TULIPS

Summary of the TULIPS roadmap



Practical solutions, lessons and takeaways from the TULIPS roadmap (2022-2026)

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Initiated by
TULIPS consortium, coordinated by Royal Schiphol Group.

Based on
Overall roadmap report with vision on Green Airport targets and measures towards 2030 and 2050, in line with the EU Green Deal. This publication was developed as part of the TULIPS roadmap activities in Deliverable 10.7 (available here: https://tulips-greenairports.eu/publications/) and is based on the practical solutions, lessons and takeaways brought together in the consortium.

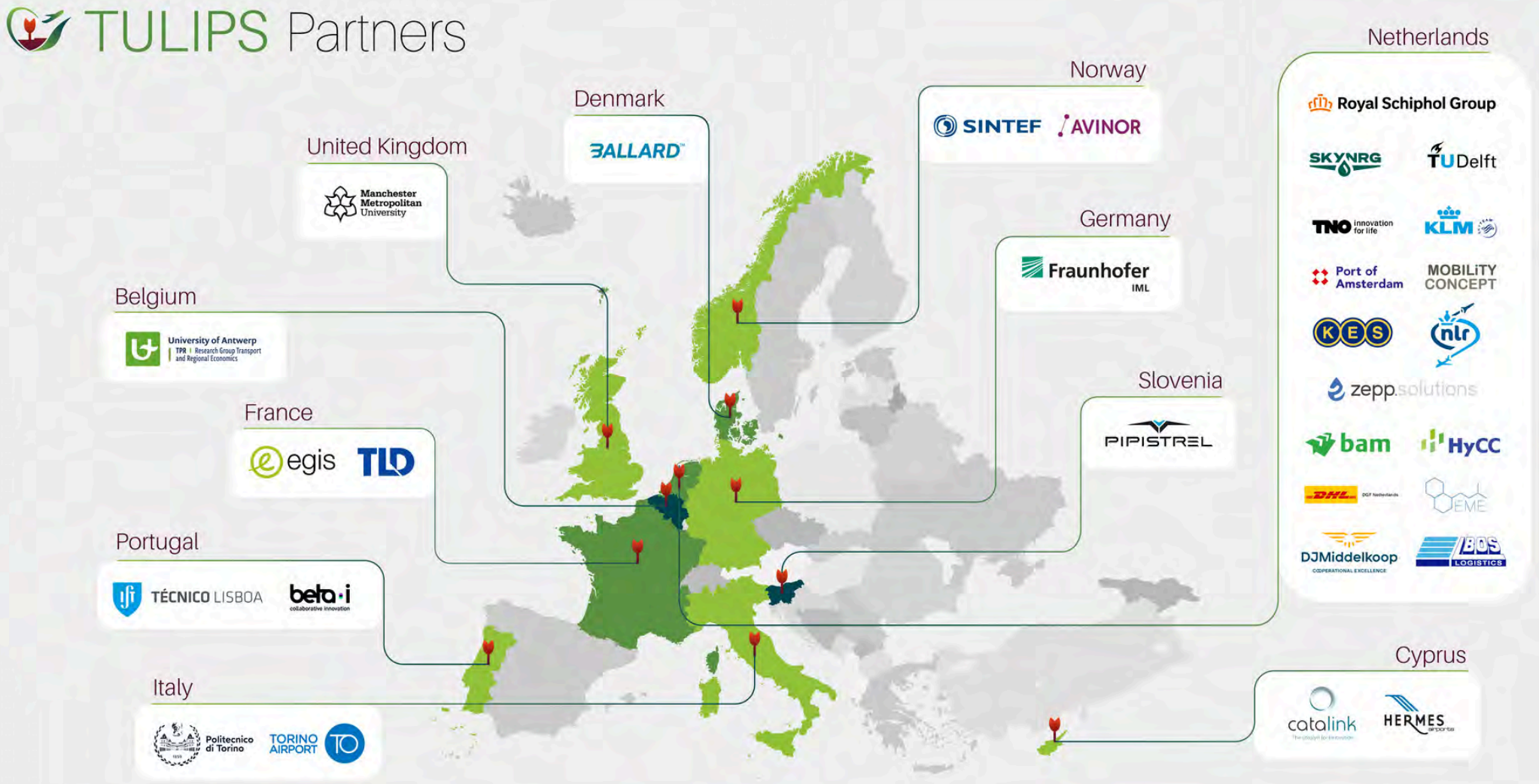
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Fraunhofer, Jørgen Syversen, Larnaka International Airport (Hermes Airports), Middelkoop, NLR, Oslo Airport (Avinor), Øystein Løwer, Rotterdam The Hague Airport (RTHA), Royal Schiphol Group (Sanne van der Leest and Roger Cremers), and SAGAT Torino Airport.

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TULIPS is a European innovation programme led by Schiphol and funded through the European Union's Horizon 2020 programme (Grant Agreement No. 101036996). TULIPS brings together a broad consortium of partners and accelerates the implementation of innovative and more sustainable airport solutions through demonstrations in live airport environments. Schiphol serves as the lighthouse testing ground for multiple demonstrations, enabling practical learning that can be scaled and replicated. 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.

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By Esmé Valk

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Foreword

When TULIPS started in 2022, the partners set themselves an ambitious goal: to demonstrate that the solutions needed to achieve zero-emission airports and aviation can be developed and tested in real airport operations, not simply designed on paper. At Schiphol Group, we had the privilege of serving as the lighthouse airport and working alongside an exceptional group of partners, including airports, research institutes, technology providers, energy and fuel suppliers, ground handlers and airlines. I am proud of what this five-year partnership has achieved.

This close cooperation connected people, knowledge and ideas from across Europe, creating a platform for collaboration, learning and progress.
The partners worked together on innovations such as aircraft charging, hydrogen ground operations, sustainable aviation fuels (SAF), material reuse and carbon sequestration, culminating in this roadmap.

These solutions were demonstrated and assessed at Amsterdam Airport Schiphol, Rotterdam The Hague Airport, Oslo Airport and across the wider Avinor network, Torino Airport, and Larnaka International Airport, operated by Hermes Airports. Each brought its own operational context, expertise and ambitions to the programme. That diversity proved to be one of TULIPS' greatest strengths. It demonstrated that sustainable solutions must be adapted to local circumstances, making the lessons in this roadmap relevant to airports of all sizes and types.

The five-year TULIPS journey has been both enlightening and inspiring, also for us at Schiphol Group. We have used the results of these demonstrations to further refine our own sustainability roadmap. When we embarked on this journey, we had clear ambitions for 2030 and 2050, but not yet a complete understanding of the most effective route to achieving them. TULIPS enabled us to test promising innovations in a real-world airport environment, helping us understand not only whether they work, but also how they can contribute to achieving our sustainability ambitions. As a result, our pathway to 2030 and 2050 is now clearer and more robust. The outcomes of this programme will help Schiphol Group fulfil its ambition to create happy travellers, airlines and employees, while operating in balance with the environment. I hope they will also support many other airports pursuing similar ambitions.

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The lessons captured in this roadmap are intended above all as a practical guide for airports across Europe. It is not a fixed blueprint to be copied, but a source of inspiration and evidence-based insight into how airports can decarbonise their operations and embed sustainability throughout their organisations. Airports start from different positions, with varying infrastructure, regulatory frameworks, energy systems and strategic priorities. Yet they share the same challenge: meeting continued demand for air travel while contributing to Europe's climate ambitions and maintaining a competitive aviation sector. Some solutions can be implemented in the short term, while others require further development, supporting infrastructure or policy change. We encourage every airport to select the approaches most relevant to its own transition pathway and adapt them to their local context, just as we will continue to do across Schiphol Group's airports as we prepare for the future.

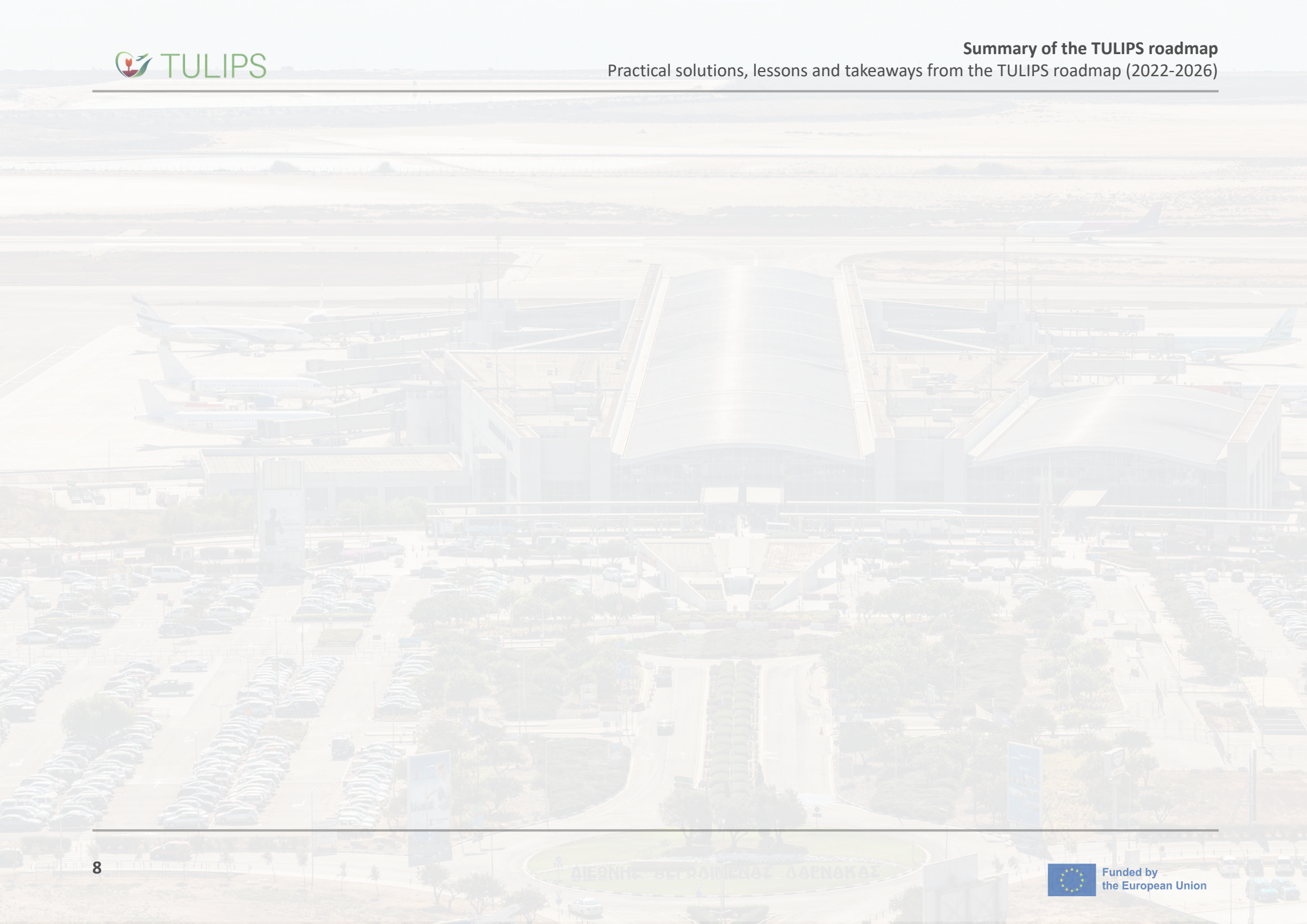
Finally, I would like to sincerely thank everyone who contributed to making TULIPS a reality: the European Commission and CINEA for their support through Horizon 2020; our sister green airport and port projects, with whom we collaborated closely to create a broader perspective, STARGATE, OLGA, ALIGHT, MAGPIE and PIONEERS; our consortium partners; our fellow airports; the work package and demonstration leads; and the many colleagues who integrated new solutions into daily operations. Your dedication, expertise, and collaboration have turned an ambitious vision into a shared achievement.



Let us continue building more sustainable airports together, ensuring that the European aviation sector remains resilient and future-proof for generations to come.

Esmé Valk
Chief People and Transformation Officer
Royal Schiphol Group

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PART I
BUILDING SUSTAINABLE AIRPORTS

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The TULIPS journey

Royal Schiphol Group launched TULIPS in 2022 under the European Green Deal as a five-year programme to accelerate the transition of European airports towards low-emission, resource-efficient and climate-resilient operations by developing, testing and assessing innovative solutions in real airport environments. Rather than addressing sustainability through a single technology, the programme takes a system perspective: airport access and mobility, aircraft and ground operations, energy supply, resource use and residual emissions all form part of the transition to decarbonise and embed sustainability into the airport operating environment. The TULIPS programme is a consortium of 32 partners from across Europe, including airports, research organisations, technology providers, operational partners and other aviation stakeholders.

Four airport groups, different operating contexts

Amsterdam Airport Schiphol acts as the lighthouse airport, providing the large and operationally complex environment in which many TULIPS solutions were developed and demonstrated. Rotterdam The Hague Airport (part of Schiphol Group) and the three fellow airports broaden this perspective: SAGAT Torino Airport; Larnaka International Airport, an island airport with different infrastructure and supply-chain conditions; and the Avinor airport network, which brings Nordic operating conditions and airports of different sizes into the project. These different contexts are important because sustainable airport solutions are rarely one-size-fits-all. Infrastructure, traffic volumes, climate, energy availability, regulation and organisational structures all influence whether and how a solution can be implemented. The airport-specific roadmap work therefore covers all four contexts.



Royal Schiphol Group



SAGAT Torino Airport



Larnaka International Airport



Avinor Oslo Airport

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Tackling interconnected airport challenges

Across its demonstrations, TULIPS addresses a broad range of challenges: reducing emissions from passenger and freight access, preparing airports for new aircraft energy carriers, decarbonising ground operations, managing increasing energy demand, improving local air quality, improving recycling and increasing material reuse, and addressing residual emissions through carbon removal. These challenges are closely connected. Introducing a new technology can require changes to infrastructure, operating procedures, safety and regulation, skills, investment and cooperation between multiple organisations.

Connecting and exchanging knowledge

Throughout the five-year programme, TULIPS partners brought people and ideas together through joint workshops, panel discussions, conferences and demonstrations. Collaboration with sister airport and port projects STARGATE, OLGA, ALIGHT, MAGPIE and PIONEERS created opportunities to share results, learn from practical experience and tackle common challenges. From Passenger Terminal Expo and the Paris Air Show to the Seas to Skies Conference, these exchanges helped knowledge travel beyond individual projects.

Airports as living labs

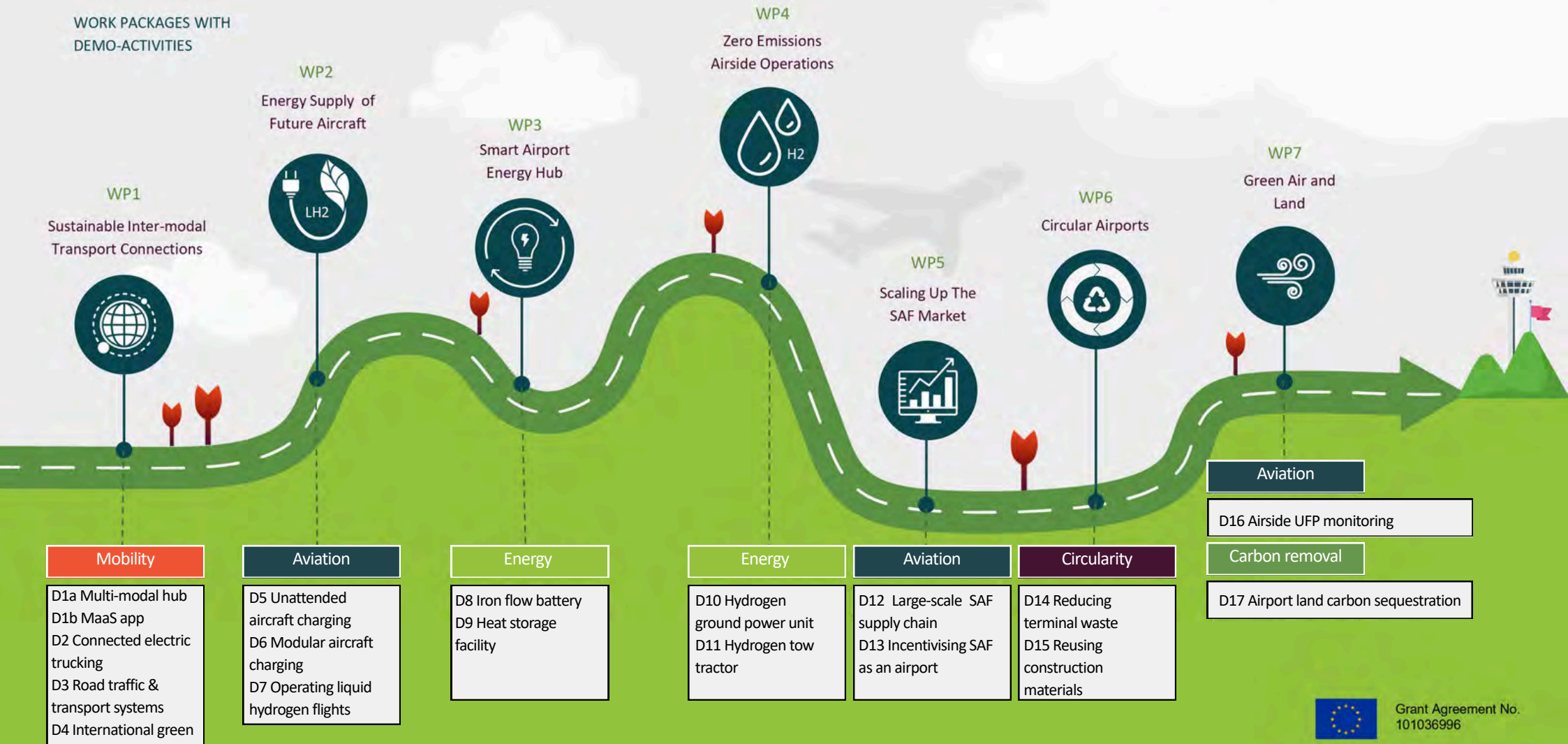
Demonstrations are at the core of the TULIPS approach. Airports provide a demanding real-world environment in which new technologies, methods and operational concepts can be tested alongside existing processes and infrastructure. The 17 TULIPS demonstrations took place across landside, terminal and airside precincts.

The demonstrations were organised in seven work packages (WP1–WP7), each focused on one part of the airport transition, from transport connections and aircraft energy supply to circularity and green air and land. Five overarching work packages (WP8–WP12) connected them through performance monitoring, exploitation, the roadmap, project management and communication. Annex I shows which demonstrations belong to each work package. The demonstrations generated more than technical results. They also revealed what implementation requires in practice: stakeholder coordination, infrastructure readiness, suitable regulation and permitting, and organisational capabilities.

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TULIPS

DemonsTrating lower pollUting soLutions for sustaInable airPorts acrosS Europe

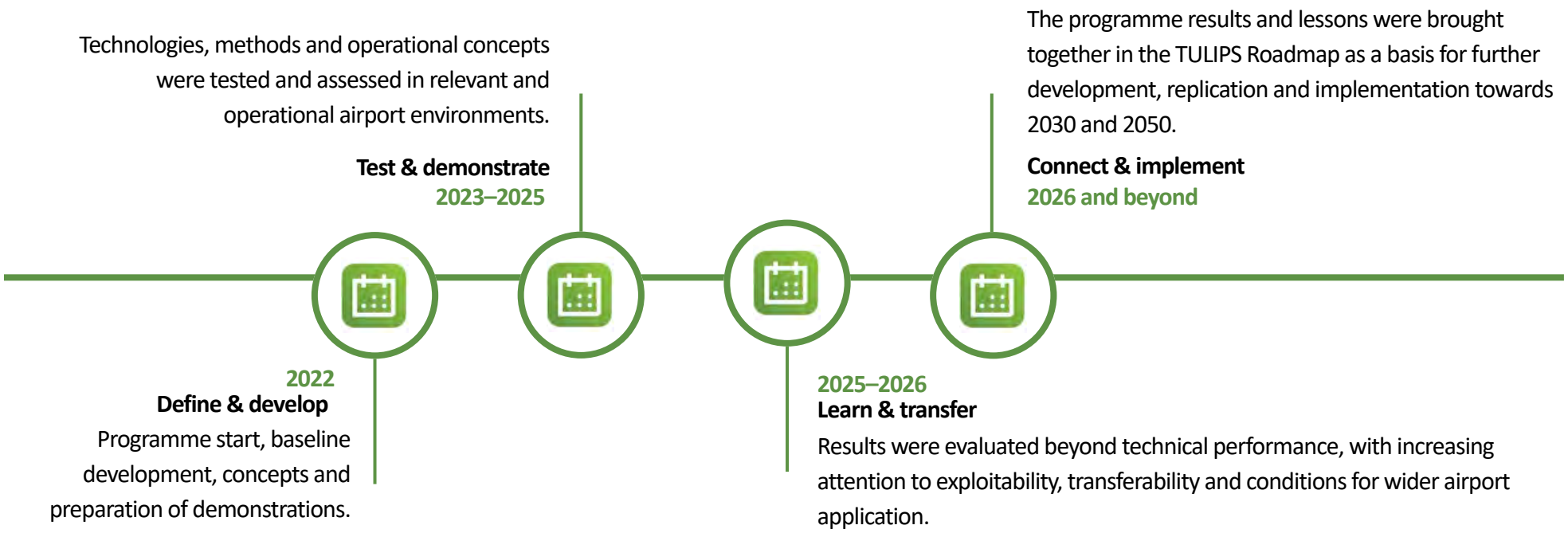


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From demonstrations to an integrated roadmap

The demonstrations have been assessed on transferability, financial and operational feasibility and explored in a scenario analysis. These findings were translated into the TULIPS Roadmap, published as Deliverable 10.7 on the TULIPS website. This booklet summarises that roadmap. The roadmap has been part of the TULIPS approach from the beginning, linking individual innovation activities to the longer-term transition of airports. As the programme progressed, the roadmap evolved with the evidence generated by the demonstrations. What began as a portfolio of individual demonstrations has therefore developed into a more integrated view of the green airport of the future. The final roadmap connects the results across five domains: Mobility, Aviation, Energy, Circularity and Carbon Removal, and shows how different innovations contribute to various aspects of the airport ecosystem.



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This battery

















IATA
IATA




Meet the Panel:
Karsten Uhing
Daniela Stange
Denise Pronk
Caroline van' t Hoff
Schiphol
CIRCULAR AIRPORTS 2030




TULIPS
Schiphol Micro-Conference
on Circularity in Airports
CIRCULAR AIRPORTS 2030



About the TULIPS roadmap

This booklet provides a high-level summary of the TULIPS Roadmap, capturing key insights and lessons from five years of collaboration between 32 partners. It brings together findings from demonstrations, deliverables and supporting research in an accessible guide, while directing readers to the underlying evidence and resources. Rather than prescribing a single pathway, it offers a flexible starting point for airports and stakeholders to identify and apply the approaches most relevant to their own airport sustainability ambitions.

For full details of the final TULIPS Roadmap, please read the formal publication, Deliverable 10.7, "Overall roadmap report with vision on Green Airport targets and measures towards 2030", accessible, like all other TULIPS deliverables, via the QR code.

Scan the QR code to access all TULIPS deliverables.



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How to use this publication

THE BIG PICTURE

AIRPORT MAP

One map with all 17 demonstrations together, showing where each one took place: landside, in the terminal or airside.



BY DOMAIN

FIVE DOMAINS

The 17 demonstrations are grouped into five domains, each with its own colour. Each domain chapter explains the challenge and the links to other domains.

- Mobility
- Aviation
- Energy
- Circularity
- Carbon Removal

PER DEMO

DEMO ONE-PAGERS

Every demonstration is described on one or two pages, always in the same order:

- What is it?
- What TULIPS demonstrated
- Key results
- Lessons learned
- Main replication conditions
- Recommended first step
- Learn more

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PART II
FIVE CONNECTED DOMAINS

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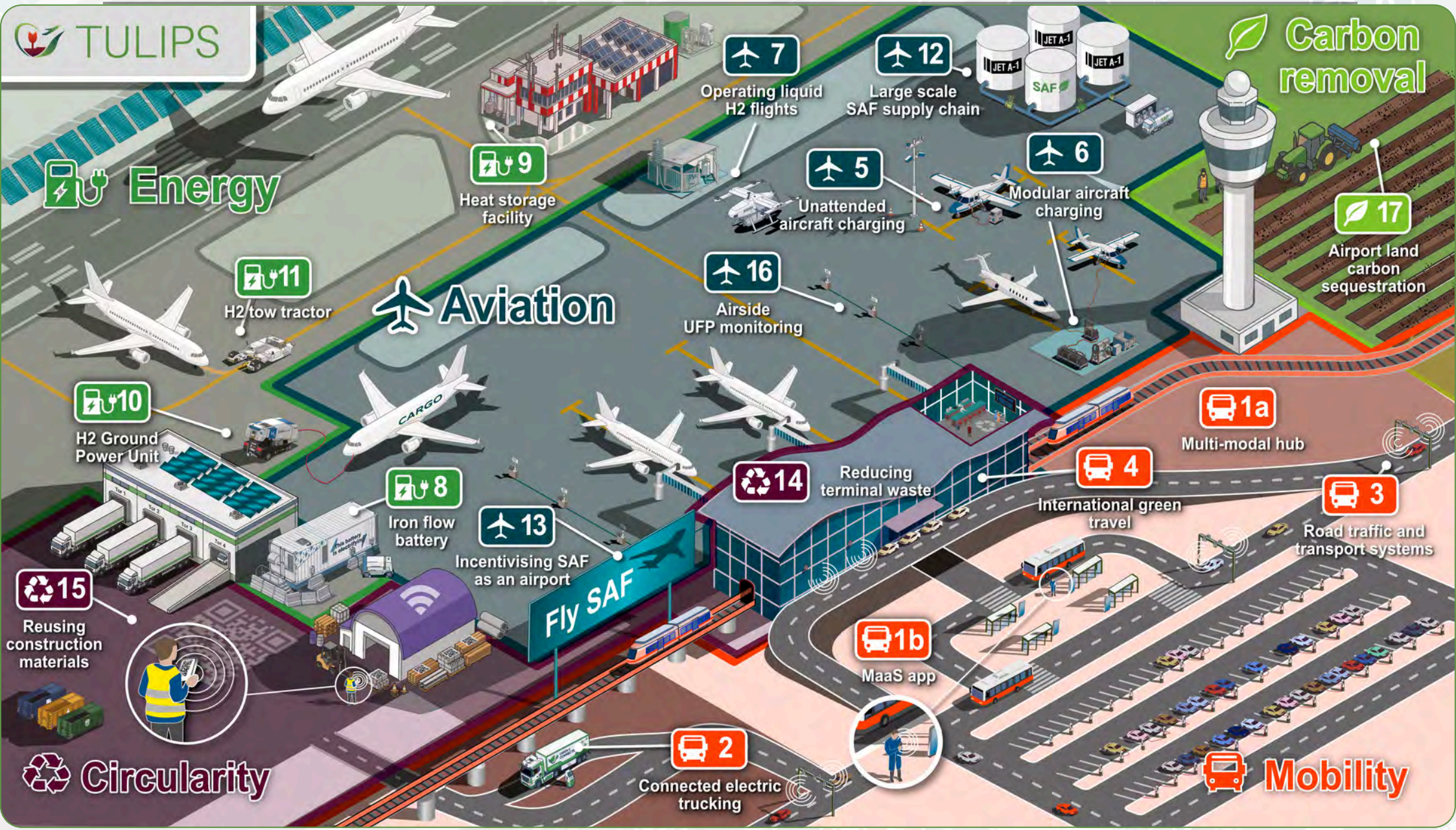
One airport system, five domains

The airport map shows all 17 demonstrations side by side, from landside access and the terminal to the apron and the airport's surrounding land. The TULIPS Roadmap groups them into five domains: Mobility, Aviation, Energy, Circularity and Carbon Removal. They are not separate visions of the future, but connected parts of one airport system.

Each domain makes its own contribution to the roadmap. Mobility enables lower-emission and better-integrated access to the airport for passengers, employees and freight. Aviation prepares airport operations and infrastructure for new aircraft technologies, fuels and environmental requirements, while growing demand makes net-zero targets harder to reach and the airport has only limited direct control over aircraft and third-party operations. Energy provides the flexible, resilient and increasingly zero-emission energy system that much of this relies on: as road transport, heating and ground equipment move away from fossil fuels, electricity demand rises while grid capacity is constrained. Circularity embeds resource efficiency and reuse in airport operations, procurement and construction, reducing the impacts of materials as well as energy. Carbon Removal addresses the residual emissions that cannot yet be avoided, complementing rather than replacing direct emission reductions.

The domains also depend on each other. Mobility and Aviation rely on Energy for charging, hydrogen and grid capacity, and energy choices determine which technologies can be deployed. Changes in travel behaviour and freight transport influence airport-related emissions. Circularity changes how airport infrastructure is built and maintained, and links to Carbon Removal, where waste is turned into biochar that stores carbon in the soil. Progress in one domain therefore often depends on progress in another. The following chapters describe each domain and its demonstrations in more detail.

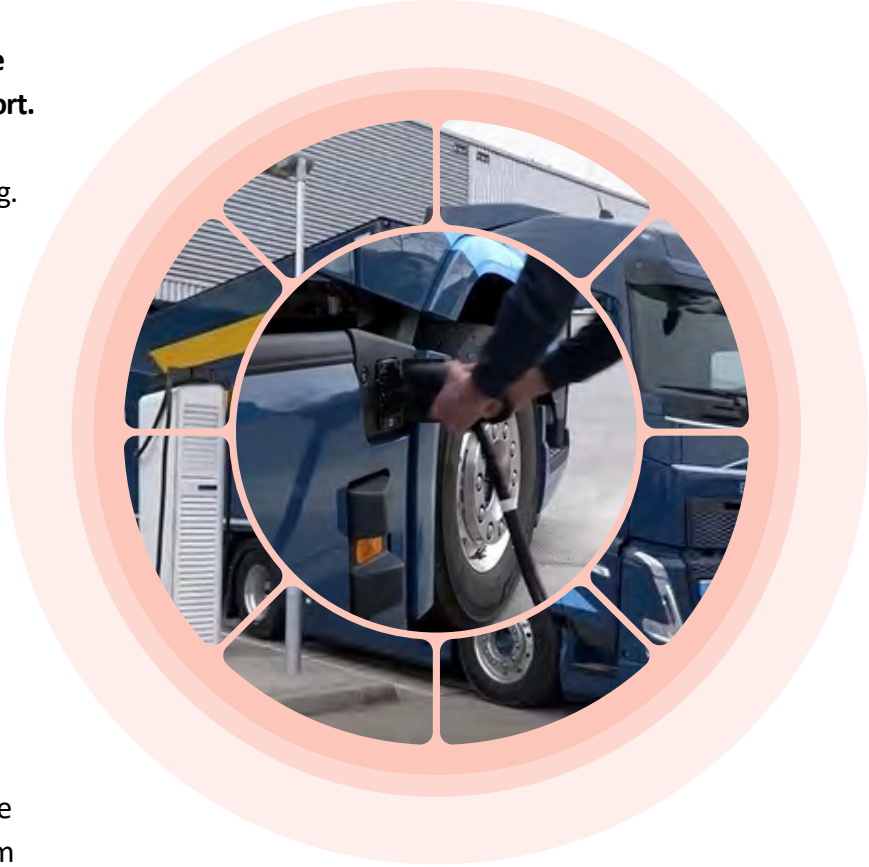
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MOBILITY

Sustainable airport mobility entails connecting passengers, employees, freight and the surrounding region through accessible, efficient and increasingly low-emission transport. The airport is not simply the start or end point of a journey, it is part of a wider mobility network linking rail, public transport, road transport, shared mobility, cycling and walking. Reliable surface access is essential to airport operations, and airports can work with transport partners to help reduce the associated emissions.



For airports, the challenge is therefore broader than reducing emissions from vehicles alone. High shares of private-car use, growing passenger volumes, congestion on access roads and parking areas, uneven public-transport provision and the shift patterns of airport employees can all make the transition more difficult. Freight and logistics add another dimension, as airports depend on reliable road transport while increasingly needing to reduce emissions from heavy-duty vehicles.
Within TULIPS, the focus was on shifting airport access away from private cars towards low-carbon, integrated alternatives such as public transport, shared mobility and active travel.

TULIPS explored these challenges through demonstrations covering different parts of the mobility system: multimodal modelling, Mobility-as-a-Service, operational evidence from 40-tonne electric trucks, simulation-based traffic management and greener international travel choices through behavioural nudging. Together, they show how digital tools, operational evidence and behavioural approaches can support more informed mobility planning and accelerate the shift towards lower-emission transport.

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Electric trucking was found to be one of the most effective demonstrations, achieving a 71% reduction in well-to-wheel CO_2e emissions and a 100% reduction in tailpipe NOx emissions compared with diesel trucks. Drivers responded positively to the electric trucks, but their purchase price, currently two to three times that of diesel trucks, remains a major barrier; the modelling and travel-behaviour approaches require further work, such as local data, calibration and stakeholder coordination, before they can be applied at other airports.

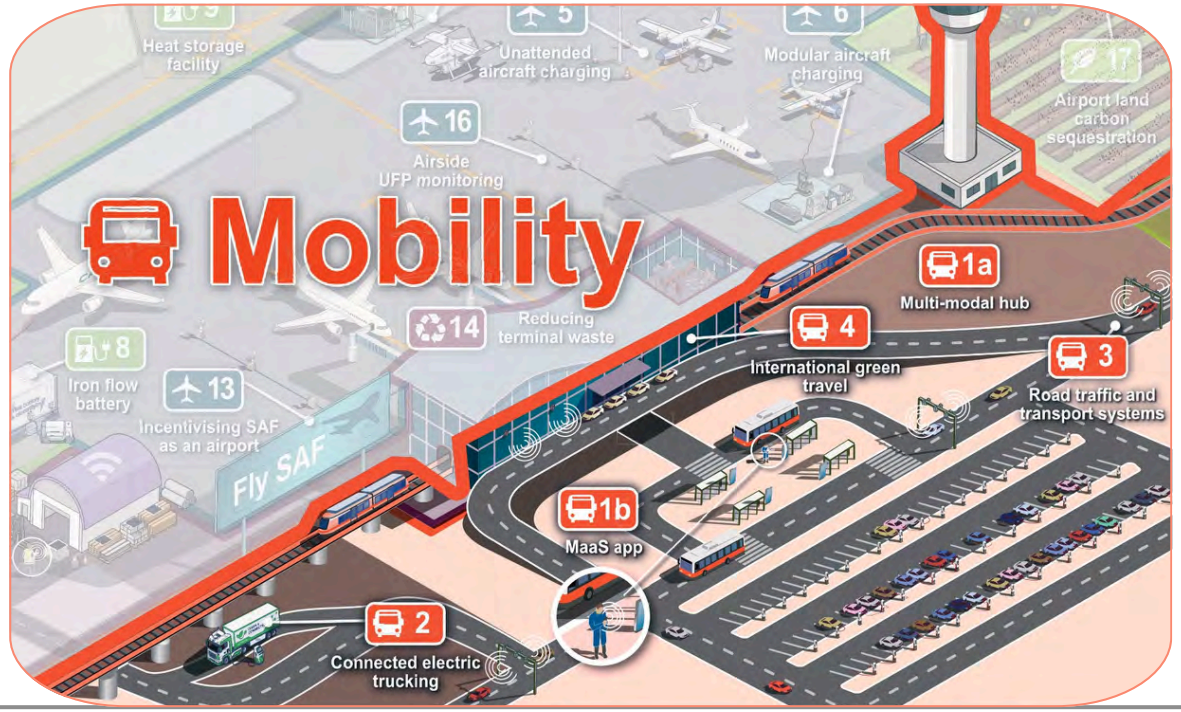
The results also underline that sustainable airport mobility cannot be delivered by the airport alone. Airports can play an important role as facilitators and conveners, but implementation depends on cooperation with passengers, employees, logistics operators, public-transport providers, municipalities, road authorities and other regional partners. This links to EU policy such as the TEN-T Regulation[1], which positions airports as nodes in a multimodal transport network, the Ambient Air Quality Directive, which tightens limits for NO_2 and particulate matter, and local zero-emission zones. Mobility therefore connects directly with the wider airport transition: it influences accessibility, local air quality, the local economy and emissions, while electrification and new transport technologies also depend on the energy and infrastructure systems addressed elsewhere in the roadmap.

TULIPS Demonstrations:

D1a Multi-modal hub
D1b Mobility as a Service – MaaS app
D2 Connected electric trucking
D3 Road traffic and transport systems
D4 International green travel

Contribution to the roadmap:

Supporting lower-emission, accessible and better-integrated journeys to, from and around the airport.



[1] The Trans-European Transport Network (TEN-T) is the EU's framework for an interconnected transport network comprising railways, roads, inland waterways, maritime routes, airports and multimodal transport terminals. It aims to improve connectivity, interoperability and integration between transport modes.

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Multi-modal hub

Demo 1A - Mobility

What is it?

A digital twin-based multimodal modelling framework – the Digital Twinning Environment (DTE) – was developed to simulate and assess policy interventions for low-emission landside access.

What TULIPS demonstrated

The DTE links travel demand, mode choice, road and public transport modelling with emissions assessment.

The framework enables "what-if" analysis of airport-access measures, including: Zero-emission zones, metro extensions, remote check-in, car-free access and combined strategies.

It quantifies impacts on CO_2, NO_2, vehicle-km, passenger-km and modal share – at multiple spatial scales.

Key results

1. A zero-emission zone achieved the largest modelled reductions, with 32.6% lower CO_2 emissions and 32.4% lower NO_2 emissions at Schiphol.
2. The Car Free Schiphol Landside scenario reduced modelled CO_2 emissions by 23.5% at Schiphol, increasing to 25.5% when combined with remote check-in. The combined scenario also increased the modelled public transport share from approximately 40% to 73%.
3. The strongest air quality benefits were observed locally, while regional impacts varied between scenarios.

Lessons learned

These results come from five modelled policy scenarios tested in the demonstration. Lessons from the demonstration include:

- Measures restricting conventional car access were generally more effective than improvements to public transport alone. Combining measures provided additional benefits.
- Restrictions on car access should be accompanied by attractive public transport alternatives and suitable mobility hubs.

Main replication conditions

The methodology is validated and documented, but deployment at new locations requires:

- Local network data.
- Calibration against regional traffic models.
- Stakeholder coordination between the airport and local authorities.

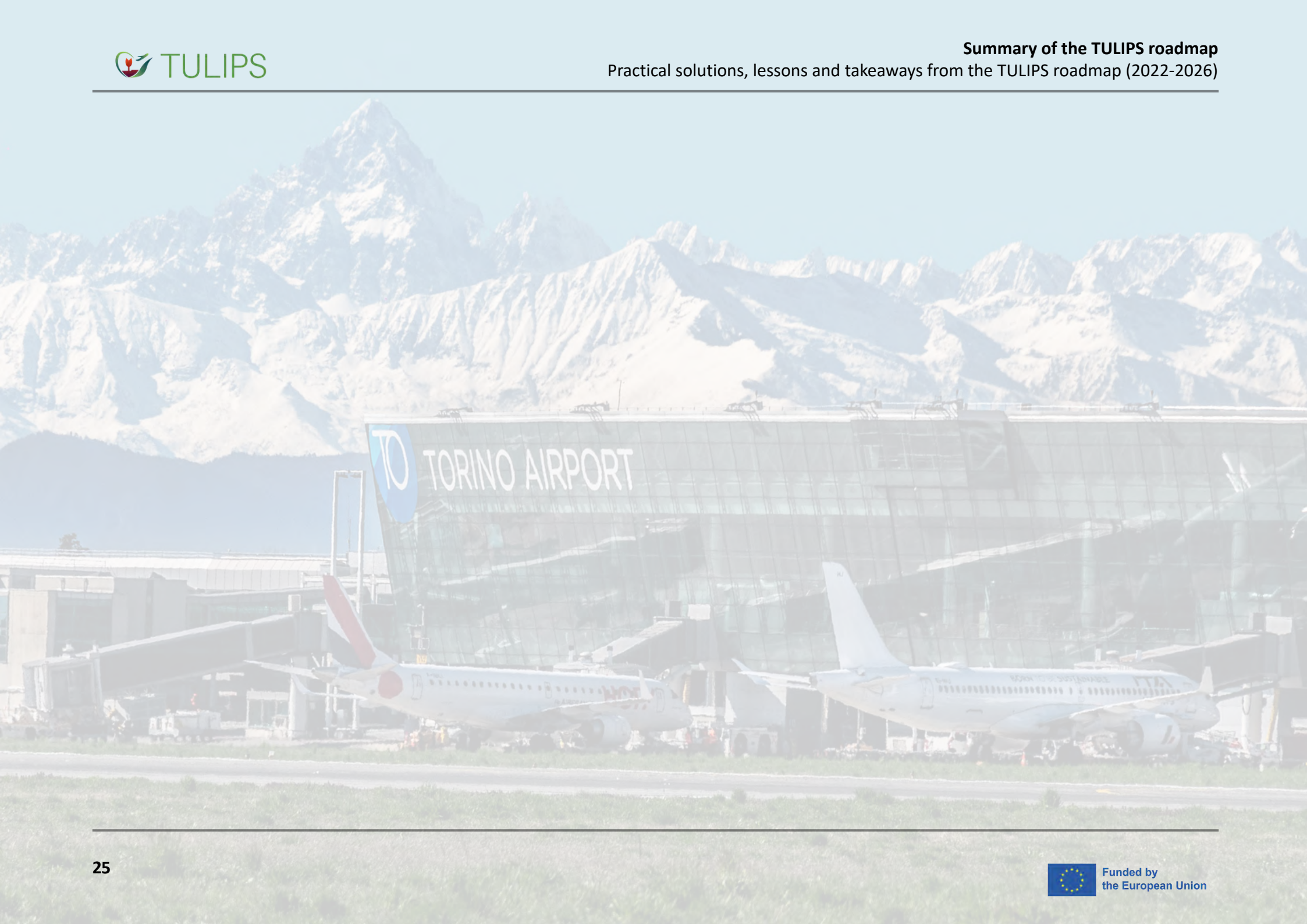
Recommended first step

Start with a zero-emission zone and expand it step by step towards car-free access, supported by mobility hubs and pilots of remote check-in at major train stations.

Learn more

- Official deliverables linked to this demo in Annex I.

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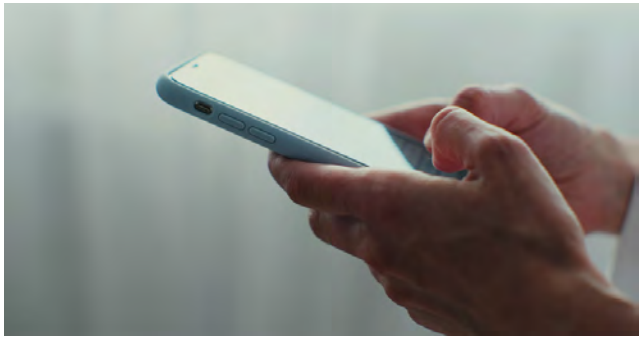
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MaaS App

Demo 1B - Mobility

What is it?

A Mobility-as-a-Service (MaaS) app that brings travel planning, access to sustainable mobility services, trip registration and reimbursement together in one digital environment. Two versions were configured on a shared integration layer: one for Schiphol employees and one for passengers.



What TULIPS demonstrated

Employees
real-life use at Schiphol

- A flexible mobility policy: employees choose their travel mode day by day.
- Trip registration by car, bicycle or public transport, plus access to shared mopeds, bicycles and electric taxis.
- Higher reimbursement for cycling than for driving: €0.40 vs €0.23 per km, plus a lease bicycle scheme (part of Schiphol's wider mobility policy, not introduced by the MaaS app itself).
- Payroll-ready reimbursement data and a personal overview of trips and indicative CO_2.

Passengers
small-scale demonstration

- Door-to-door journey planner with travel time, cost and indicative CO_2, and public transport ticket purchase.
- Alongside it, Schiphol's own travel website, reached via QR codes in the baggage halls.

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MaaS App

Demo 1B - Mobility

Key results

1 Among surveyed employees, the share mainly commuting by car decreased from 57% to 47%, reflecting changes in the wider mobility-policy context rather than the impact of the MaaS app alone.

2 Cycling increased from 10% to 19% as the main commuting mode among surveyed employees.

3 Average reported CO_2 emissions per commuting kilometre decreased by approximately 11% between 2022 and 2025.

Despite the reduction in emissions per kilometre, total reported commuting-related CO_2 emissions increased as overall commuting activity grew.

Lessons learned

These changes reflect the combined app and mobility-policy context. Hybrid working, housing costs and other policy changes also influenced commuting. Lessons from the demonstration include:

- Financial and practical incentives were stronger motivations than sustainability alone.
- Gaps in public transport remained a key barrier.
- Passengers wanted a simple, user-friendly and trustworthy travel-planning tool.

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Main replication conditions

- A flexible mobility policy with clear incentives for sustainable modes.
- Adequate public transport, including off-peak and night services, coordinated with transport operators.
- Integration with payroll and administration, in line with security and privacy requirements.

Recommended first step

Link a MaaS app to a flexible mobility policy with clear incentives for sustainable travel. Establish a commuting baseline before launch and monitor travel patterns and uptake from day one, combining registered trip data with user feedback.

Learn more

- Official deliverables linked to this demo in Annex I.

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Connected electric trucking

Demo 2 - Mobility

What is it?

TULIPS demonstrated three heavy-duty battery-electric trucks in airport logistics operations around Schiphol to assess their emissions, energy use and operational performance compared with diesel alternatives under real-world conditions.

What TULIPS demonstrated

The demonstration generated real operational data to support decisions on fleet electrification and charging infrastructure, helping reduce uncertainty around range, energy consumption, charging requirements and operational reliability. Three heavy duty battery-electric trucks drove on average 114 km per day and completed their daily operations on a single charge, mostly charged at the operators' own depots.

Key results

1. 71% lower well-to-wheel CO_2e emissions compared with diesel, using the Dutch electricity mix emission factor.
2. Approximately 151.7 tonnes of CO_2e avoided over 182,000 km.
3. Approximately 371.8 kg of tailpipe NOx emissions avoided (100% reduction) and estimated total particulate-emission reductions of 13% for PM_{10} and 47% for $PM_{2.5}$.

Lessons learned

These results are based on the Dutch electricity mix emission factor for the GHG assessment and apply to the duty cycles tested in the demonstration. Lessons from the demonstration include:

- Grid capacity and higher investment and operating costs were the main barriers.
- Daily operations could be completed on a single charge within the demonstrated duty cycles.
- Drivers responded positively to the electric trucks.

Main replication conditions

Wider uptake depends on a viable total cost of ownership and suitable charging infrastructure, including sufficient grid capacity at depots.
Higher vehicle costs remain a key barrier, with electric trucks currently reported to cost around 2–3 times more than fossil-fuel alternatives.
Future cost reductions and policy measures, including ETS2 and the Dutch truck charge, could improve their competitiveness with diesel trucks.

Recommended first step

Facilitate charging locations in depots and access to logistics areas. Coordinate cargo operators, transport companies and infrastructure providers and integrate the findings into zero-emission logistics and charging strategies.

Learn more

- Official deliverables linked to this demo in Annex I.

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Road traffic and transport systems

Demo 3 - Mobility

What is it?

TULIPS developed strategic traffic management initiatives to reduce the number of late arrivals and the time spent in traffic based on traffic simulation models.

Key results

The following reductions were modelled for the tested scenarios:

1. 21.3% lower modelled CO_2 emissions with ramp metering on a lower-volume motorway.
2. 5% lower modelled CO_2 emissions with a green wave on a corridor with little turning traffic; however, measures produced mixed results.
3. 4% lower modelled CO_2 emissions by moving car rentals off-site at Schiphol Plaza.

Main replication conditions

The methodology is not a plug-and-play digital product. The key insight from this demo is that traffic management effectiveness is highly location-specific: the same strategy produced opposite results at different sites. This underscores the need for site-specific assessment before implementation.

This makes the approach more suitable for expert modelling than direct off-the-shelf deployment.

What TULIPS demonstrated

The framework uses calibrated and validated traffic models, integrating data from external sources like the NDW[1], Rijkswaterstaat[2], the Province of North Holland, as well as Schiphol operational data. Use cases were developed on motorways, provincial roads and at Schiphol Plaza.

It can assess measures including: motorway ramp metering, green-wave traffic signals, incident management and dynamic rerouting, Kiss-and-Ride management, pick-up traffic buffering, off-site car-rental relocation and speed adjustments

The model assesses effects on: CO, CO_2, NOx, $PM_{2.5}$, fuel consumption, vehicle delay, stopped delay, number of stops.

Lessons learned

These results come from traffic simulations of the tested scenarios. They are not reductions measured in live traffic. Lessons from the demonstration include:

- Incidents raise emissions and delays; rerouting helps, but only partly.
- There is no one-size-fits-all solution: the same measure helped on one road but not on another.

Recommended first step

Prioritise ramp metering on lower-volume corridors and green waves on corridors with little turning traffic. At busy terminals, start with buffering of pick-up traffic.

Learn more

- Official deliverables linked to this demo in Annex I.

[1] NDW (Nationaal Dataportaal Wegverkeer) is the Dutch national data portal for road traffic data.
[2] Rijkswaterstaat is the Dutch government agency responsible for managing national roads and waterways.

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International green travel

Demo 4 - Mobility

What is it?

TULIPS explored how information-based nudging within the TULIPS TRIP door-to-door travel platform could influence international travellers' choices towards lower-carbon, multimodal travel options.

What TULIPS demonstrated

The approach was based on two user studies with 445 participants and the live TULIPS TRIP demonstrator.

It showed how tailored sustainability information and visual cues can support shifts from high-emission modes (e.g. short-haul air) to lower-carbon alternatives (e.g. rail), while acknowledging uncertainties linked to behavioural variability, contextual factors and self-selection.

The demonstrator combined:

- User-friendly travel interface;
- Traffic-light-style environmental ecolabels;
- Decentralised data integration.

The platform brought together public transport, micromobility and aviation data and used sustainability information and visual cues to support lower-carbon travel choices.

Key results

1 2.5× more likely to choose the train with a traffic-light ecolabel in the experiment.

2 A scenario-based assessment for the Amsterdam–Berlin route estimated a potential 22.4% reduction in CO_2e emissions if the experimental shift from air to rail were replicated.

3 Clear sustainability information positively influenced participants' stated choices of rail over short-haul air.

4 Over 80% of participants expressed interest in using such a platform.

These results come from user studies and an experimental setting. They are not choices observed in real bookings, and they may be influenced by self-selection of participants. The estimated CO_2e reduction is based on a hypothetical modal-shift scenario rather than measured changes in travel emissions.

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International green travel

Demo 4 - Mobility

Lessons learned

Lessons from the demonstration include:

- How sustainability information is presented matters: simple visual cues such as ecolabels make lower-carbon options easier to recognise.
- Nudging can support change but does not guarantee it: responses depend on the journey, the available alternatives and the individual traveller.
- Providing transparent sustainability information within integrated multimodal travel planning tools can support more sustainable travel choices, highlighting the importance of high-quality data integration, interoperability, and cross-sector collaboration in influencing traveller behaviour.

Main replication conditions

Replication requires cooperation with transport operators and access to interoperable timetable, fare and real-time travel data.

Limited data availability constrained the geographical scope and functionality of the demonstrator. Further real-world validation is needed to determine whether the observed effects on travel preferences translate into actual booking behaviour.

Recommended first step

Establish interoperable data-sharing between airports, rail and public transport providers, and introduce comparable environmental impact information into multimodal journey-planning tools to support more informed low-carbon travel choices.

Learn more

- Official deliverables linked to this demo in Annex I.



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AVIATION

Sustainable aviation at airports entails enabling lower-emission aircraft operations while preparing airport infrastructure, processes and partnerships for new aircraft technologies and energy carriers. Aviation-related impacts extend beyond the airport boundary: they include emissions from aircraft movements close to the airport, auxiliary power use on the ground and, most importantly, full-flight emissions. Airports do not directly control many of these sources, but they can influence the transition through infrastructure, operational requirements, incentives and collaboration with airlines, fuel suppliers and technology providers. Most of these emissions fall under the airport's Scope 3.



The main challenge is that aviation decarbonisation will require several complementary pathways rather than a single replacement technology. Sustainable Aviation Fuels (including eSAF) can reduce lifecycle emissions from conventional aircraft, while electric and hydrogen-powered aircraft may become relevant for suitable route segments. Airports must therefore prepare for new charging requirements, hydrogen infrastructure and changing fuel supply chains, while maintaining safe and reliable operations. TULIPS explored these challenges through six demonstrations. They address safe and scalable charging for electric aircraft, preparing for future hydrogen aviation, the integration and uptake of Sustainable Aviation Fuels (SAF), and improved understanding of ultrafine particle emissions around airport operations.

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Together, the results show how airports can create the conditions for cleaner aviation, even where the emissions come from airlines or other actors. The large-scale SAF supply chain showed that 30,000 tonnes of SAF could be integrated into Schiphol's existing fuel system without disrupting operations, and a site-assessment method was developed for future eSAF production. The charging demonstrations delivered a validated safety concept for unattended charging and a basis for assessing the grid demand of charging several aircraft at once. Hydrogen flight, SAF incentives and UFP mitigation need further development or evidence before wider implementation.

The Aviation domain is closely connected to the wider airport system. New aircraft technologies depend on the Energy domain for electricity, hydrogen and infrastructure, and SAF requires coordinated operations, supply chains and investment. Work on ultrafine particles links aviation with local air quality: there are no EU limit values for UFP yet, and research into their health effects is ongoing. Airports therefore increasingly act as enablers and coordinators, bringing together airlines, fuel and energy providers, grid operators, technology suppliers, regulators and operational partners. This links to EU policy such as ReFuelEU Aviation, which sets SAF supply obligations at EU airports from 2025, and to EASA aerodrome rules, where TULIPS identified gaps for electric-aircraft charging, firefighting and training.

TULIPS Demonstrations:

D5 Unattended aircraft charging
D6 Modular aircraft charging
D7 Operating liquid H_2 flights
D12 Large-scale SAF supply chain
D13 Incentivising SAF as an airport
D16 Airside UFP monitoring

Contribution to the roadmap:

Preparing airport infrastructure, operations and partnerships for lower-emission aviation and emerging aircraft energy systems.



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Unattended aircraft charging

Demo 5 - Aviation

What is it?

TULIPS developed and demonstrated a validated concept for charging electric aircraft without continuous on-site human supervision, using an EASA-certified Pipistrel Velis Electro and a Skycharge M20 charger.

What TULIPS demonstrated

The concept combines an airport-owned alerting architecture with two detection layers:

- Smart charger: internet-connected, providing real-time charging data;
- Smart camera system: detection of fire/smoke, unauthorised persons or vehicles, and aircraft movement.

The demonstration showed how remote monitoring and control, combined with camera-based detection of safety-related events, can support unattended charging operations and trigger appropriate safety responses.

Key results

The demonstration validated a remote-monitoring and safety concept for unattended electric aircraft charging.

The demonstration provides a basis for developing safety procedures and regulatory guidance for future unattended aircraft charging operations, rather than delivering immediate, quantifiable emissions reductions. Lessons learned include:

1. Strong regulatory support is required; aircraft/charger communication, central monitoring, cybersecurity and safety validation are critical.
2. Safety depends on the whole chain (monitoring, automatic shutdown, alerting, emergency response), not on the charger alone.
3. Existing aerodrome regulations do not yet provide a fully established approval framework and specific means of compliance for unattended electric aircraft charging.

Main replication conditions

The concept is not yet a ready-to-deploy unattended charging product.

- A defined regulatory approval pathway and appropriate means of compliance for unattended charging operations.
- Additional technical testing under different local conditions.
- Airport-specific safety assessments.
- Reliable monitoring and communication.
- Emergency-stop functionality.
- Integration with airport systems.
- Stronger firefighting and emergency-response procedures.

Recommended first step

Develop a regulatory approval pathway and develop a site-specific safety assessment with airport operations, emergency services, security teams and aircraft operators before planning a controlled trial.

Learn more

- Official deliverables linked to this demo in Annex I.

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Modular aircraft charging

Demo 6 - Aviation

What TULIPS demonstrated

The modular charging system was tested at Avinor Oslo Airport Gardermoen using Pipistrel Velis Electro battery modules.

The demonstration explored how a common charging system could accommodate different battery voltage levels, supporting the development of flexible charging infrastructure for electric aircraft. This shows that in the future aircraft batteries of different voltage levels can use the same charging infrastructure.

What is it?

TULIPS developed and tested a mobile system that simultaneously can charge batteries at different voltages.

The system used a high-capacity battery bank with aerospace-certified propulsion batteries to simulate future electric aircraft charging. The demonstration focused on charging the batteries at different voltage levels using the same modular charging system. It also included activities to improve emergency response procedures through lithium-battery fire testing and training.





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Modular aircraft charging

Demo 6 - Aviation

Key results

1 The modular charging system was validated for multiple battery configurations and voltage levels between 400 V and 1.5 kV.

2 A transportable test platform for site specific charging was developed.

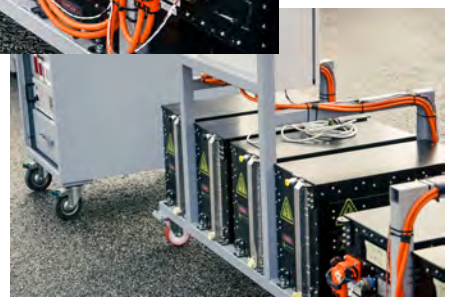
3 The battery fire test provided operational knowledge for the airport firefighters.

Lessons learned

Lessons from the demonstration include:

- Battery fire testing requires extensive safety and waste management planning.
- Simultaneous aircraft charging must be planned as part of the airport's wider energy system.
- A modular set up lets airports test different battery and charging configurations before committing to permanent infrastructure.
- Repurposed aircraft batteries can serve as test storage, although no lifecycle assessment was made.





Main replication conditions

The system is a planning and testing tool, not a ready-to-deploy charging solution.

Further use requires:

- A suitable grid connection based on the system configuration and charging requirements.
- Testing with other aircraft types, battery capacities and charging configurations.
- Integration with airport and grid-management systems.
- Validation of charging standards, interoperability and safety procedures.

Recommended first step

Estimate expected aircraft charging demand (battery configurations, charging power, simultaneous charging) and identify likely charging locations. Then plan a site-specific technical and safety evaluation with the grid operator, aircraft and charging-system providers, and the aviation authority.

Learn more

- Official deliverables linked to this demo in Annex I.

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Operating liquid hydrogen flights

Demo 7 - Aviation





What is it?

TULIPS conducted an airport-facilitated hydrogen flight demonstration as part of preparing airport operations and infrastructure for future hydrogen aviation. The demonstration used the liquid hydrogen (LH_2)-powered HYDRA-2 drone at Rotterdam The Hague Airport.

What TULIPS demonstrated

TULIPS developed a concept of operations and a functional safety assessment for liquid hydrogen (LH_2) storage and aircraft refuelling at Rotterdam The Hague Airport. The work addressed storage filling, aircraft refuelling, system interfaces and safety requirements within an active airport environment.

The demonstration showed that a liquid hydrogen-powered drone could be safely refuelled and operated at a commercial airport, validating the associated refuelling infrastructure and operational procedures.

Related infrastructure studies assessed future hydrogen demand and modelled options for larger-scale LH_2 storage, distribution and refuelling.

Key results

1 Successful demonstration of LH_2 refuelling and operation of the HYDRA-2 drone at Rotterdam The Hague Airport, supported by a documented operating and safety protocol.

2 Site-specific assessment addressed the safety requirements and infrastructure needed for LH_2 storage and refuelling at the airport.

3 A methodology was developed to estimate future hydrogen demand and assess the infrastructure needed for larger-scale LH_2 storage, distribution and refuelling, including the management of hydrogen boil-off.

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Operating liquid hydrogen flights

Demo 7 - Aviation

Lessons learned

The demonstration established the feasibility of LH_2 handling and refuelling in an operational airport environment, while the infrastructure studies provided a basis for future scale-up. No direct greenhouse-gas emission reductions were quantified. Lessons from the demonstration and assessment include:

- Hydrogen-powered flight has the potential to become a genuinely low-carbon aviation solution, but the environmental benefits depend heavily on the source of the hydrogen.
- Minimising hydrogen leaks and venting will be an important design and operational objective for future hydrogen infrastructure.
- Infrastructure scale must follow realistic hydrogen demand from future aircraft operations, including boil-off management.
- The safety protocol must be reviewed against each airport's layout and operations; it cannot simply be copied.

Main replication conditions

The main challenge for replication is establishing safe, appropriately sized LH_2 infrastructure within the specific operational and regulatory conditions of each airport. This requires:

- Airport-specific siting and safety assessment
- Suitable LH_2 supply and storage
- Cryogenic handling and refuelling procedures
- Relevant permits and approvals
- Trained personnel and emergency-response arrangements

Infrastructure sizing must reflect anticipated hydrogen demand from future aircraft operations and local operating conditions. The Rotterdam safety assessment cannot be transferred without reviewing the receiving airport's layout and proposed operations.

Recommended first step

Define the intended hydrogen-aircraft trial and its supply requirements. Bring together the airport, aircraft provider, hydrogen supplier, relevant authorities and emergency services to assess a suitable site and develop a local operating and safety concept.

Learn more

- Official deliverables linked to this demo in Annex I.

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Large-scale SAF supply chain

Demo 12 - Aviation

What TULIPS demonstrated

At Amsterdam Airport Schiphol, 30,000 tonnes of neat SAF were sourced over four months and transported to the EVOS tank facility at the Port of Amsterdam, where they were blended with conventional Jet A-1. Blending took place outside the airport because only fuel recertified to ASTM D1655 Jet A-1 specifications may enter the airport fuel system.

The resulting compliant fuel was integrated into Schiphol's existing fuel-supply infrastructure, covering:

- Supply scheduling
- Storage
- Blending
- Recirculation
- Sampling
- Fuel-quality testing
- Certification
- Traceability and sustainability reporting (RED II).

In parallel, TULIPS developed a framework for assessing potential PtL eSAF production sites, considering renewable hydrogen and CO_2 supply, grid capacity, land, infrastructure, zoning, permitting and stakeholder acceptance.

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What is it?

TULIPS demonstrated how large volumes of Sustainable Aviation Fuel (SAF) can be integrated into an existing airport fuel-supply system, while maintaining fuel quality, certification, traceability and normal fuelling operations.

The demonstration was complemented by a site-assessment methodology for future Power-to-Liquids (PtL) eSAF facilities.

Key results

1. 30,000 tonnes of neat SAF blended in a 27% certified fuel blend (100,000 tonnes) containing the SAF.
2. Reductions of 89% CO_2e, 7% PM_{10} and 30% SO_2.
3. Existing infrastructure was used to integrate the compliant SAF blend into Schiphol's fuel-supply system.
4. No disruption to normal airport fuelling operations reported.
5. SAF upscaling with new eSAF-types (in 2030) and raise of SAF mandated volumes (in 2035) may lead to increasing operational, infrastructural and regulatory constraints at EU airports.

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Large-scale SAF supply chain

Demo 12 - Aviation

Lessons learned

Each tonne of SAF supplied replaced a tonne of fossil Jet A-1. The climate benefit depends on the SAF used and its batch-specific sustainability evidence; where this confirms at least 70% lifecycle greenhouse-gas savings in line with the EU RED-II criterion (RED = Renewable Energy Directive). No cost comparison was made. Lessons from the demonstration include:

- Large SAF volumes can be handled through existing airport fuel infrastructure, without a separate distribution system.
- Certification and sustainability documentation must accompany the fuel through the whole supply chain.
- The airport is not automatically the best eSAF production site: land, grid capacity, CO_2 supply and zoning are key constraints.

Main replication conditions

Replication depends on local fuel infrastructure and supply-chain conditions and may require site-specific adaptation or investment. More data on costs, lifecycle emissions and infrastructure requirements is needed to assess the business case.

For the complementary assessment of future PtL/eSAF facilities, key conditions include:

- Renewable electricity and grid capacity
- Hydrogen supply
- CO_2 availability
- Suitable land
- Zoning and permitting
- Infrastructure
- Stakeholder acceptance

The methodology supports early-stage screening only; it is not an engineering design, investment-grade feasibility study or permit approval.

Recommended first step

Map the existing fuel-supply chain with fuel suppliers, storage and blending operators, airlines and regulators. Identify the requirements for introducing a compliant SAF blend, including volumes, logistics, quality assurance and traceability, before planning an initial supply campaign.

Learn more

- Official deliverables linked to this demo in Annex I.

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Incentivising SAF as an airport

Demo 13 - Aviation

What is it?

TULIPS explored how airports can support increased awareness and uptake of Sustainable Aviation Fuel (SAF) through passenger awareness campaigns.

What TULIPS demonstrated

The work examined airport-led SAF support options and passenger engagement through awareness campaigns and surveys.

A proof-of-concept campaign at Schiphol and Oslo explored passengers' understanding of SAF, willingness to pay and responses to targeted communication.

Key results

1. First upscaling SAF campaign in the EU.
2. 1,000+ passenger responses across two airports (Schiphol and Avinor Oslo).
3. Limited initial passenger awareness of SAF. Targeted communication increased interest in lower-carbon travel.
4. Willingness to pay varied between passenger groups.
5. Targeted physical SAF supply with credible demand from airlines and customers provides a basis for airport-led SAF engagement.

Lessons learned

Lessons from the demonstration include:

- Passenger awareness cannot be assumed; it is the starting point for any incentive.
- One incentive or campaign will not suit every passenger: segmentation and targeted messaging matter.
- Communication alone does not create SAF volumes; it needs a credible mechanism for buying or supporting SAF.

Main replication conditions

- Clear, credible passenger information.
- Coordination between airports, airlines and SAF partners.
- Adaptation to local passenger groups
- Applicable legal and financial arrangements for any SAF incentive or voluntary contribution scheme.

Evaluation should distinguish awareness, stated willingness to pay and actual contributions or SAF uptake.

Recommended first step

Assess potential deployment of additional SAF and define the intended engagement objective with airline partners

Learn more

- Official deliverables linked to this demo in Annex I.

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Airside UFP monitoring

Demo 16A - Water droplets

Demo 16B - UFP research lab

What is it?

Demo 16A

The demonstration combined a water-spray trial aimed at mitigating Ultra-Fine Particles (UFP) with the development of a high-resolution UFP monitoring and research capability at Twente Airport and Schiphol Airport.

Demo 16B

TULIPS explored how airports can better measure, understand and mitigate UFP exposure in the airside environment by creating a monitoring/living lab. There are no legal limits for UFP, so airports measure them voluntarily, and their health effects are still unclear.

What TULIPS demonstrated

Demo 16A

A water-spray system was tested under real apron conditions to assess whether it could reduce UFP concentrations.

Demo 16B

A 24/7 hyper-local monitoring network was deployed across two operational apron areas at Schiphol, linking high-resolution UFP measurements with airport operational activities.

Key results

1

Demo 16A

The water-spray intervention affected particle concentrations and size distribution but did not achieve the targeted 15% UFP reduction. The tested configuration was assessed as unsuitable for operational deployment.

2

Demo 16B

Monitoring data was combined with operational information to identify exposure patterns, hotspots and potential sources.



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Airside UFP monitoring

Demo 16A - Water droplets

Demo 16B - UFP research lab

Lessons learned

Monitoring can support the development and evaluation of mitigation measures but does not itself demonstrate reduced UFP exposure. Lessons from the demonstration include:

- Measure first, mitigate second: a reliable baseline is needed to judge any intervention.
- Linking UFP data with airport operations shows where and when exposure occurs.

Main replication conditions

Demo 16A

For the water-spray concept, the evidence does not support replication as a proven mitigation solution for UFP.

Demo 16B

For the UFP Living Lab / monitoring approach, wider use requires:

- Reliable high-resolution monitoring.
- Connection with operational data.
- Sufficient spatial and temporal coverage.
- Further validation of mitigation approaches.

Recommended first step

Demo 16B

Establish a UFP monitoring baseline in relevant apron areas and link measurements with operational activities and meteorological conditions. Use the findings to identify exposure patterns and select potential mitigation measures for controlled testing.

Learn more

- Official deliverables linked to this demo in Annex I.



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CIRCULARITY



Circularity entails moving away from a linear "take–make–dispose" model towards an airport system in which materials, products and resources are kept in use for as long as possible and their value is preserved. For airports, this means reducing the use of virgin resources and the generation of waste while increasing reuse, repair, refurbishment, remanufacturing, recycling, designing infrastructure for longer lifetimes and disassembly, more circular approaches to procurement and construction, and careful use of water.

The main challenge is that airports manage large and complex material flows across terminals, construction projects, maintenance activities and supply chains. Reusable materials are often not visible across projects, data on composition and condition may be incomplete, traceability is lost once materials leave a project and procurement processes are usually designed around buying new materials rather than reusing existing ones. This can lead to unnecessary waste, higher embodied emissions and missed opportunities to retain material value within the airport system.

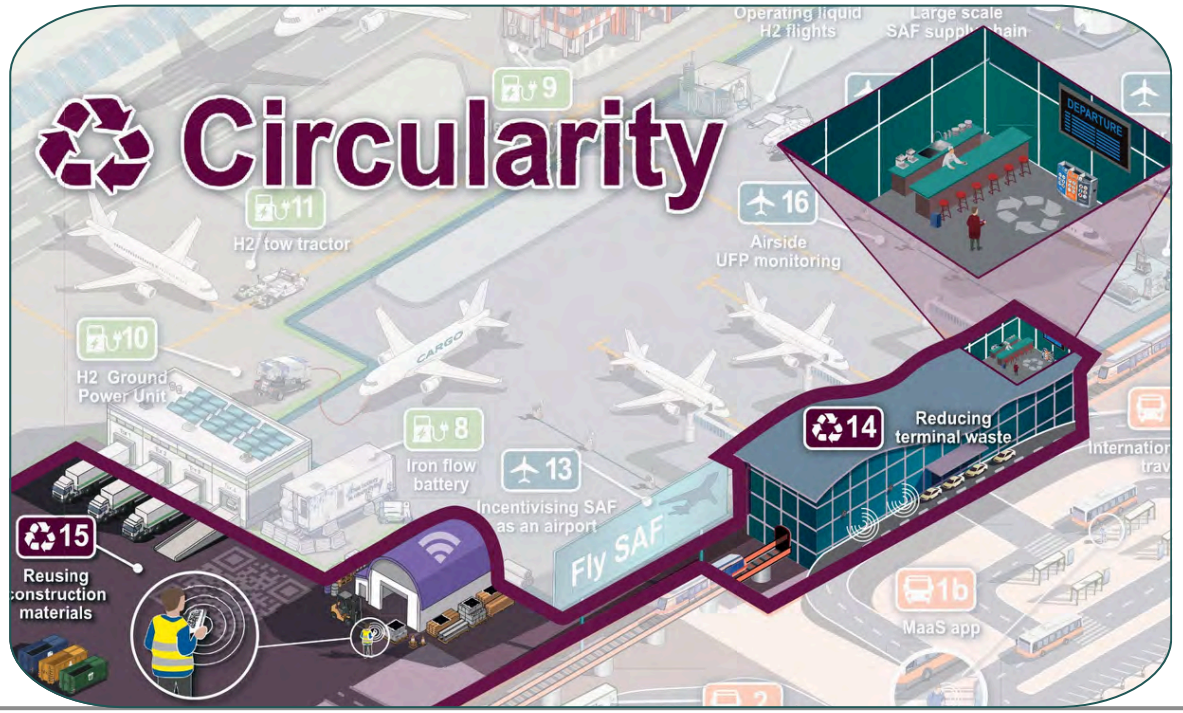
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TULIPS explored these challenges through two demonstrations: terminal waste reduction and the reuse of secondary construction materials. Together, they show that circularity is not only about waste treatment; it also requires changes in procurement, data management, logistics, asset management and project delivery. The construction-materials demonstration provides the strongest evidence. By combining digital material passports, a digital marketplace and warehouse-linked logistics, it avoided 70 tonnes of CO_2e, diverted almost 27 tonnes of materials from disposal and saved around €220,000 in sourcing and waste fees across three airports, supported by circular design guidelines for airport construction. The terminal-waste demonstration, with reusable bowls and waste hubs at Avinor Oslo Airport and redesigned bins at Schiphol, showed that no single intervention is enough: infrastructure, behaviour and policy, such as tax rules that favour take-away packaging, need to work together. It needs further development before wider implementation.

Circularity is closely connected to the wider airport transition. Reusing materials reduces embodied carbon and resource demand, and better waste and resource data support climate reporting, including CSRD and Scope 3. Circularity also complements Energy and Carbon Removal, for example when organic airport waste is turned into biochar that stores carbon in the soil. In the long term, the ambition is an airport where waste is virtually eliminated, materials stay in productive use for as long as possible and economic activity is decoupled from resource consumption.

TULIPS Demonstrations:
D14 Reducing terminal waste
D15 Reusing construction materials

Contribution to the roadmap:
Embedding resource efficiency, reuse and circular design into airport operations, procurement and infrastructure development.



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Reducing terminal waste

Demo 14 - Circularity

What is it?

This demo experimented with different behavioural and operational interventions to improve passenger waste separation and circular practices.

What TULIPS demonstrated

Case 1 The Reusable Bowl System for Takeaway: Avinor Oslo Airport trialled the adoption of QR-coded reusable takeaway bowls combined with emerging technologies for payment and smart return machines, and central dishwashing.

Case 2 Waste Management Redesign Through Waste Hubs: Avinor Oslo Airport trialled sustainable waste management through the pilot of a local waste hub integrated with a Pay-As-You-Throw (PAYT) approach with real-time feedback, aiming to improve waste separation in the residual waste stream.

Case 3 Schiphol Airport tested redesigned waste-separation stickers on 43 passenger-facing bins to assess whether clearer visual communication could improve disposal behaviour and reduce contamination.









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Reducing terminal waste

Demo 14 - Circularity

Key results

1 Case 1 achieved very low uptake, with only 35 bowls per month used during the trial period in Avinor Oslo Airport.

2 The most successful intervention was Case 2, which improved waste segregation performance and reduced residual waste by around 3%.

3 Case 3 produced mixed results. While contamination decreased in paper and residual waste bins, contamination increased in plastics and drinking cartons.

4 Overall, operational waste per passenger decreased by 10.6% across the three TULIPS demonstration airports, from 218 g to 195 g per passenger.

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Lessons learned

Lessons from the demonstration include:

- Individual pilots brought only limited change; avoiding waste in the first place needs more systemic change.
- Combine infrastructure, behaviour and policy – nudges alone are not enough.

Recommended first step

- Start small, scale smart: map your waste streams and most common items, then pilot in a controlled area, such as specific gates or staff zones, before rolling out airport wide.
- Enforce existing waste-separation rules, with monitoring and financial incentives. Use upcoming PPWR obligations as a lever: takeaway outlets must offer a reusable option from 12 February 2028, and single-use plastic packaging for food and drink consumed on the premises is banned from 1 January 2030.
- Focus on representative waste-producing groups (such as retailers) to understand waste flows and identify opportunities for more impactful waste-management interventions.

Main replication conditions

- The results suggest that combining improved infrastructure with employee engagement and feedback can increase awareness of recycling practices and encourage more sustainable behaviors beyond the immediate intervention area. This highlights the importance of behavioral change and stakeholder participation in achieving operational waste reductions.
- Make interventions effortless and part of existing workflows.

Learn more

- Official deliverables linked to this demo in Annex I.

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Reusing construction materials

Demo 15 - Circularity



What is it?

TULIPS developed an operating model for identifying, tracking, storing and reusing secondary construction materials across airport construction, renovation and maintenance projects. The approach combined digital material matching, QR-based material passports and warehouse-linked logistics to make reusable materials visible and traceable across projects.

What TULIPS demonstrated

The operating model connects three key elements:

- Digital marketplace matches available materials with potential receiving projects and allows them to be reserved.
- Material passports provide traceability and information on condition and reuse potential.
- Warehouse-linked logistics support accountable storage and movement of reusable materials.

The workflow enables items reused, avoided waste, avoided CO_2e and avoided costs to be systematically tracked. The model was piloted in three settings: a gate deconstruction and rebuild at Avinor Oslo Airport, an office refurbishment at Larnaka Airport, and the registration and matching of secondary materials through a digital marketplace at Schiphol Airport.

Key results

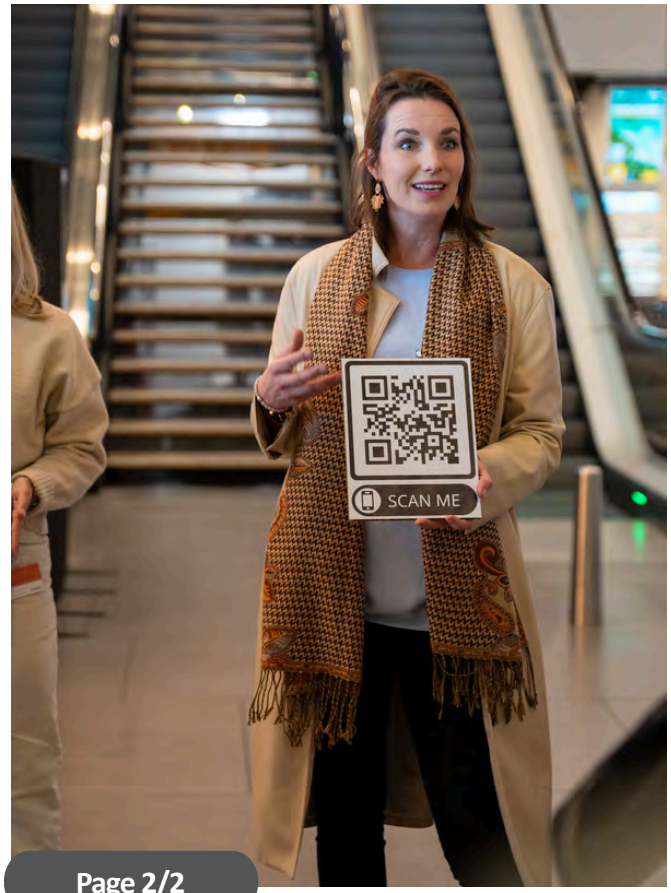
1. 70 tonnes CO_2e avoided across three airports.
2. 945 assets retained in circulation.
3. 27 tonnes of products diverted from disposal.
4. €220,000 saved on sourcing and waste fees across the three pilots.

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Reusing construction materials

Demo 15 - Circularity



Lessons learned

Avoided CO_2e is embodied carbon compared with buying virgin materials, and falls mainly under Scope 3 (value-chain) emissions. Lessons from the demonstration include:

- Early availability of material data is essential for effective reuse. But missing data, regulation and manual tagging still limit reuse.
- Reuse requires partnership and close collaboration between construction, warehouse and sustainability teams.

Recommended first step

Capture material data at the start of your next renovation or demolition project, and check what is already available before buying new materials.

Main replication conditions

Scaling requires the approach to become part of normal governance, procurement and contracting, rather than remaining an optional project practice.

Key conditions include:

- Inventory checks before procurement
- Material-passport coverage at design freeze
- Confirmed reuse routes before dismantling
- Circular procurement clauses
- Common KPIs and verification criteria
- Clearer rules on reusing structural components
- Common digital traceability standards.

Learn more

- Official deliverables linked to this demo in Annex I.

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ENERGY



Sustainable airport energy entails reducing energy-related emissions while building an airport energy system that is reliable, flexible and able to support new technologies. Airports are not only energy consumers: they increasingly need to manage electricity, heat, storage and alternative energy carriers across terminals, buildings, airside operations and ground support activities. Within TULIPS, the energy domain covers airport energy systems, energy storage, heat supply and zero-emission ground support equipment.

The main challenge is that decarbonisation often increases pressure on already constrained energy infrastructure. Electrification of vehicles and equipment, future aircraft charging and the replacement of fossil-based heating can create new peak loads, while grid reinforcement may be costly, slow or technically difficult, particularly at remote stands. Airports therefore need solutions that reduce emissions without compromising operational reliability and that make better use of available energy infrastructure.

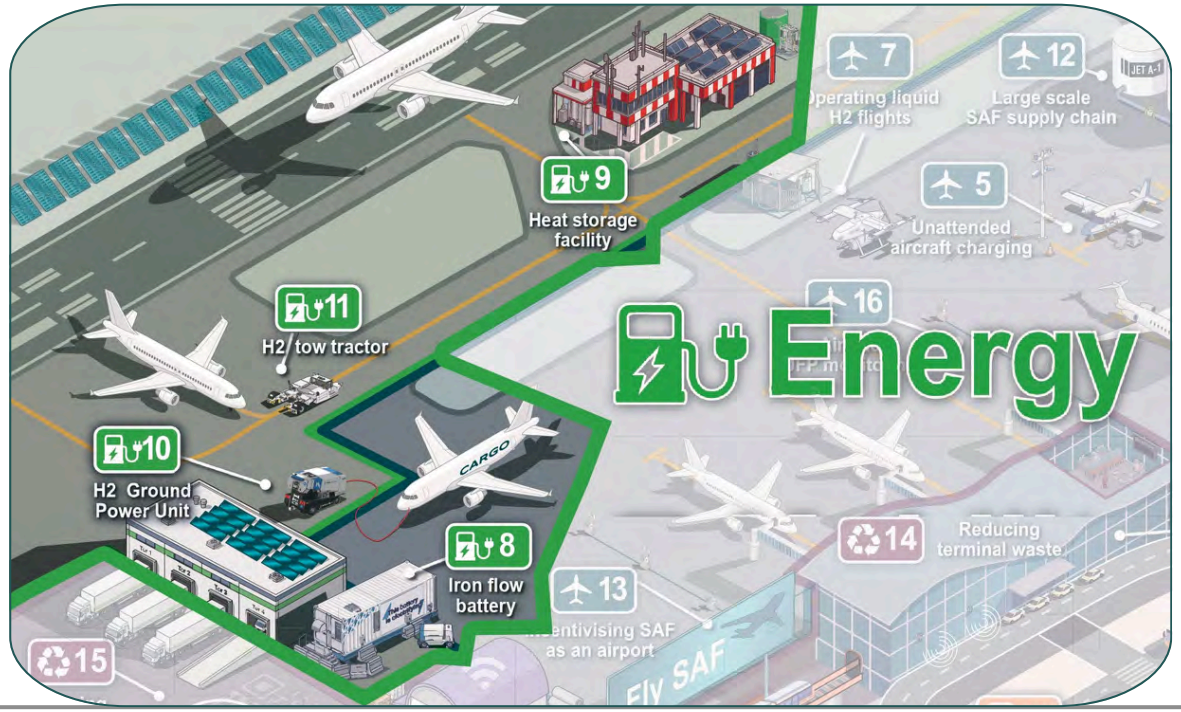
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TULIPS explored these challenges through four demonstrations. They include an iron flow battery for airside electricity storage, heat supply facilities, a Hydrogen Ground Power Unit and a hydrogen tow tractor. Together, the results show that the airport energy transition is not about one technology, but about combining storage, flexible demand, alternative energy carriers and operational integration in ways that fit local airport conditions. Hydrogen offers an alternative where battery-electric solutions are limited by charging time, grid capacity or high power demand. All four demonstrations were assessed as feasible, but at different levels of readiness: heat storage can be deployed within 6-12 months, while the iron flow battery needs several combined loads for a viable business case, and hydrogen equipment depends on hydrogen supply, certification and permitting.

The Energy domain is closely connected to the wider airport system. It enables the electrification and hydrogen solutions within Aviation, supports lower-emission vehicles and logistics in Mobility, and contributes to broader climate objectives by reducing fossil-energy use across airport operations. In the longer term, airports are expected to become integrated energy hubs in which generation, storage, distribution and smart energy management are coordinated across different airport uses, and which may provide flexibility services to the wider grid.

TULIPS Demonstrations:
D8 Airside electricity 'traffic' demonstration using an iron flow battery
D9 Heat storage facility demonstration
D10 Hydrogen Ground Power Unit
D11 Hydrogen tow tractor

Contribution to the roadmap: Enabling flexible, resilient and increasingly zero-emission energy systems for airport operations.



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Iron flow battery

Demo 8 - Energy

What is it?

TULIPS demonstrated how a containerised, trailer-mounted iron flow battery combined with a smart microgrid can replace diesel GPUs and support airport electrification by storing electricity and making it available where grid capacity is constrained.

The system was used to support electric Ground Power Unit (eGPU) charging without requiring immediate major grid reinforcement.

What TULIPS demonstrated

The iron flow battery can:

- Store electricity during lower-demand periods
- Support eGPU charging at constrained stands
- Supply stored electricity during periods of higher demand.

The technology also uses non-flammable, earth-abundant materials such as iron, salt and water, avoiding reliance on scarce battery metals such as lithium and cobalt.



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Iron flow battery

Demo 8 - Energy

Key results

1. The demonstration team estimated daily savings of 214 kg CO_2e compared with conventional diesel GPUs and 15–20 kg CO_2e compared with HVO100-powered GPUs, based on equivalent operations at five aircraft stands.
2. Replacing the diesel GPUs serving stands A31–A35 reduces annual emissions by approximately 410 kg NO_x and 16.85 kg PM_{10}. These are modelled emission reductions, with limited effects on overall airport-wide pollutant concentrations.
3. €0.21/kWh modelled Levelised Cost of Storage, compared with €0.54/kWh for HVO100.
4. Up to €40,000/year projected fuel savings at full utilisation (30,000 L HVO100 avoided).
5. ~14 years estimated payback period.
6. 20+ year expected lifespan for the iron flow battery technology.

Lessons learned

Savings and payback are indicative Schiphol calculations at full utilisation. In the pilot, the battery was not used at its intended level, because of limited eGPU availability, permitting delays, restricted maintenance access and complex microgrid-control logic. Lessons from the demonstration include:

- The business case only becomes strong when the battery serves several recurring loads, not a single small eGPU fleet.
- Mobile storage can defer costly and slow grid reinforcement at constrained stands.

Recommended first step

Identify a grid-constrained location and assess recurring electricity demand with ground handlers, airlines and the grid operator. Compare storage capacity, charging schedules and costs with alternative infrastructure options, prioritising opportunities to serve several loads.

Main replication conditions

With larger-scale deployment, the impact in terms of GHG savings and air quality could extend across a wider area of the airport.

Replication is more effective when the battery serves several recurring loads, for example: eGPUs, other electric GSE, demand-response services.

Further deployment also depends on: Alignment between battery availability and demand, streamlined permitting, local maintenance support, simplified microgrid control and clearer certification pathways for non-lithium storage.

Learn more

- Official deliverables linked to this demo in Annex I.

Funded by the European Union

Heat storage facility

Demo 9 - Energy

What is it?

TULIPS demonstrated a thermal energy-storage solution for hot-water supply that can replace natural-gas heating while avoiding significant increases in peak electrical demand. The NEStore system stores heat using off-peak electricity and supplies hot water when needed, decoupling heat generation from heat demand.

What TULIPS demonstrated

The thermal battery was demonstrated in a critical airport facility (a fire station) at Schiphol Airport, where continuous hot-water availability was required. The existing gas boiler stayed in place as a backup but was never needed.

The system:

- Stores heat using off-peak electricity.
- Supplies hot water during peak demand.
- Minimises additional peak electrical demand.
- Retains operational reliability while replacing gas heating.

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Key results

1 Elimination of ~4,000 m^3 natural gas for hot-water production, resulting in a 67.3% (location-based) to 92.0% (market-based) reduction in CO_2e emissions compared with the gas baseline.

2 Full hot-water availability was maintained throughout the demonstration, with system uptime exceeding 90%. The backup gas boiler was not required.

3 6–12 months to deploy; payback ~17.5 years (~14% ROI over 20 years).



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Heat storage facility

Demo 9 - Energy

Lessons learned

Results come from one installation. Near-zero operational emissions depend on using green electricity for charging. Lessons from the demonstration include:

- Decarbonisation and operational reliability are not mutually exclusive, even in critical facilities.
- Storing heat off-peak avoids new peak load and grid upgrades.

Main replication conditions

Replication is most suitable for airport buildings with consistent hot-water demand and sufficient electrical capacity. The system can be integrated into existing hot-water infrastructure without major modifications, while its economic viability depends on local energy prices, installation conditions and operating demand.

Deployment requires standard electrical and plumbing connections (a 3.6 kW socket), with sufficient electrical capacity and integration into the existing hot-water system and building management system (BMS). No regulatory barriers were identified: the system complies with standard plumbing and electrical codes and Legionella guidelines (≥65 °C).

The business case improves with:

- Bulk procurement
- Rising gas and carbon prices
- Subsidies
- Off-peak electricity availability
- Smart Energy Hub / renewable-energy integration.

Recommended first step

Identify a building with consistent hot-water demand, such as a fire station, or maintenance building, and assess its consumption profile, electrical capacity and available installation space. Size the storage system and charging schedule to maintain hot-water availability while avoiding electricity peaks, then monitor performance before wider rollout.

Learn more

- Official deliverables linked to this demo in Annex I.

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Hydrogen ground power unit

Demo 10 - Energy



What is it?

TULIPS demonstrated a hydrogen fuel cell-battery hybrid Ground Power Unit (hGPU) as an alternative to diesel ground power where battery charging, grid capacity or operational flexibility can limit battery-electric solutions.

What TULIPS demonstrated

The hGPU combines a high energy capacity (350 kWh) with 350-bar compressed-hydrogen refuelling, enabling consecutive aircraft turnarounds without battery-recharging downtime.

The system was demonstrated at Schiphol with KLM narrow-body aircraft, including Embraer E175/E190/E195 and Airbus A320-family aircraft, with performance on par with HVO100 GPUs. Replication took place at Rotterdam – The Hague Airport.

The operational demonstration also generated practical experience with hydrogen refuelling, equipment handling, safety procedures and integration into existing airport ground operations.

Key results

1. 44 aircraft turnarounds completed at Schiphol, demonstrating operational performance comparable to conventional GPUs.
2. Approximately 5.4 kg CO_2e saved per turnaround (85% well-to-wheel reduction) compared with a conventional fossil-diesel GPU, assuming renewable hydrogen.
3. 15–20 dB quieter than a conventional GPU, depending on cooling-fan operation.
4. Zero NO_x and PM_{10} exhaust emissions at the point of use. Replacing one diesel GPU was estimated to avoid 150–190 kg NO_x and 6–8 kg PM_{10} annually, depending on utilisation.

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Hydrogen ground power unit

Demo 10 - Energy

Lessons learned

Lessons from the demonstration include:

- The demonstration confirmed that hydrogen-powered GPUs can provide a technically viable zero-tailpipe-emission alternative without compromising operational performance, particularly where high utilisation rates, battery-recharging requirements or grid limitations restrict battery-electric solutions.
- Beyond the hardware itself, the demonstration provided transferable knowledge on hydrogen supply and refuelling logistics, operational integration, safety procedures and infrastructure requirements. These findings can support airports in planning future hydrogen-powered ground support equipment and related infrastructure.

Main replication conditions

Wider deployment depends on:

- Hydrogen supply & refuelling logistics
- Standardised safety procedures for airside hydrogen
- Certification / CE marking
- Insurance acceptance
- Trained personnel and maintenance support
- Airport-specific permitting

The refuelling concept and required safety distances must fit local stand layouts and operational schedules. The availability and lifecycle emissions of the hydrogen supply are also essential for achieving meaningful climate benefits.

Recommended first step

Identify a suitable ground-power use case, such as remote or grid-constrained stands, and assess hydrogen supply, refuelling logistics and stand constraints. Involve ground handlers, airlines, technology providers and emergency services early to define the local safety, permitting and operating requirements.

Learn more

- Official deliverables linked to this demo in Annex I.

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Hydrogen tow tractor

Demo 11 - Energy

What TULIPS demonstrated

The hydrogen tow tractor has 300 kWh of combined hydrogen and battery energy capacity and was used in live commercial aircraft operations with KLM in 2025.

The demonstration included:

- Pushback and towing of narrow-body aircraft
- Hydrogen refuelling and permitting
- Safety and commissioning procedures.

The project also generated operational experience, documented safety assessments and a step-by-step commissioning methodology to support future hydrogen-GSE deployments, using hydrogen that complies with EU renewable hydrogen criteria.

What is it?

TULIPS demonstrated a hydrogen fuel cell-battery hybrid tow tractor for heavy-duty aircraft pushback and towing operations at Schiphol. The battery supplies peak power during acceleration and towing, while the fuel cell acts as a range extender, combining high-duty-cycle operation with rapid refuelling.

Lessons learned

Airport-wide impact requires fleet-scale deployment and a reliable hydrogen supply; no well-to-wheel energy-efficiency comparison was reported. Lessons from the demonstration include:

- Hydrogen can support heavy-duty tasks where battery-electric tractors face operational limitations, as a complement to wider GSE electrification.
- Documented safety analyses and commissioning steps provide a practical reference for future rollouts.
- Permits and certification still have to be obtained airport by airport; harmonisation would speed up adoption.
- The GHG savings depend on the assumed diesel baseline and hydrogen production pathway, with substantially lower benefits if non-renewable hydrogen is used.
- Wider fleet replacement would increase both climate and air-quality benefits.

Key results

1. 29 pushbacks completed in live operations at Schiphol.
2. 3 towing operations completed under operational airport conditions.
3. Approx. 240 kg CO_2e (92%) lower estimated well-to-wheel emissions over the demonstration period compared with an equivalent fossil-diesel tow tractor, assuming renewable hydrogen.
4. The modelled replacement of one diesel tow tractor could reduce total tow-tractor fleet emissions by 7.5–8.8% for NO_x and 7.5–8.7% for PM_{10}, depending on utilisation.

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Hydrogen tow tractor

Demo 11 - Energy

Main replication conditions

The demonstration and preparatory activities show that H-GSE is not universally applicable in the same way at every airport, but may be adapted where local hydrogen supply, infrastructure, certification, insurance, stakeholder acceptance and operational requirements are sufficiently aligned.

By successfully integrating these prototypes into live airport operations, the project establishes a practical reference for introducing hydrogen-powered GSE at other airports, subject to local operational, infrastructural and regulatory conditions.

Recommended first step

Identify suitable GSE, aircraft types and duty cycles where battery-electric alternatives face operational limitations with ground handlers and airlines. Assess hydrogen supply, refuelling arrangements and maintenance requirements, and coordinate the safety and permitting process before planning an operational pilot.

Learn more

- Official deliverables linked to this demo in Annex I.



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CARBON REMOVAL



Carbon removal addresses residual emissions, particularly from long-haul aviation, that cannot yet be eliminated once airport-related greenhouse-gas emissions have been reduced as far as possible. For airports, this requires a clear hierarchy: first avoid and reduce emissions through measures such as electrification, renewable energy, sustainable fuels and operational improvements; carbon removal can then complement these efforts where residual emissions remain.

The main challenge is that airports may manage significant areas of land (for example 3,679 ha at Schiphol), but the potential of these assets for carbon sequestration is often not systematically assessed. Any land-based solution must also remain compatible with airport safety, such as bird-strike risk, operational requirements, local soil and climatic conditions, and credible monitoring and verification. Without a consistent methodology, it is difficult to determine which measures are suitable, quantify their impact and integrate them responsibly into an airport's climate strategy.

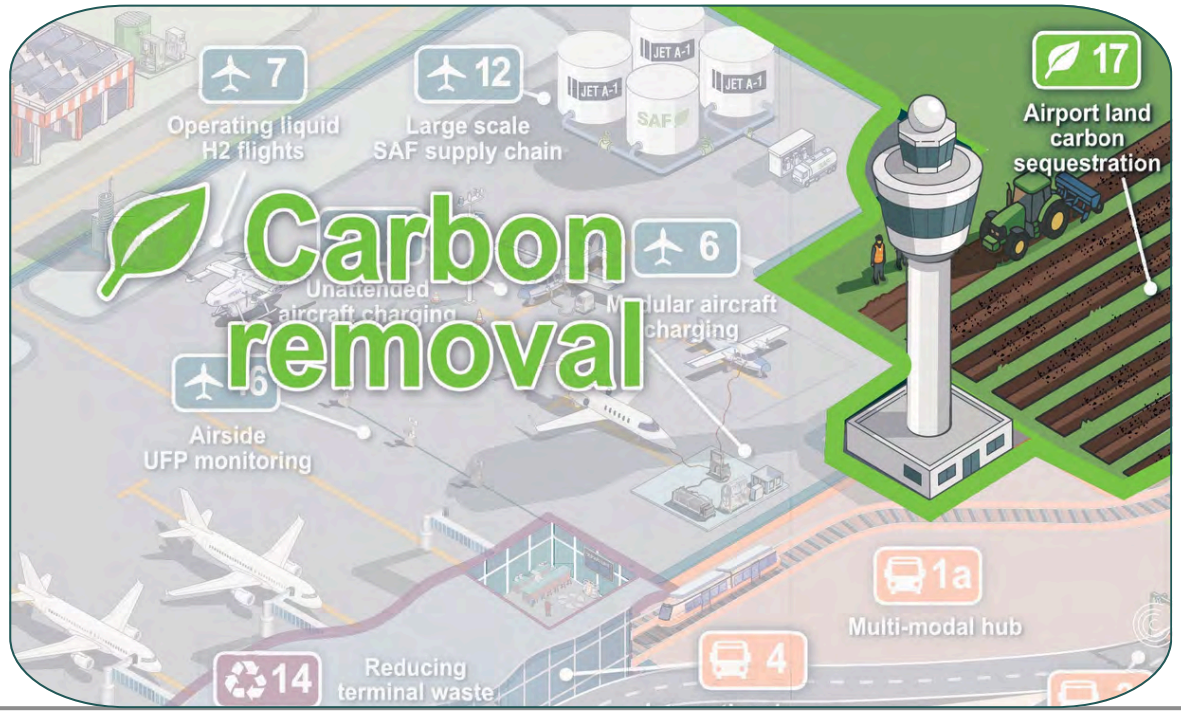
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TULIPS addresses this challenge by demonstrating a methodology for assessing the carbon-sequestration potential of airport land, including nature-based solutions and biochar. The result helps airports identify where land management could contribute to their climate objectives while also considering implementation conditions, certification, monitoring and possible co-benefits such as soil quality, water retention and biodiversity where aviation safety permits. Tested at Larnaka and Schiphol, the methodology is considered feasible for wider application; the assessment identified a potential additional sequestration of approximately 29,825 tCO_2e over 20 years on airport-owned land.

Carbon removal is closely connected to all other roadmap domains. Mobility, Aviation and Energy focus primarily on avoiding and reducing emissions, while Circularity can reduce emissions associated with materials and resource use. Biochar also links Carbon removal and Circularity: organic waste from the airport can be converted into biochar that stores carbon in the soil. Carbon removal therefore represents a complementary element of the transition rather than an alternative to direct decarbonisation. This distinction is central to the longer-term TULIPS vision for airport climate action.

TULIPS Demonstrations:
D17 Airport land carbon sequestration

Contribution to the roadmap:
Complementing direct decarbonisation with credible approaches for addressing residual emissions and making better use of airport land as a climate asset.



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Airport land carbon sequestration

Demo 17 - Carbon removal

What TULIPS demonstrated

The approach was applied across Torino, Larnaka and Schiphol to assess opportunities for additional carbon sequestration through airport land management and biochar. Airports often manage large areas of land, for example 3,679 ha at Schiphol and 578 ha at Larnaka.

The work combined biochar field trials with assessments of nature-based land-management measures, considering the different soil conditions, land uses and climatic characteristics of the participating airports.

It considers:

- Nature-based land management
- Biochar application
- Soil and climatic conditions
- Aviation-safety constraints (e.g. bird-strike risk) Carbon monitoring and certification

What is it?

TULIPS developed a structured methodology for assessing whether airport-owned land can contribute to carbon removal through nature-based solutions and biochar.

The methodology helps airports evaluate carbon-sequestration potential while considering land availability, local conditions, aviation safety and future monitoring and certification requirements. Carbon removal should complement rather than replace direct emissions reductions.









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Airport land carbon sequestration

Demo 17 - Carbon removal

Key results

1 13–15.6 tonnes of CO_2e/ha carbon-sequestration potential reported for biochar application under the assessed conditions.

2 For Schiphol, the assessment identified a potential additional carbon sequestration of approximately 29,825 tonnes CO_2e over 20 years through nature-based land management and biochar application, on top of the carbon already stored in airport soils and vegetation.

3 An estimated 766 tonnes of organic waste per year at Schiphol could potentially be converted into approximately 260 tonnes of biochar, creating opportunities to combine waste valorisation with carbon sequestration.

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Lessons learned

These figures are assessed potentials, not carbon removals already achieved or independently certified. Lessons from the demonstration include:

- There is no universal measure: soil, climate and available land decide what works at each airport.
- Carbon removal claims require robust monitoring, verification and alignment with recognised certification frameworks, including relevant Airport Carbon Accreditation requirements.
- Potential financial returns depend on certification eligibility, carbon-credit market conditions and the costs of implementing and monitoring the measures.
- The EU Carbon Removals and Carbon Farming Certification Framework (CRCF) provides an emerging framework for certification, while airport-specific implementation guidance and harmonised monitoring approaches are still needed.

Main replication conditions

Wider application requires:

- Local soil and climate assessment
- Suitable land availability
- Aviation-safety compatibility
- Standardised Monitoring, Reporting and Verification (MRV), developed with certification bodies
- Further validation across different airport contexts
- Guidance on integrating measures safely into airport land-use planning

Recommended first step

Identify potentially suitable airport-owned land and assess soil, climate, existing land use and aviation-safety constraints. Select locally appropriate measures and establish a monitoring baseline before planning a pilot with land-management and carbon-removal specialists.

Learn more

- Official deliverables linked to this demo in Annex I.

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PART III
FROM DEMONSTRATION TO WIDER IMPLEMENTATION

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Continuing the transition to sustainable airports

TULIPS has shown that the transition towards sustainable airports cannot be achieved through isolated technologies or individual projects, but requires coordinated action across the entire airport ecosystem. The roadmap brings together the work carried out across the programme and shows how solutions in the five domains of Mobility, Aviation, Energy, Circularity and Carbon Removal interact within one airport system.

The end of TULIPS does not mark the end of these solutions. Some results are already ready for further application, while others require additional development, investment, infrastructure readiness, regulatory progress, skills development, stakeholder coordination or further evidence. Their value therefore lies not only in what was demonstrated, but also in the knowledge generated about how implementation works in practice — and where barriers remain. These barriers are rarely technological: they mostly concern organisational alignment, infrastructure availability, stakeholder coordination, regulatory frameworks, financing and operational integration.

The roadmap, digital resources, project deliverables, methodologies and guidance developed within TULIPS remain an entry point for airports wishing to explore these results in greater depth. They provide the connection from the concise overview in this booklet to the detailed work carried out in the individual Work Packages and deliverables.

Airports are invited to use these results as a starting point rather than as a fixed blueprint: to identify relevant solutions that fit their own airport strategy, assess their own local conditions, adapt the approaches where necessary, continue testing, implementing and improving them, and share their lessons with the wider airport community so that others can learn faster. The next step is not to replicate TULIPS everywhere in the same way, but to use its evidence and experience to build transition pathways towards 2030 and 2050 that fit each airport.

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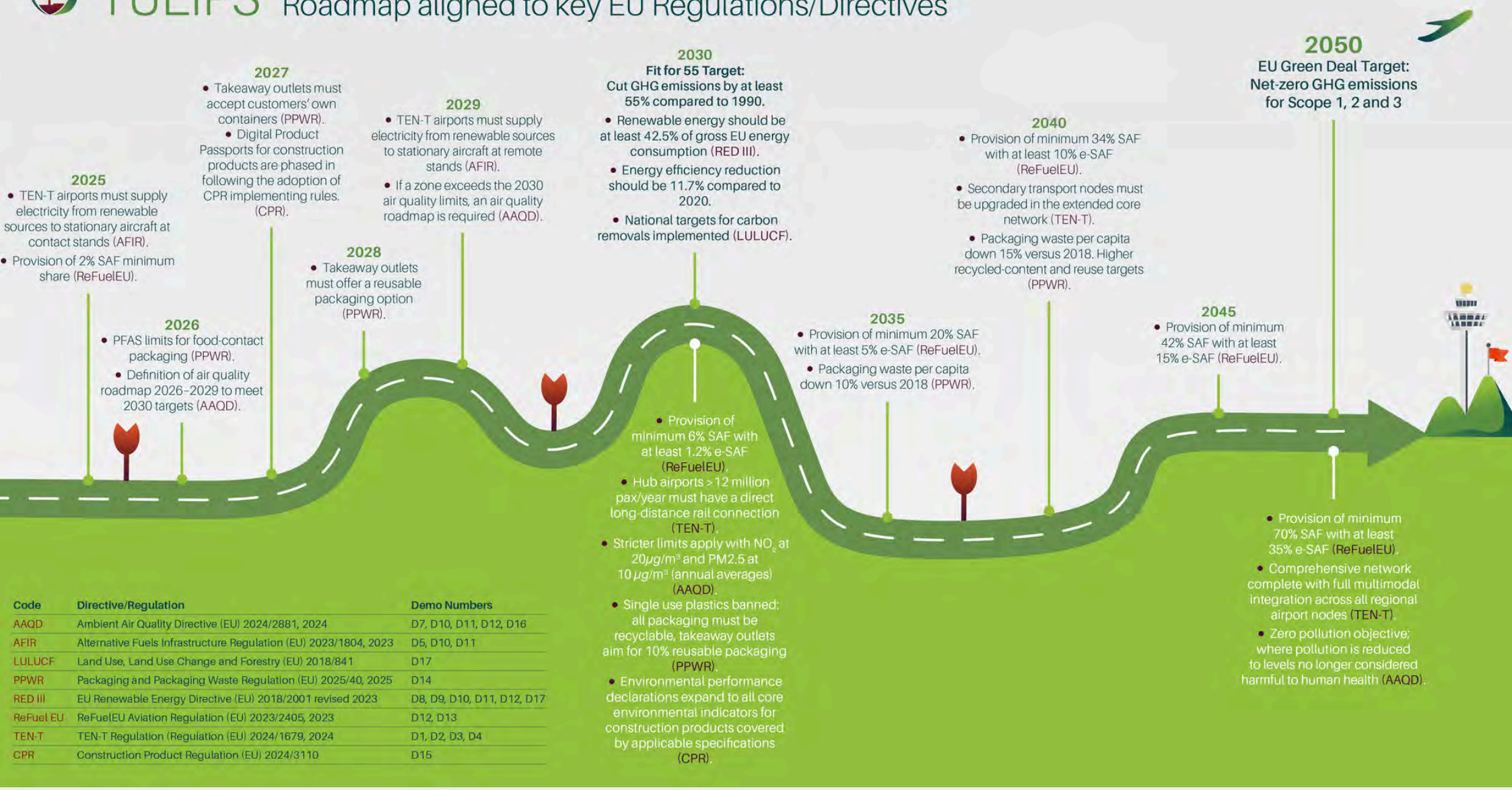
Policy recommendations

DOMAIN	POLICY RECOMMENDATION*	WHY IT'S IMPORTANT
Mobility	The demonstrations in the mobility domain related to intermodal transport connections were centred on IT solutions with a strong conceptual component and did not encounter regulatory barriers, thus no recommendations were derived from it.	
Aviation	Develop a dedicated European regulatory framework for hydrogen at airports.	This is the foundational barrier. Without a harmonised regulatory framework covering storage, distribution and refuelling, airports cannot confidently invest in hydrogen infrastructure. Many of the other recommendations (safety guidance, certification, permitting) depend on this.
Energy	Develop dedicated EU guidance for hydrogen-powered ground support equipment (GSE) and airside hydrogen refuelling.	This was a recurring challenge across demonstrations. Harmonised pathways would reduce uncertainty, accelerate replication and lower regulatory burdens for airports adopting hydrogen technologies.
Circularity	Develop common EU indicators for measuring circularity at airports, covering both construction materials and operational waste.	Data on materials and waste is now fragmented and calculated differently, so progress cannot be compared or steered. Common indicators would let airports set targets and track results.
Carbon removal	Develop clear guidance and standardised Monitoring, Reporting and Verification protocols for airport biochar and carbon removal projects.	Reliable Monitoring, Reporting and Verification is essential for credibility, scaling, certification and participation in carbon markets. Without it, airport carbon removal projects remain difficult to replicate and finance.

* Full list of policy recommendations is available in Deliverable D10.7 (available on TULIPS website: https://tulips-greenairports.eu/publications/).

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TULIPS Roadmap aligned to key EU Regulations/Directives



Code	Directive/Regulation	Demo Numbers
AAQD	Ambient Air Quality Directive (EU) 2024/2881, 2024	D7, D10, D11, D12, D16
AFIR	Alternative Fuels Infrastructure Regulation (EU) 2023/1804, 2023	D5, D10, D11
LULUCF	Land Use, Land Use Change and Forestry (EU) 2018/841	D17
PPWR	Packaging and Packaging Waste Regulation (EU) 2025/40, 2025	D14
RED III	EU Renewable Energy Directive (EU) 2018/2001 revised 2023	D8, D9, D10, D11, D12, D17
ReFuel EU	ReFuelEU Aviation Regulation (EU) 2023/2405, 2023	D12, D13
TEN-T	TEN-T Regulation (Regulation (EU) 2024/1679, 2024	D1, D2, D3, D4
CPR	Construction Product Regulation (EU) 2024/3110	D15

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PART IV: CLOSING AND LEGACY

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Five years of TULIPS

Looking back on the past five years, it is remarkable to reflect on what we have achieved together. Managing such a large and diverse consortium was already an ambitious undertaking, yet we did so in a world that proved far more dynamic and unpredictable than any of us could have anticipated. The preparation of the project brought together 32 partners over a six-month period, entirely during the COVID-19 pandemic, when in-person meetings were impossible. Only two months after the project officially started, Europe was confronted with the war in Ukraine, creating new uncertainties and challenges for all of us. Despite these circumstances, the consortium remained resilient, committed, and focused on delivering meaningful results.

What I will remember most is the spirit of collaboration that developed throughout the project. We built a remarkably positive team, engaged in numerous deep-dive sessions, challenged each other constructively, and continuously worked together to stay on course towards our shared ambitions. The willingness of everyone involved to contribute, learn, and support one another has been one of the greatest successes of TULIPS.

As we close this chapter, I am confident that the results and innovations achieved through TULIPS will continue to find their way into practice and contribute to the transition towards more sustainable airports and aviation. Innovation does not stop when a project ends, and my sincere hope is that the strong relationships, trust, and collaborative spirit built within this consortium will continue to thrive long after TULIPS. Our European innovation ecosystem is stronger when we work together, and I believe the foundations we have created over these five years will inspire and enable many future achievements.

On a personal note, it has been a privilege to serve as project coordinator and to work alongside so many dedicated and talented colleagues. Thank you all for your commitment, expertise, perseverance, and friendship throughout this extraordinary journey. Together, we have demonstrated what can be achieved when ambition, innovation, and collaboration come together around a common purpose.



Fokko Kroesen
TULIPS Project Coordinator

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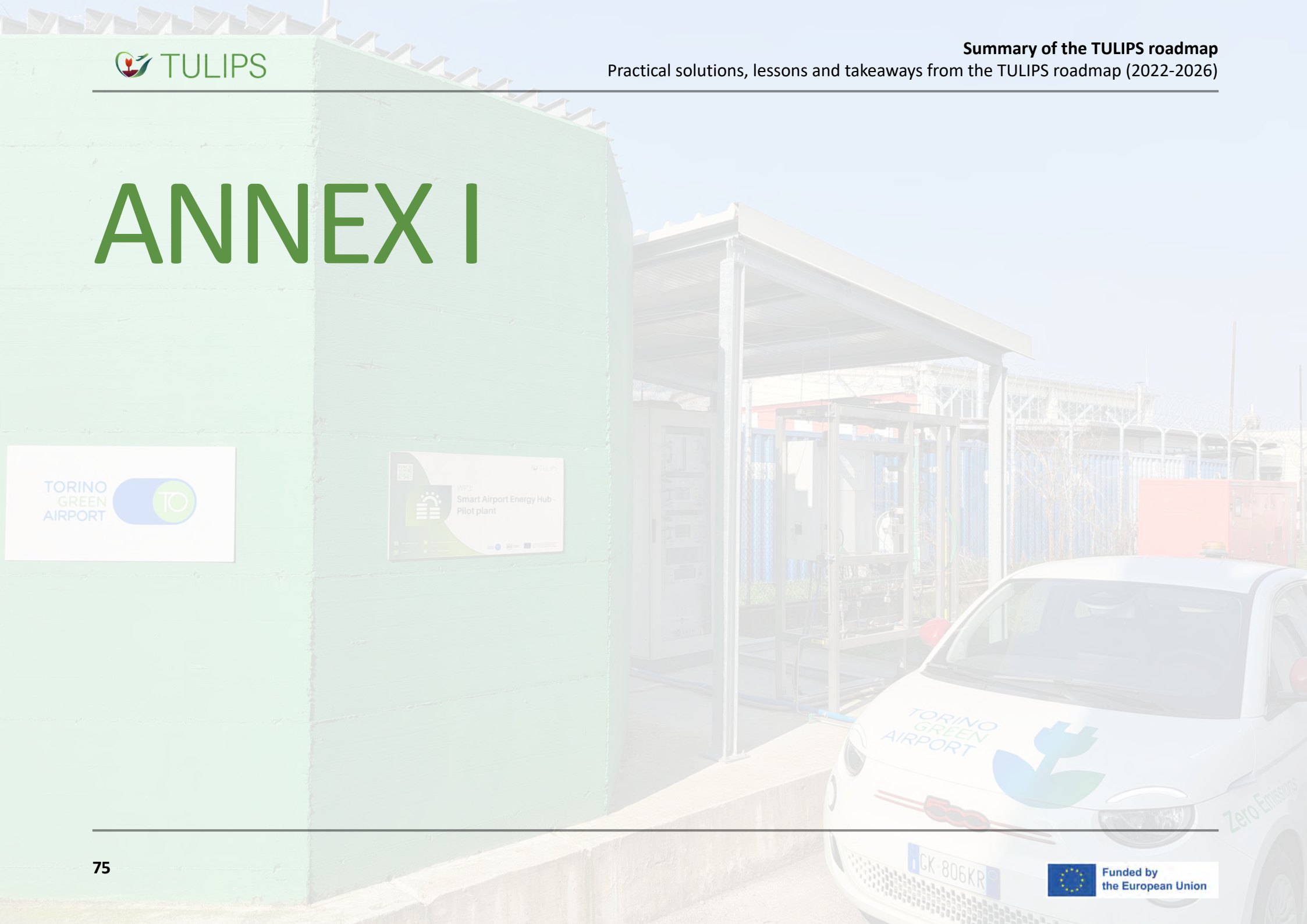
ACKNOWLEDGEMENTS

TULIPS was made possible by many people and organisations. We thank:

- The European Commission and CINEA, for supporting TULIPS under Horizon 2020 (Grant Agreement No. 101036996).
- Amsterdam Airport Schiphol, as lighthouse airport and project coordinator and our fellow airports, Avinor Oslo Airport, SAGAT Torino Airport, Larnaka International Airport (Hermes) and Rotterdam The Hague Airport.
- All consortium partners, for their expertise, commitment and cooperation
- The work package and demonstration leads, and the many colleagues who brought new solutions into daily airport operations.
- The external stakeholders, advisory experts and all involved contributors.
- Sister projects ALIGHT, OLGA, STARGATE, MAGPIE and PIONEERS for their insights and exchange.

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ANNEX I



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DOMAIN	WORK PACKAGE	DEMONSTRATIONS	TULIPS DELIVERABLES	OTHER PUBLICATIONS / USEFUL LINKS
MOBILITY	**WP1 – Sustainable Inter-modal Transport Connections**	**Demo 1a:** Multi-modal hub modelling **Demo 1b:** Enabling travellers' modal shift with support from MaaS solutions – MaaS app **Demo 2:** Logistic solutions: green and connected trucking **Demo 3:** Road traffic and transport systems **Demo 4**: International green travel	**D1.1** Data ecosystem design, including relevant modules for management, cleaning, fusion, prediction, and exchange (broker or marketplace) modules final report **D1.2** Development, demonstration and evaluation of use case green and connected trucking **D1.3** Inter-modal hub model and MaaS app demonstration at Lighthouse Airport **D1.4** Impact of at least 5 scenarios on enabling travellers modal shift towards emission reduction **D1.5** Evaluation report outlining the development, demonstration and evaluation of use case of road-based traffic management for airport landside emissions reduction **D1.6** Evaluation report outlining the development, demonstration and evaluation of the use case of international green travel	Decarbonising airport access: A review of landside transport sustainability

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DOMAIN	WORK PACKAGE	DEMONSTRATIONS	TULIPS DELIVERABLES	OTHER PUBLICATIONS / USEFUL LINKS
AVIATION	**WP2 – Energy Supply of Future Aircraft**	**Demo 5:** Unattended charging demo development **Demo 6:** Modular charging system demo development **Demo 7:** Airport-facilitated hydrogen flight demo development	**D2.1** Feasibility study: airports delivering energy supply for future aircraft. Appendices: Generic safety assessment and project plan for all demos **D2.2** System survey acceptance protocol: Concept of unattended charging with belonging test plans and technological solutions implemented on a Velis Electro aircraft **D2.3** Functional modular battery farm and simulator for airside distributed charging **D2.4** Operation at the airport of an aircraft powered by a liquid hydrogen fuel cell system and the associated refuelling infrastructure **D2.5** Scale-up of LH_2 infrastructure **D2.6** Summary report of energy supply demonstrations findings	• Infrastructure and supply pathways for liquid hydrogen at airports: A technical framework for feasibility and airport master planning • Charging Demand Prediction: Small All-Electric Aircraft and Electric Vertical Takeoff and Landing Aircraft • Integrating liquid hydrogen infrastructure at airports: Conclusions from an ecosystem approach at Rotterdam The Hague Airport • Charging Technology for Electric Aircraft: State of the Art, Trends, and Challenges

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DOMAIN	WORK PACKAGE	DEMONSTRATIONS	TULIPS DELIVERABLES
AVIATION	**WP5 – Scaling up the Sustainable Aviation Fuel (SAF) Market**	**Demo 12:** Executing large-scale SAF supply chain **Demo 13:** Incentivising SAF as an airport	**D5.1** Replicable framework with boundary conditions for successful PtL projects **D5.2** Toolbox to assess feasibility and benefits of an on-airport PtL facility site **D5.3** Report on assessment of policy in relation to PtL facility **D5.4** Final structure of the EU-CH **D5.5** Report on the setup, experience and impact of large-scale SAF supply, serving as a blueprint for other airports **D5.6** Supply of 30,000 metric tons of SAF to Schiphol airport in an integrated set-up **D5.7** Comprehensive overview of all potential roles an airport can take in supporting SAF scale up
	WP7 – Green Air and Land	**Demo 16:** Airside UFP mitigation	**D7.2** Report of current airside UFP levels and ionised mist first results **D7.3** Final report on airside UFP mitigation, process and project results

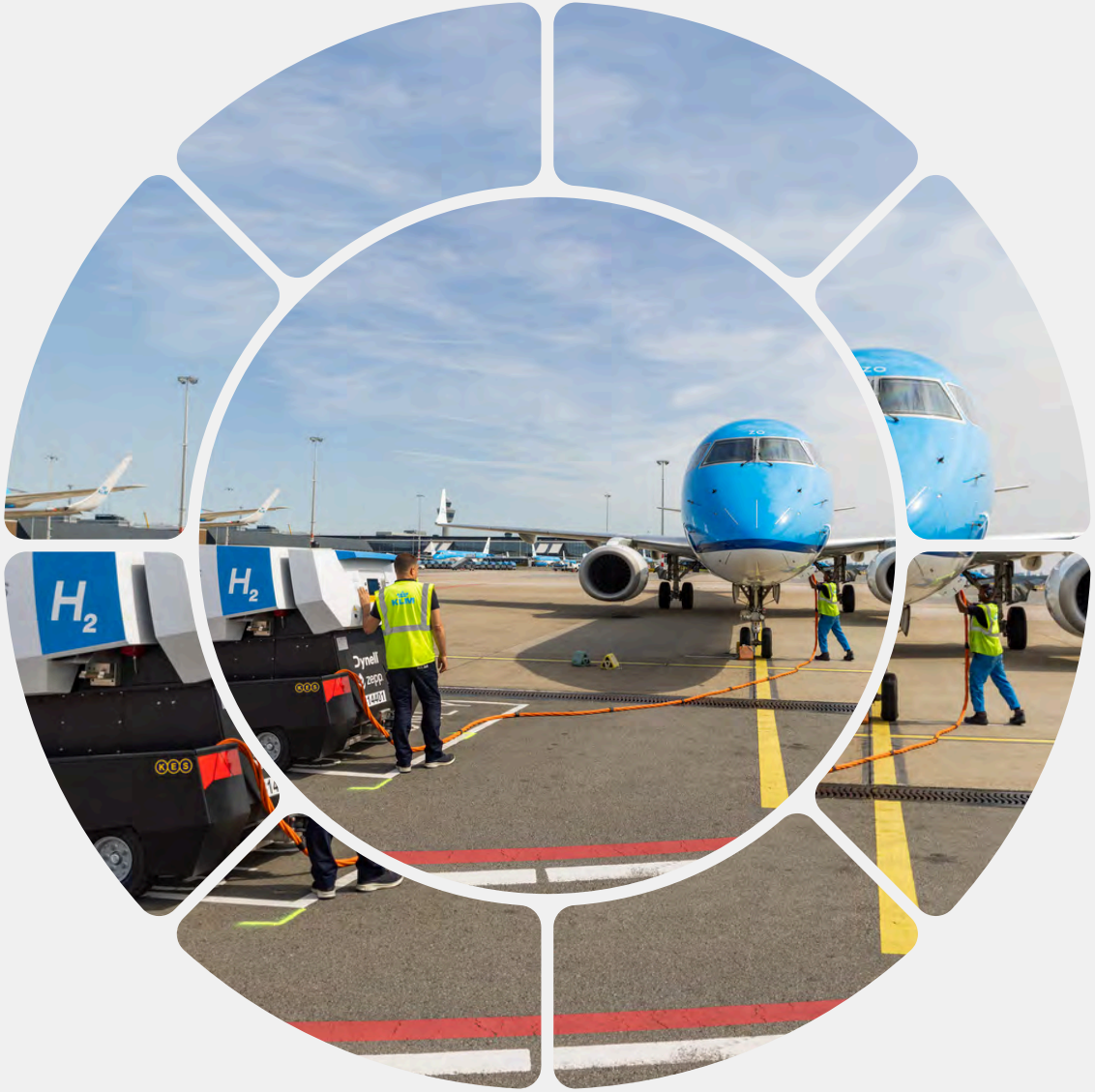
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DOMAIN	WORK PACKAGE	DEMONSTRATIONS	TULIPS DELIVERABLES	OTHER PUBLICATIONS / USEFUL LINKS
ENERGY	**WP3 – Smart Airport Energy Hub**	**Demo 8:** Airside electricity 'traffic' demonstration using an iron flow battery **Demo 9:** Heat supply facilities demonstration	**D3.1** Concept designs of the smart energy hub at the airports for various scenarios **D3.2** Integrated heat management system demonstration at the Schiphol airport **D3.3** Airside electricity traffic demonstration showing solar powered, modular, intelligent, direct DC charging infrastructure for EVs **D3.4** Lessons learnt and the upscaling and knowledge transfer approaches developed for smart energy hub	• The potential role of biomethane in the transition towards low-carbon large-scale buildings: the case study of the Torino Airport • Electrification of airports and air transport: Airports becoming integrated energy systems • Critical review of energy planning models for the sustainable development at company level • Green Hydrogen Applications for Sustainable Airport Ground Operations
	WP4 – Zero Emission Airside Operations	**Demo 10:** Hydrogen Ground Power Unit demonstration **Demo 11:** Hydrogen tow tractor demonstration	**D4.1** Demonstration plan including operational concept for demonstrating the GSE equipment **D4.2** H_2-GPU prototype for demonstrations **D4.3** H_2-Tow tractor for demonstrations **D4.5** Demonstration report of h-GPU and tow tractor in use for lighthouse and fellow demos **D4.6** Low emission H_2 supply chain and certification scheme **D4.7** Workshop with final report on roadmap for H_2-rollout to airports **D4.8** Transferability & guidance material for ZE GSE **D4.9** Demonstration plan including operational concept for demonstrating the Tow Tractor	

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DOMAIN	WORK PACKAGE	DEMONSTRATIONS	TULIPS DELIVERABLES	OTHER PUBLICATIONS / USEFUL LINKS
CIRCULARITY	**WP6 – Circular Airports**	**Demo 14:** Reducing terminal waste **Demo 15:** Maximise use of secondary construction materials	**D6.1** Airport circularity baseline study **D6.2** Circularity performance management system (also D6.7) **D6.3** Demonstration report for pilot in terminal **D6.4** Smart resources passport connected to tracking devices and digital marketplace **D6.5** Circular design guideline document **D6.6** Impact assessment of circularity practices	• EU ATLAS on Circularity for Airports • Digital Product Passports at Airports • FROM BETTER BIN STICKERS TO BETTER WASTE SYSTEMS • DPP Opportunity Heatmap template (circular airports) • Stakeholders' Resources (circular airports) • Airport Circularity Baseline Study • Pioneering Circularity in Airport Operations: Schiphol's Path to Zero-Waste • Transforming waste management methods: a Dutch Airport's journey toward a circular economy through baseline measurements and strategic priority setting
CARBON REMOVAL	**WP7 – Green Air and Land**	**Demo 17:** Airport land carbon sequestration	**D7.1** Land carbon soil study for Schiphol and Larnaca, biochar characterization and definition of biochar field trials set-up **D7.2** Report of current airside UFP levels and ionised mist first results **D7.4** Final report on Airport Land Carbon Sequestration, including results from biochar field trials	

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