 is high-TRL and achieved very high uptime, future scale-up should still pass an EVABAT[4]/LoS[5] gate to confirm economic viability, availability of components, and explicit policy alignment. Please note, these governance gates are complementary to PESTLE; they should be treated as separate go/no-go criteria.

- **Policy and Funding Recommendations:** Policymakers should note that while the solution is effective, financial support (grants, low-interest loans, or carbon pricing incentives) can accelerate adoption. For example, including thermal storage projects in Green Airport funding schemes or adding them to lists of eligible measures for government subsidies (like the Netherlands' ISDE subsidy for sustainable heating) would help more airports and even other industries adopt this. We recommend that the EU consider dedicated funding for airport energy storage projects as part of its next climate funding rounds – this will help replicate the TULIPS success across Europe quickly. The Airport Council International (2022) guidance on fuel transition and various national "gas-phaseout" plans are moving in this direction – these should be reinforced and aligned with available funding. Moreover, regulators should consider recognizing demand-response contributions of thermal storage in reward mechanisms, since our project proved peak reduction (if airports could earn efficiency credits or demand-response payments, it improves the business case).

- **Future Research and Innovation:** While thermal storage in this form is mature, the project identified a couple areas for further innovation: (1) Pairing thermal storage with heat pumps – currently it was resistive heating; adding a heat pump could boost efficiency 3-4× by using ambient heat or low-grade waste heat. Exploring this could drastically increase CO_2 savings (near 100% even with grid power as the COP would be high) and reduce operating cost. Schiphol should pilot a heat-pump-charged Nestore next, perhaps

[3] Plans for a roll out of this system has been devised as part of the MICRO SMART Grid project.

[4] EVABAT: confirm the chosen heat-storage solution remains the economically viable available best alternative given site conditions and tariffs (especially when adding heat pumps/PV).

[5] Line-of-Sight: maintain a documented chain; i.e. from strategy to policy/legislation to planning to demonstrations/operations. The LoS should be used to prioritize buildings and integration into the EMCS.

in a building that needs both heating and cooling (using heat pumps for cooling and dumping excess heat into the storage). The Long Duration Energy Storage Council's analysis (Somers et al., 2022) suggests that diverse storage solutions will be key to fully decarbonize. (2) Investigate phase-change materials (PCM) for even more compact storage – though Nestore's performance was great, PCM could store more heat in a smaller volume (but at a fixed temperature). If space is a concern somewhere, PCM storage might help. Schiphol suggests partnering with research institutes to test advanced thermal storage materials under airport conditions (maybe a small PCM unit in parallel to compare). (3) Digital twin and forecasting – develop a predictive model for hot water demand (using shift schedules, etc.) to fine-tune when to charge/discharge. This could be integrated into the EMS, as WP3 already gathered data to train such a model.

- **Phase-Out Gas Strategy:** For any airport still using gas boilers, Schiphol recommends adopting a two-step transition approach similar to Schiphol's: install electric/thermal solution alongside existing system (or in partial capacity) >> monitor and prove performance >> decommission old system. This "no regrets" approach ensures reliability and builds confidence. It's a template other sites can follow to systematically retire gas assets by 2030. We specifically recommend airports set target dates for each gas boiler to be replaced or backed up by thermal storage by a certain year, using the TULIPS Task 3.4 data as justification that it works. The IEA has noted that heating and cooling in buildings is a lagging sector in the clean energy transition (International Energy Agency, 2022); this project shows a practical solution to help close that gap in the aviation domain.
- **Holistic Energy Planning:** Incorporate the outcomes of Task 3.4 into the airport's master planning and environmental management system. For Schiphol, update Energy Efficiency Plans with the new reduction figures and include rolling out thermal storage as a measure to meet next period targets. For fellow airports, use Task 3.4 as a case study to push for inclusion of similar projects in their capital plans (many airports plan 5-year investments; this should be on the list). Essentially, move such projects from pilot to mainstream by including them in strategic planning documents and budgets.

In closing, Task 3.4 has provided not just a successful pilot but a scalable solution and a set of data-driven insights. By acting on the recommendations above, airports can multiply the benefits seen at Schiphol across many sites, significantly advancing the sustainability of the aviation sector's ground operations. The path to zero-emission airports is clearer now: electrify everything (including heating) if there is enough capacity available on the grid, if capacity is limited switch from high-grade electricity to low-grade heat[6] to release capacity in the grid[7], buffer with smart storage, and optimize with intelligent control – all while keeping safety and service at the forefront. Task 3.4 is a concrete example of how smart storage can contribute to this pathway, and we strongly encourage its replication and evolution as part of each airport's journey to a greener future.

[6] With low emissions solutions.
[7] For example, for charging of vehicles.

9 Appendix 1. Additional Strategic Considerations

Beyond raw performance metrics, Task 3.4 yields insights into strategic areas relevant to sustainable energy transitions at airports: cross-cutting analysis, integration with broader systems, human factors, digital infrastructure, lifecycle impacts, and governance.

A1.1 Cross-Airport Comparative Insights: As noted in Section 6, the heat storage solution is broadly applicable. Strategically, airports should evaluate their energy profiles and identify where thermal vs. electrical solutions bring the most benefit. Schiphol's approach will likely differ from, say, Larnaca's in emphasis, but the core comparative insight is that every airport has some thermal demand that can be optimized. WP3's cross-airport analysis recommended all airports in the consortium consider implementing heat storage for any persistent hot water or heating loads, as it's a low-regret option (mature tech, immediate emissions cut). Additionally, the interplay of solutions is strategic: e.g., Stavanger's focus on electric vehicles might shift more attention to battery storage, whereas Larnaca's solar abundance makes a strong case for thermal storage – but in the end, both airports plan to adopt both, just with different sequencing. The comparative readiness is that thermal storage is ready to deploy now.

A1.2 Integration with EU/National Energy Systems: The Task 3.4 demonstration aligns with and supports broader energy system trends. By flattening demand spikes, the airport becomes a more grid-friendly consumer, aiding national grid stability. The fact that peak shaving was achieved (and even controllable via signals) means Schiphol could, in future, offer demand response services to the national TSO (turning heaters off/on as grid needs). This is a synergy with Europe's push for flexibility in electricity markets. Also, phasing out gas supports Dutch national policy (to eliminate gas heating in buildings by 2050) – Schiphol is ahead of the curve here, setting an example in its region. EU Fit for 55 policies propose higher carbon prices and potentially mandates on public bodies to decarbonize: Schiphol's project provides a real case study for compliance. *In summary:* the integration with wider energy systems is positive – the airport's actions reduce strain on gas distribution and flatten electric load, which if replicated widely, would significantly assist national energy transitions. WP3's strategic note suggests airports and utilities should coordinate on such projects to possibly receive incentives for the peak reduction achieved.

A1.3 Human Capital and Operational Readiness: Deploying new technology requires people readiness. For Task 3.4, minimal specialized training was needed because the system is conceptually simple. However, WP3 emphasizes the importance of staff engagement and upskilling as airports adopt more advanced energy systems. On a larger scale, as multiple systems (batteries, thermal storage, microgrids) roll out, Schiphol is considering a central Energy Hub Operations Center staffed with energy managers – an example of human capital preparation triggered by WP3 learnings. The project shows that fear of complexity should not impede adoption; with a bit of targeted training airport facility teams can readily operate these sustainable technologies.

A1.4 Cybersecurity and Digital Infrastructure: As systems like Nestore get integrated into IoT and smart controls, cybersecurity becomes a consideration. The current fire station setup is rudimentarily controlled (timer + analogue signal), so attack surface is minimal. But future networked control (e.g., remote EMCS control via IP) requires secure communication protocols to avoid malicious interference (one wouldn't want a hacker turning off tank heating just before usage or during a cold snap). WP3 recognized this need – guidelines for secure SCADA integration were acknowledged (e.g., use of VPN tunnels or isolated networks for energy management). The digital infrastructure at Schiphol is already robust (with segregated networks for building controls), so adding the thermal battery to the BMS followed those existing cybersecurity standards. Fellow airports need to do similarly. So, while cybersecurity is an important strategic consideration, it is well-managed by extending existing building automation security practices. So, embracing digital (with security in mind) is the path forward – manual or analogue control works for a pilot, but at scale, digital control unleashes full optimization potential safely.

A1.5 Lifecycle and End-of-Life Considerations: The sustainability of a solution spans manufacture to disposal. LCA analysis for Task 3.4 considered the long life (20+ years) of the steel tanks – meaning the embedded emissions get amortized over a long useful life, which is good. End-of-life, the tanks are made of recyclable materials (stainless steel, insulation) – so disposal impact is low, many parts can be recycled. The electric elements and sensors are minor components. Compared to gas boilers, which have similar materials, there's no extra burden. In fact, by eliminating gas combustion, Schiphol eliminated the creation of NOx and other local pollutants (a co-benefit not heavily quantified in metrics but environmentally valuable). A life-cycle consideration: the circulation pump might run slightly more (to push through storage), marginally raising electricity use, but that is negligible in the big picture (and high-efficiency pumps minimize it). WP3 also considered if old gas boilers could be repurposed or need scrapping – in this case, the boiler remains as backup or is removed; either way, its material is scrapped (again mostly steel) or reused elsewhere. Conclusion: The heat battery system doesn't introduce problematic end-of-life waste; it aligns with circular economy principles with recyclable components. This addresses any stakeholder concerns about "are we introducing new waste streams?". The answer is no – mostly replacing one metal tank with another, both recyclables. In fact, the Zero Waste 2030 goal cited in WP3 sees this as positive: using stored energy optimally means wasting less energy, and the hardware itself can be largely recycled at end-of-life, indicating a sustainable lifecycle.

A1.6 Stakeholder Engagement and Governance: Implementing such changes at an airport requires buy-in from multiple stakeholders: operations, sustainability office, finance, regulators (for safety), and end-users. Stakeholder engagement is key to the smooth adoption. For example, once firefighters understood the rationale (“we’re doing this to make Schiphol more sustainable and it won’t affect your hot showers”), they became supporters of the initiative. This kind of bottom-up support is invaluable – it turns potential critics into advocates. At a higher level, this project’s success can be communicated to airport executives and included in Schiphol’s sustainability progress reports, strengthening management commitment to further rollouts. The role of governance in success here is noteworthy: because it followed internal quality assurance and delivery guidelines (as required by grant agreement), it sets a precedent to treat energy projects with the same rigor as core ops projects. Thereby, they gain legitimacy within the organization.

In summary, the Task 3.4 demonstration not only hit its technical marks but also navigated strategic dimensions effectively: cross-learning with other initiatives, seamless integration into broader systems, minimal new demands on personnel, secure and smart use of digital controls, responsible lifecycle footprint, and strong stakeholder buy-in. These factors combined mean the solution is not just technically sound, but organizationally and societally sound. The project serves as a model for how to implement sustainability innovations in airports in a way that engages people and ensures long-term success.

10 Appendix 2. Risk Assessment and Uncertainties

No project is without risks and uncertainties. For Task 3.4, potential risks were identified early and mitigated proactively, resulting in an incident-free demonstration. Going forward, understanding these risks ensures robust replication. Key risks and their mitigation strategies include:

- **Hot Water Supply Risk (Service Continuity):** *Risk:* The thermal storage might not keep up with an unusually high hot water demand, risking cold showers for firefighters (an operational failure). *Mitigation:* The system was oversized relative to average demand (storage >3× daily use), providing a large safety margin. Additionally, the existing gas boiler was left in place as an automatic backup. In the pilot, this risk did not materialize at all – storage met 100% of demand and the backup never had to kick in. Nonetheless, the backup remains until full trust is established. For future implementations, similar backup or hybrid designs can be used during a transition period. This ensures no single-point failure in hot water supply.
- **Legionella/Water Quality Risk:** *Risk:* Storing water warm for long periods could breed bacteria, a health hazard. *Mitigation:* The control strategy enforced a minimum of 65 °C in the tanks, above the 60 °C threshold that kills Legionella. Water tests were conducted regularly – none showed any contamination. If the storage had to be kept cooler (not the case here), one would periodically heat-shock it to mitigate this risk. With proper temperature maintenance, the risk is effectively nullified, as evidenced by the safe operation in the pilot.
- **Electrical Load Uncertainty:** *Risk:* There was a concern that simultaneous charging of the thermal battery and other airport loads could still cause some unforeseen stress on the local grid (e.g., if an emergency caused many systems to run at once, would the added 10 kW heater load be an issue?). *Mitigation:* Charging was scheduled during known low-demand periods (night or midday when other loads like lighting or HVAC were lower). Furthermore, the system could receive a signal from the building's smart meter – if overall draw ever exceeded a set limit, the thermal battery heaters would throttle or pause. In practice, this never had to occur because the chosen windows were truly off-peak (this was verified by monitoring building load profiles). This shows that with a bit of planning; load conflicts can be avoided. As more units are added, Schiphol's EMCS will coordinate them to ensure aggregate charging doesn't cause a new peak (that's part of the Smart Energy Hub development).
- **Equipment Failure Risk:** *Risk:* A component of the Nestore system (heating element, pump, controller) could fail, potentially leading to loss of heating capability. *Mitigation:* The design inherently has redundancy – three separate units, each capable of contributing. If one fails, the others still provide partial capacity (and the backup gas can cover shortfall if needed). Also, the equipment is relatively simple and robust (heating elements are akin to those in standard boilers, which are very reliable; pumps are standard). Preventive maintenance checks (temperature sensors, pressure valves) will be done to catch any degradation early. Over the pilot, there were no failures, suggesting the risk is low. However, to be safe, Schiphol will stock a spare heating element and will include the Nestore units in its routine facility maintenance schedule. So even if a unit went down, it can be fixed within hours, and in the interim gas backup or remaining units ensure operations continue.

- **Economic/Market Risk:** *Risk:* Fluctuations in energy prices or policy might affect the economic viability (e.g., if gas becomes cheap again, or electricity much more expensive). *Mitigation:* The system was justified partly on sustainability rather than short-term economics; however, a sensitivity analysis shows even if gas halved in price, the emissions factors still favour electrification (and EU policy trajectory is making gas more costly via carbon pricing, not cheaper). The airport also hedges energy costs to avoid volatility. Moreover, the investment is somewhat future proof: even if relative fuel prices change, the sunk cost is amortized, and the airport still benefits from a flexible asset. Policy risk (like changes in incentives) is mitigated by the fact that the system cost did not heavily rely on subsidies; it stands on its own merits. So, while payback could extend if conditions shift, the airport's commitment to decarbonization makes that acceptable. Essentially, the strategic value and environmental mandate override the moderate financial uncertainty.

- **Integration/Interoperability Risk:** *Risk:* New tech may not integrate well with existing systems or future upgrades, causing headaches. *Mitigation:* We saw in practice that integration was smooth – standard connections were used, and system interfaces (0-10V control, BMS monitoring) are industry-standard. Should the airport upgrade to a full smart grid, the Nestore unit is ready to accept external control (it's designed for that). There's no proprietary lock-in; in worst case, it operates standalone in default mode. So, interoperability risk is low.

- **Safety (General) Risks:** This includes electrical safety (risk of short circuit or heater overheating) and pressure safety (risk of tank overpressure). *Mitigation:* All electrical work was done to code with proper circuit protection. The Nestore unit has multiple safety cut-outs: thermostatic limits, pressure relief valves. During commissioning, these safeties were tested. No unsafe conditions occurred. Additionally, because no combustion is involved, some risks (like carbon monoxide leaks, which gas boilers have) are eliminated, arguably making the system safer overall than the baseline. Routine inspections of safety valves are scheduled. Thus, standard adherence to safety regulations has kept risk effectively neutral or improved relative to gas.

External Dependencies: A risk assessment also considered external factors:

- *Grid dependency:* The system relies on electricity; if there's a power outage and no backup generator, hot water would eventually cool (though with 2700 L at 65 °C, it would supply many hours). Schiphol has backup generators that can power critical systems, and the gas boiler could also be used in such an emergency. So, resiliency is maintained. In the long run, adding a small UPS for the control system could ensure even during short outages, data isn't lost.

- *Renewable supply:* The performance assumes some solar input; a prolonged period of gloomy weather means more grid draw, which is a cost/environmental external factor. This isn't a failure per se (hot water still provided), just slightly higher emissions. It's mitigated by sizing and the fact that grid in NL is moderately clean and getting cleaner. If anything, this risk just affects the emission outcome variability – one year might save 7.3 t CO_2, another 8.8 t, depending on sun; but it will always be a hefty reduction vs baseline.

Mitigation Strategies in Summary:

- Overdesign storage capacity by ~>30% to handle demand spikes and growth (already done).
- Keep legacy backup until new system proven, then optional removal (the two-step approach used was perfect to ensure continuity).
- Use smart control to avoid conflicts with other loads – either via fixed schedules or dynamic load control.
- Implement monitoring and preventive maintenance – a digital dashboard now alerts if any tank’s temperature deviates unexpectedly, allowing quick intervention.
- Engage users in safety practices, e.g., flushing seldom-used outlets – which the fire station already did and continues as good hygiene practice.
- Plan financially with conservative estimates; treat any upside (like higher carbon prices making ROI better) as bonus.

Thus far, these risk measures have been effective – the project had zero incidents and met all requirements. Going forward, the remaining uncertainty is mostly around long-term performance (will the insulated tanks perform as well in 10 years? Will savings persist?). To address that, WP3 could set up a long-term monitoring regime: data will then continue to be collected beyond the project. If any trend of performance degradation appears (e.g., slight loss of insulation vacuum), it will be detected and can be remedied (the tanks have warranty and service options). So, while some uncertainty exists (as with any system) about very long-term behaviour, the airport would then be prepared to manage it. Given the robust initial results, there is strong confidence that risks are low and manageable, and uncertainties are outweighed by the proven benefits. This risk assessment provides assurance to decision-makers at other airports that adopting such a system is not a risky venture but a well-demonstrated improvement.

11 Appendix 3. Exploitation summary table

Subject	Description
Demo #. Title	Demonstration #10 – Thermal Energy Storage for Heat Supply at Schiphol Fire Station
Business Case	Replacement of gas-fired hot water system with modular thermal storage to reduce emissions, improve energy efficiency, and avoid grid congestion in critical airport facilities.
Solution's competitive advantage	• 100% gas elimination for water heating purposes • ~88-93% CO_2 reduction (for water heating purposes) • Limited/no peak load increase • Modular, plug-and-play design • High user satisfaction and operational reliability
Lead Partner(s) for business case	• SNBV – Schiphol Airport (lead implementation and pilot site) • Newton Energy Solutions (technology provider) • Supported by SAGAT (Turin), Avinor (Stavanger), Hermes (Larnaca) for replication
Innovation Type	Integrated Solution – Combines product (thermal battery), process (smart charging), and service (energy management)
Exploitation Readiness (Low /Med /High)	High – TRL 7–8; validated in operational airport setting with proven performance, scalability, and stakeholder acceptance
Societal & Environmental Value	• Significant CO_2 reduction (~7.3 tons/year) • Elimination of fossil fuel use • Improved energy resilience • Supports EU Green Deal and Fit for 55 targets
Cost/Benefit (+ / -)	+ Positive ROI (~14% over 20 years) + Annual savings ~€2,964 − High upfront CAPEX (~€52k) + Long-term strategic and environmental gains
Cost of implementation	CAPEX: €52,000 per unit (total cost, higher because of initial startup costs) Additional costs: integration with BMS, minor plumbing/electrical

	retrofits, staff training Region-specific costs vary (labor, permits)
Estimated Time to market	Immediate – operational at Schiphol; replication possible within 6–12 months at similar facilities
Market Entry Strategy	Target: Airports with high hot water demand Channels: Direct partnerships, EU sustainability forums Lead adopters: Schiphol, SAGAT, Hermes Sales via technology provider and public-private partnerships
Scale-Up Preparation	• Bulk procurement to reduce unit cost • Integration into centralized EMCS • Development of SOPs and training modules • Minor design tweaks for site-specific needs
Regulatory Influences	• EPBD compliance • Carbon taxation and RES obligations support adoption • No major legal barriers; standard plumbing/electrical codes apply
Sources of financing	Not yet analyzed in detail Potential: Green loans, EU climate funds, national subsidies (e.g., ISDE), energy performance contracts
Status of Intellectual Property Rights (IPR) or other exploitation agreements	No patents filed; technology is commercially available Exploitation via direct industrial use and knowledge transfer Deployment guide and SOPs in development

12 List of abbreviations

Abbreviation	Explanation
BMS	Building Management System
CBA	Cost-Benefit Analysis
EMCS	Energy Management Control System
EVABAT	Economically Viable Available Best Alternative Technology – principle to select the best available technology that is both available and economically viable.
EPBD	Energy Performance of Buildings Directive
HVAC	Heating, Ventilation, and Air Conditioning
ISDE	Investment Subsidy for Sustainable Energy
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LoS	Line of Sight – explicit mapping Strategy → Policy/Legislation → Plans → Demo (TRL).
NEStore	Thermal energy storage system
PESTEL	Political, Economic, Social, Technological, Environmental, and Legal
PV	Photovoltaic (solar panels)
ROI	Return on Investment
SOP	Standard Operating Procedure
TRL	Technology Readiness Level
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply
WP3	Work Package 3

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