# Wings of the Future

## Sustainable Aviation

LDE Thesis Lab 2025-2026

Universiteit Leiden
TU Delft
Erasmus University Rotterdam
Thesis Labs
Leiden-Delft-Erasmus Universities
FLYING VISION accelerator
LUCHTVAART in transitie
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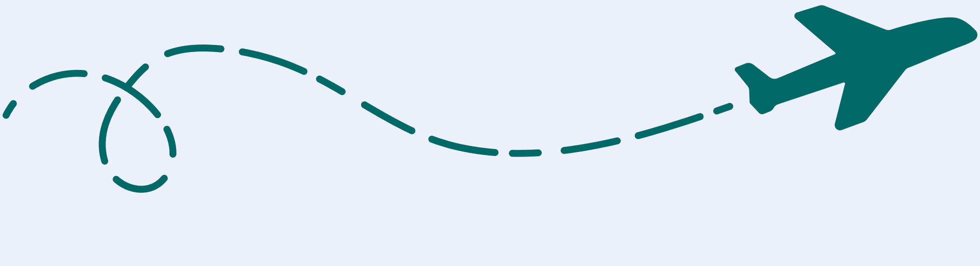

# Foreword by Flying Vision Accelerator

Flying is one of humanity's most powerful achievements, bringing together people, cultures, and economies across vast distances. It enables families and friends to reunite, ideas to circulate, and opportunities to transcend borders. Aviation has shaped the world as we know it today: connecting people, supporting economies, knowledge exchange, and international collaboration. In many ways, it has shrunk the world:

"*A stranger is a friend we haven't met yet*" (attributed to William Butler Yeats)

This remarkable connectivity comes at a cost. The growth of aviation contributes significantly to environmental degradation. Emissions and noise pollution remind us that progress is not without consequences. The challenge is clear: how can we preserve the undeniable benefits of aviation while drastically reducing its environmental footprint? This is not merely a technological question, but a societal one that demands technology, creativity, responsibility, and collaboration.

It is precisely within this context that the LDE Centre for Sustainability Thesis Lab "Wings of the Future" emerges as a powerful catalyst for insights. Insights that the aviation ecosystem needs to allow the transition to happen. This transition is the heart of Flying Vision Accelerator. This project is part of National Growth Fund "Luchtvaart in Transitie" and aims to give insights of the changes required.

And insights can be seen! Bringing together students and researchers from Leiden University, Delft University of Technology, and Erasmus University Rotterdam, the LDE Thesis Lab demonstrates how education can act as a catalyst for meaningful change. Complex challenges such as the sustainability transition of aviation should be addressed holistically. Legal frameworks, technological innovation, economic feasibility, and societal acceptance are not to be treated as separate domains, but as interconnected pieces of a single puzzle. This approach reflects the reality of today's sustainability challenges: no single discipline holds the solution on its own. There is no silver bullet.

The insights gathered will inspire not only further academic inquiry, but also tangible action in industry, policy, and society. The challenges are complex and urgent, but the work of these students shows that solutions are within reach when we dare to think differently and act collectively. By embracing innovation, collaboration, and responsibility, aviation can continue to fulfill its vital role as a connector.

Ultimately, the LDE Thesis Lab demonstrates that the transition of aviation is not solely a technological challenge, but a societal one that requires collaboration, imagination, and courage. The work presented in this book is both a reflection of that collective effort and an invitation to policymakers, industry leaders, academics, and citizens to continue building bridges between knowledge and action.

Just as aviation has increasingly connected the world, from a first hop by the Wright Flyer in 1903, via affordable and fast flights through jet engines in the '60's, we must now connect disciplines, stakeholders and perspectives to shape a future in which flying remains a force for good, in harmony with the limits of our planet.

Dear reader, please enjoy your read of this booklet, be inspired and enthused by the work of the students.

**Victor Rijkaart**
Co-lead Flying Vision Accelerator, part of National Growth Fund "Luchtvaart in Transitie"

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***Sustainable aviation***
*through novel design, technological innovation, new business models, and legislation*

# Introduction

**Wings of the Future**

Aviation has connected people, economies, and cultures across the globe for over a century, but that progress has come at a cost. $CO_2$ emissions from aviation have more than doubled since the mid-1990s, contributing to global climate change. It is clear that the aviation sector needs a sustainable future. What is far less clear is exactly how to get there. One thing, however, is certain: only an interdisciplinary perspective can bring together all the puzzle pieces needed to truly reduce aviation's environmental impact.

Bringing these disciplines together is exactly the aim of this Thesis Lab. Students from Leiden University, Delft University of Technology, and Erasmus University Rotterdam picked up master thesis topics to help answer one key research question:

**How can design, technological innovation, new business models, and legislation help the aerospace industry reduce its impact on the environment?**

In this Thesis Lab, highly motivated students work on the topic of sustainable aviation, bringing their own background knowledge and integrating it with insights from other disciplines. This booklet explores the research carried out by the students and gathers their key conclusions to formulate recommendations toward a sustainable future for aviation.

The research topics in this Thesis Lab were provided by Airbus and NLR, embedded within the wider Flying Vision Accelerator — a Dutch Growth Fund initiative working toward climate-neutral aviation by 2050. The Thesis Lab is coordinated by Delft University of Technology, with support of the LDE Centre for Sustainability.

# About Flying Vision Accelerator

Flying Vision Accelerator (FVA) aims to contribute to the industry ambitions* of net- zero aviation by 2050. It develops dynamic roadmaps and a vision to help the sector navigate the pathways to attain this ambition while informing government policies.

Led by TU Delft, Royal NLR, Airbus, Royal Schiphol Group, and KLM Royal Dutch Airlines, FVA collaborates with Dutch and international partners to foster collaboration and provide multidisciplinary insights to accelerate the aviation transition. The project aims to identify key barriers and propose effective solutions. Through deep dives and think tanks FVA co-creates with stakeholder experts on three primary themes: reducing energy demand, implementing novel energy carriers, and the passenger and travel experience of 2050.

**Highlights of FVA in 2025?**

- Flying Vision Accelerator organised a successful series of activities to gather expert input for its first roadmap. In 2025, around 35 organisations and more than 85 participants from across the aviation value chain took part.
- The first FVA roadmap was submitted to the Ministry of Infrastructure & Water Management and the LiT programme in December 2025 and is expected to be published at the end of Q2 2026.
- FVA conducted an initial study on passenger trends (led by NLR) and launched a thesis lab with the Leiden-Delft-Erasmus (LDE) university partnership. Student analyses from this interdisciplinary lab will inform the second roadmap iteration.

* The ambition set by the Air Transport Group (ATAG), the International Civil Aviation Organization (ICAO) and the global International Air Transport Association (IATA) to reach 'net zero carbon emissions by 2050'.

**What are the next steps for the project?**

- The first FVA roadmap is to be publicly released in Q2 2026.
- In 2026, Flying Vision Accelerator will launch a new round of expert sessions ("Think Tanks") on: "Reducing energy demand for the aircraft and its flight", "implementation of novel energy carriers", and "the future traveler".
- Outcomes from the LDE Thesis Lab analyses are expected around summer, and new opportunities for additional analyses are explored.
- Flying Vision Accelerator aims to expand the consortium with new partners.

**Connection FVA with LDE thesis Lab**

Through FVA's activities, such as Think Tanks, and during the development of the first version of the FVA Roadmap, numerous Research & Development questions have been identified that are highly relevant for the aviation sector. Some of these questions may evolve into topics for short FVA analyses or future Think Tank sessions, while others can be explored independently or outside the formal timeline of the FVA project.

The FVA consortium became aware of LDE thesis labs through earlier editions on sustainable aviastion, and decided to become the main content parnter for LDE Thesis Labs by bringing several research questions into the LDE Thesis Lab. This offers a valuable opportunity to involve students. It  allows them to contribute to real aviation challenges, and inspire us with fresh perspectives, while also engaging these students in the complexities of the aviation transition. The insights of the LDE analyses will feed into the next iterations of the FVA roadmap.

**Victor Rijkaart and Elise Bavelaar**
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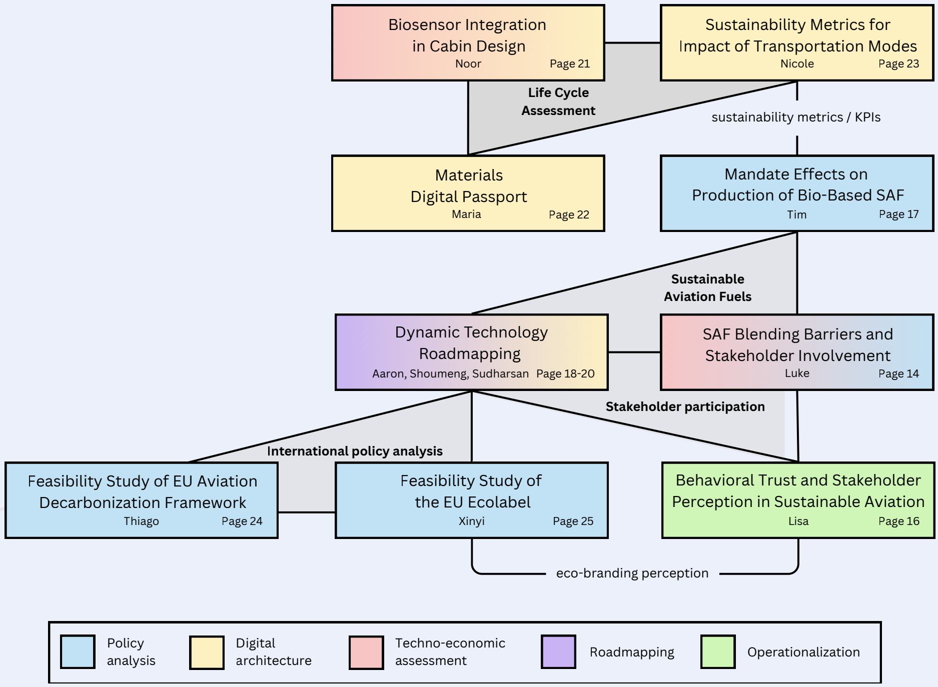
# Overview of LDE Cases

The central theme of this thesis lab was to explore the different building blocks necessary to achieve sustainable aviation. The cases represented the many different facets of sustainable aviation, each exploring a different challenge in the transition towards sustainable aviation from a different perspective and research discipline. Each case was subsequently addressed by one student, together with their supervisors. The figure below presents an overview of all LDE cases and their interconnectivity. In the following pages, each of these topics is discussed in more detail.




AIRBUS FLYING VISION accelerator nlr

# Student Research Outcomes

# Breaking the Blend Wall

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Although Sustainable Aviation Fuels (SAF) show promising signs as alternative aviation fuels in decarbonizing aviation, there are a number of challenges encountered during upscaling. Through interviews with a range of stakeholders in the SAF ecosystem, this research identifies and analyses system barriers using Ortt and Kamp's Technological Innovation System (TIS). Consequently, technical, regulatory, and market-related measures are proposed on both the short and the long term.

## Findings & Recommendations

**Quantity over quality**: Europe struggles to meet future ReFuelEU targets and focuses on scaling up production capacities. The 50% blend wall may become a problem in the future, but this does not take priority.

**Fragmented regulatory landscape:** Airlines must prove under EU ETS that a SAF batch is physically delivered, but this cannot be warranted through a branching pipeline network. ReFuelEU, on the other hand, allows fuel suppliers to do so.

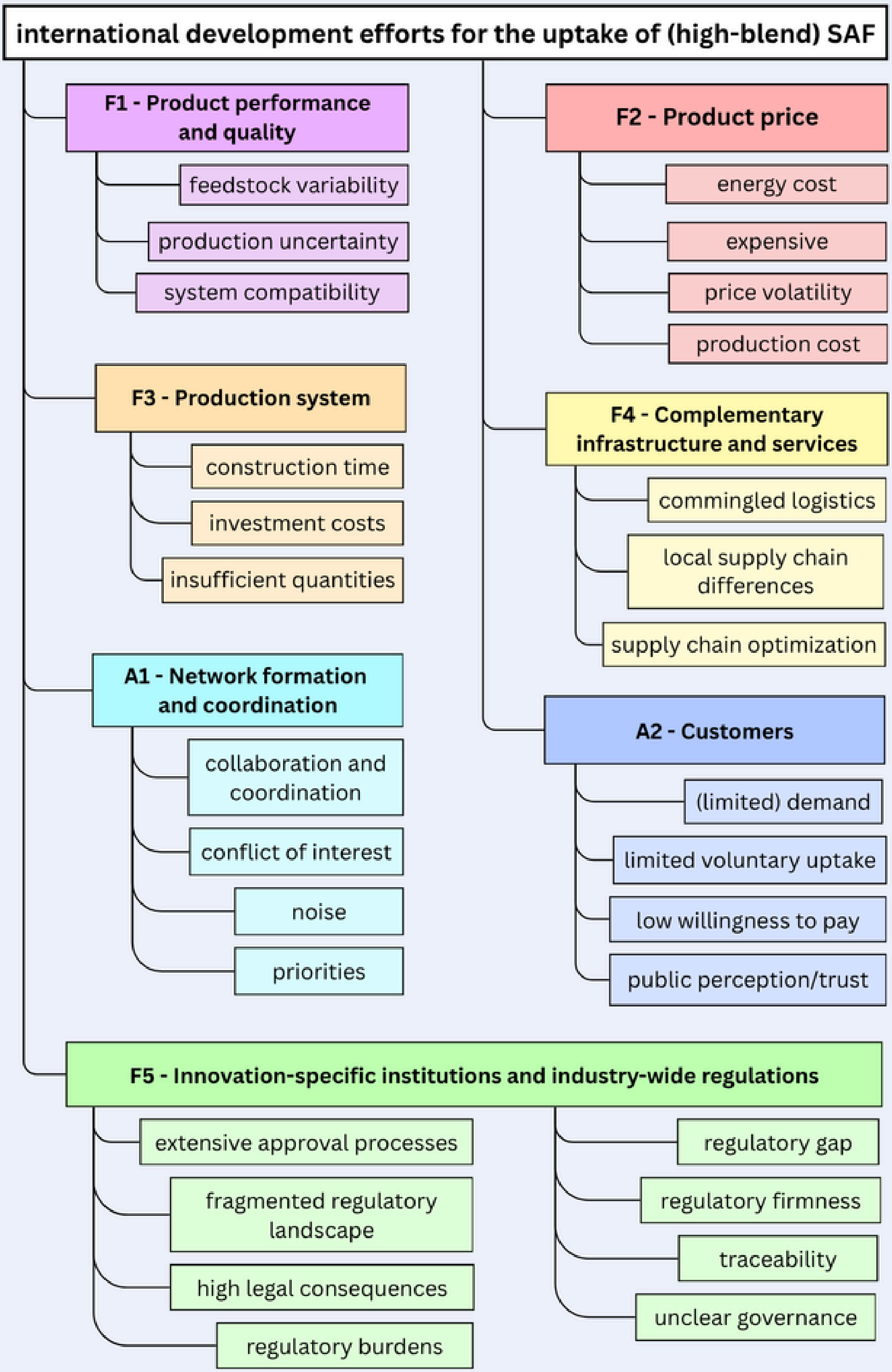
**Limited voluntary uptake:** Because the aviation industry is an international market with fierce competition, airlines are reluctant to uptake more SAF than mandated by ReFuelEU. Ultimately, passengers will have to foot the bill.

**Capacity expansion:** Address bottlenecks for (e-)SAF production through further development of other SAF pathways and accompanying infrastructure, using locally-sourced feedstock to the EU's advantage.

**Regulation harmonization:** Create a unified SAF compliance framework which links EU ETS, ReFuelEU, and other policies which standardizes reporting, monitoring, and verification procedures and creates policy certainty.

**Building trust:** Raise further awareness and build trust among the general public by communicating SAF contributions to all passengers. Standardize corporate SAF certificates to encourage further uptake among Business Aviation.

*Further elaboration on all codes identified from the interviews can be found in the figure on the next page which groups each code under one of seven building blocks of the TIS.*




Thematic network of interview codes grouped under each TIS building block.

# Does trust experience shape passenger support for SAF?

*Lisa Marie Josten*
*MSc Global Business & Sustainability*
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Trust is a precondition for cooperation under uncertainty, but it develops asymmetrically: negative trust experiences have a disproportionately larger and more enduring impact than positive ones. This thesis tests two competing psychological mechanisms behind this asymmetry: a behavioral pathway (negative experiences trigger avoidance that limits corrective learning) and a cognitive pathway (negative information is seen as more diagnostic of true character), in a practically important and understudied domain: passenger support for Sustainable Aviation Fuel (SAF) adoption. SAF is the most viable near-term decarbonization option for aviation, with EU legislation mandating a 6% SAF blend by 2030 and 70% by 2050.

## Findings & Recommendations

A single recalled violation strongly suppressed advocacy intent and activated behavioral avoidance. A single positive experience had uniformly small, non-significant effects.

The behavioral route through realized past avoidance (RPA) captured ~72% of the violation effect on advocacy intent (ACME = -.472, $p = .012$). Perceived diagnosticity was not an explicit mediator; violation participants rated their experience as less diagnostic than neutral participants.

Trust experience had no significant effect on financial willingness to contribute (WTC) through any pathway. Financial WTC was driven solely by existing financial fairness beliefs, independently of relational trust history.

Participants reported mean SAF contribution preferences of ~29-30% across all conditions, far above current blend rates (0.1-0.2%) and the EU 2030 target (6%), when the decision was framed around direct, verifiable $CO_2$ reduction rather than cost.

Trust asymmetry has direct consequences for SAF advocacy. Airlines lose more passenger advocates from a single violation than they gain from a single positive interaction. Protecting the trust relationship is more efficient than trying to build it.

Avoidance, not cognition, is the operative pathway. Re-engagement strategies for passengers who have experienced a violation should focus on behavioral re-activation rather than cognitive reframing, as avoidance operates independently of conscious appraisal.

Consumer support for SAF is not a unitary construct. Relational trust and financial contribution operate on different dimensions. Airlines and policymakers should treat relational trust management and contribution framing as parallel, not competing, strategies.

Framing SAF contribution as direct $CO_2$ reduction engages passenger contribution preferences at amounts significantly above industry aspirations, regardless of relational trust history. The diagnosticity for financial support is framing, not trust.

# EU SAF Sustainability Gap

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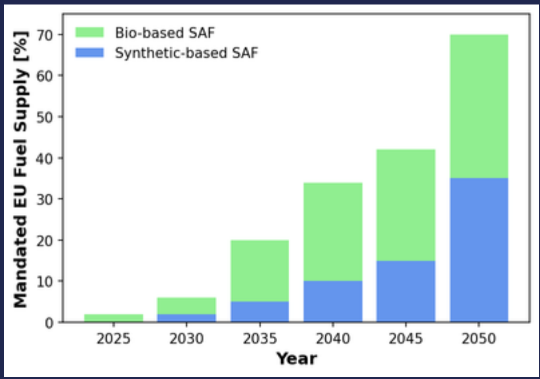
Aviation is responsible for 2.5% of anthropogenic $CO_2$ emissions and has turned to Sustainable Aviation Fuel (SAF) to decarbonise its operations, with the EU requiring 70% of all fuel supplied to EU airports to be SAF by 2050. However, little research has been done to assess whether EU SAF regulations are designed such that there is a gap between certified compliance and sustainability under EU SAF regulations.




*ReFuelEU Aviation Mandated Minimum SAF Supply*

## Findings & Recommendations

Non-$CO_2$ in-flight emissions are not included during LCAs of SAF, although they account for roughly 66% of flight emissions

Non-$CO_2$ in-flight emissions, such as contrails, $NO_x$, and water vapour, must be included in SAF LCAs to accurately portray their climate effects

RED II states a generous fossil fuel baseline, portraying SAF as having higher decarbon-isation effects that might be the case

Fossil fuel baselines should follow the same strict LCA regulations that are imposed on SAF, rather than a flat value

The degraded land use bonus promotes land restoration. However, strong social safeguards are needed such that sustain-ability is not achieved at the expense of vulnerable communities

SAF's degraded land bonus can have severe negative effects on vulnerable communities that possess degraded land. Further research should be done on this to better understand its long-term effects

The EU mentions the need for energy independence, but SAF regulations contain no requirement for EU-based SAF production, potentially swapping the reliance on fossil fuels with SAF

Further research can be done on the regulation design and certification process of each unique feedstock type

# Participatory Backcasting for the Decarbonization of the European Aviation Industy

*Aaron Donker*
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European climate policy has become increasingly ambitious, with targets requiring a 90% reduction in emissions by 2040 compared to 1990 levels and the achievement of climate neutrality by 2050. Currently, the European aviation industry contributes to around 4% of Europe's greenhouse gas (GHG) emissions. If no action is taken, the total share of GHG emissions by the industry is expected to rise rapidly, as forecasts project a more than 40% increase in number of flights by 2050. In the absence of concrete and coordinated action between stakeholders, flights may have to be curtailed.

The aviation industry faces a decarbonization challenge. Over the past decades, the aviation industry has primarily been characterized by incremental improvements aimed to reduce emissions. These improvements alone are increasingly viewed as insufficient to achieve the required emission reductions. More ambitious progress could be made through the adoption of electric and hydrogen propulsion technologies for aircraft. However, these technologies currently face technological, economic, regulatory, and infrastructural barriers.

My master thesis applies participatory backcasting to identify pathways through which stakeholders across the European aviation industry can facilitate the full-scale adoption of hydrogen and electric propulsion technologies for all flights within Europe by 2050.

## Participatory backcasting

Working backwards from a climate-neutral aviation system in 2050 to identify pathways for hydrogen and electric propulsion adoption in aircraft.

Identifying critical tipping points and sequencing actions for the deployment of hydrogen and electric propulsion technologies.

The structured, stepwise deployment of hydrogen and electric propulsion technologies requires coordinated action among policymakers, technology developers, infrastructure providers, airlines, and airports.

# Towards Net-Zero: What should aviation roadmaps deliver?

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Aviation decarbonization requires complex decisions at all levels and continuous evaluation of emerging technologies and practices. However, traditional technology roadmaps are often linear and static, lacking the capability to address uncertainty, cross-layer interactions, and evolving pathways. A grounded theory approach is employed to advance aviation roadmaps to better support global policymaking as we move towards net-zero. Insights were drawn from 18 semi-structured interviews that captured perspectives on policymaking, airline operations, airport management, aircraft manufacturing, alternative fuels, and regulations, with participants bringing diverse regional experience and backgrounds.

## Insights from Global Stakeholders

**Traceability & Transparency**
A major issue with existing roadmaps is that they do not specify the scope, assumptions, methodology, and rationale for their results.

**Concreteness**
There is a general underrepresentation of causal relationships and dependencies among levers, as well as the use of high-level, aspirational language.

**Data Accessibility**
Underlying data is often missing from roadmaps, and there is no guarantee that certain information is included due to the lack of a standardized format.

**Compliance & Responsibility**
Target delays undermine policy credibility and hinder the industry's overall progress. Roadmaps need to define responsibility and explore binding possibilities.

**Timeframe**
The longstanding target year of 2050 may no longer be sufficient. Roadmap developers should consider longer-term horizons such as 2060, 2070, or even 2100.

**Industry Dependencies**
Roadmaps must align with the broader industry target and consider aviation's interdependencies with other industries and its role in global industrial transitions.

**Overlooked Dimensions**
Social and economic perspectives, technology compatibility with existing systems, and pollutant-level impacts are often missing from roadmaps.

**Intended Use**
The intended audience, purpose, level of detail, and revision shcedule of an aviation roadmap should be determined early in the roadmapping process.

The interviews uncover both recurring themes and divergent perspectives on how aviation roadmaps should evolve to better support decision-making. This thesis project aims to provide meaningful insights into the ongoing discussion, with completion expected in August 2026.

# Dynamic Technology Roadmap

*Sudharshan SS*
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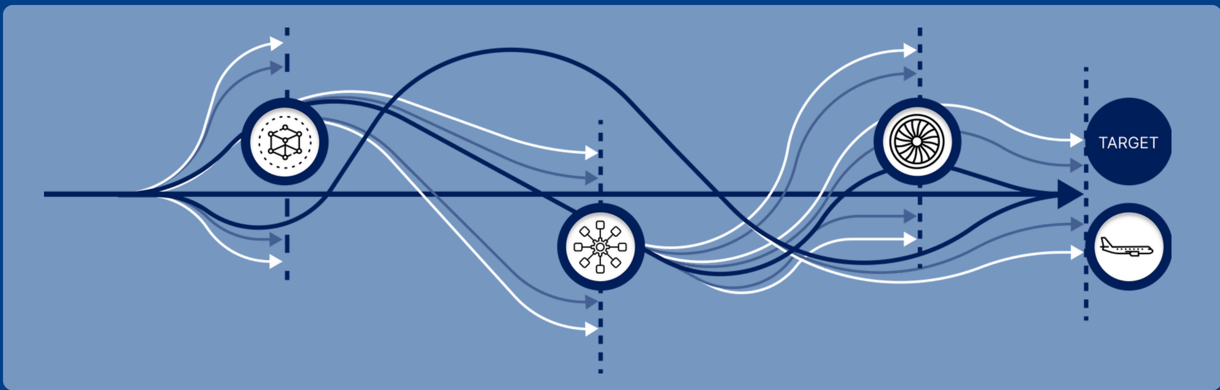
The Dynamic Technology Roadmap (DTRM) is an AI-supported roadmap application concept for aviation innovation. The project explored five key domains including technology roadmapping, AI-agent workflows, big data integration, aviation technology and collaborative innovation, to develop, test and validate a high-fidelity mock-up application with aviation industry experts, paving the way for a dynamic AI-agentic roadmap tool for complex innovation planning.




## Findings & Recommendations

Big data is a growing challenge and a critical process for strategic decision-making in aviation innovation planning

Develop a secure AI-agentic data pipeline for real-time roadmap updating

Uncertainty plays a major role in complex innovation, requiring a dynamic and adaptive planning process

Implement dynamic uncertainty interface for adaptive long-term planning

Trust is a fundamental barrier to cross-organisational collaboration, requiring a structured and secure information sharing framework.

Establish a trust and data governance framework for secure cross-organisational collaboration

The DTRM lays the groundwork for the next generation of dynamic AI-supported aviation innovation planning

# Bio-inspired and Bio-based Self-sensing Aerostructures

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Current commercial aircraft rely on heavy, centralized copper wiring networks and passive sensors, creating severe weight penalties and data analysis bottlenecks. The integration of decentralized, bio-inspired, and bio-based sensing and communication networks directly into composite aircraft structures aims to enhance structural health monitoring and predictive maintenance. By synthesizing structurally embedded bio-inspired and bio-based sensing and communication systems, the aircraft structure becomes a volumetric, self-monitoring system. An assessment matrix was created to evaluate the new technologies on their suitability for implementation in aircraft structures, based on industry stakeholders' requirements.

## Initial Findings & Recommendations

Stakeholders emphasize that any biological or bio-inspired sensor network must provide a highly quantifiable probability of detection to legally eliminate structural rivets.

While nanoscale bio-based sensors offer weightless volumetric coverage, but they are impossible for airline mechanics to physically repair on the ground.

EASA AI rules are highly strict regarding data representativeness for edge algorithms, while physical hardware must withstand DO-160 hazards like flame, EMI, skydrol, and wing-fuel toxicity.

Pure Predictive Maintenance is currently blocked by rigid regulatory intervals, forcing the industry to await new hybrid MSG-4 frameworks.

Integrate autonomous, software-driven self-calibration and redundancy loops directly into the edge network to compensate for 30-year sensor drift and localized node failures

Ensure the underlying data architecture is decentralized and self-organizing so it can adapt and recalibrate around physical structural patches and maintenance cutouts.

Align data processing architectures with ARP-6461 standards to securely compress and transmit edge diagnostics to ground servers.

Prioritize the assessment and development of combined bio-inspired and bio-based sensing and communication systems over fluid-flow sensors, directly targeting structural fatigue within upcoming matrix evaluations.

Transitioning to decentralized, bio-inspired smart aerostructures is not only a materials challenge, but a highly complex regulatory and operational integration challenge.

# Which environmental metrics should decide how Airbus ships its aircraft parts?

*Nicole Miguez*
*MSc Supply Chain Management*
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Aviation's drive to cut emissions focuses on the flight itself, yet before an aircraft flies its parts cross the world by sea, rail, road and air, a logistics footprint some aircraft manufacturers leave out of transport decisions. The obstacle is that environmental performance is complex: dozens of indicators exist, no single one captures it, and which ones belong in a decision depends on the context. This research builds a structured method to make that choice. It gathers candidate indicators from the literature, defines the criteria that make an indicator suitable for a transport decision, and screens the candidates against them into a manageable set, which is then combined into one Composite Sustainability Indicator that can sit beside cost and time at the decision point. The method is tested on Airbus's Hamburg to Mobile corridor across nine route alternatives. It integrates the environmental dimension of sustainability, and is built so the same logic can extend to the social and economic dimensions.

## Findings & Recommendations

Which indicators matter is context dependent, so the method screens on four criteria: relevance, available data, comparability across modes, and understandability. Overlaps are then removed to avoid double counting.

Applied to 35 candidate environmental indicators from the freight literature, the four selection criteria leave 10, which a redundancy check reduces to 5: $CO_2e$, $NO_x$, $SO_x$, particulate matter, and energy use.

The five indicators are normalized and weighted into one Composite Sustainability Indicator, giving each route a single environmental score with a clear direction, so environment can be weighed directly against cost and lead time.

On the tested corridor, the composite shows rail on the inland leg is both lower in environmental burden and cheaper than road, so environment and cost point to the same choice. Air freight carries a small share of volume but accounts for the majority of corridor emissions.

Embed the environmental score directly in the routing decision and its optimisation tools, so emissions weigh on the choice when the route is set, not reviewed once it is fixed.

Estimate emissions with standard default factors where carrier data is missing, treating primary data as a later refinement rather than a precondition, so assessment can begin immediately.

Tackle air freight first. A small share of shipments produces most of the corridor's emissions, so reducing how much is flown, through earlier planning and consolidation, cuts the footprint faster than any change to the sea routes.

Although this study narrows sustainability to its environmental dimension, future research should incorporate the social and economic dimensions, extending the same method toward a decision that weighs all three against cost and time.

# Materials Digital Passport for the aircraft supply chain

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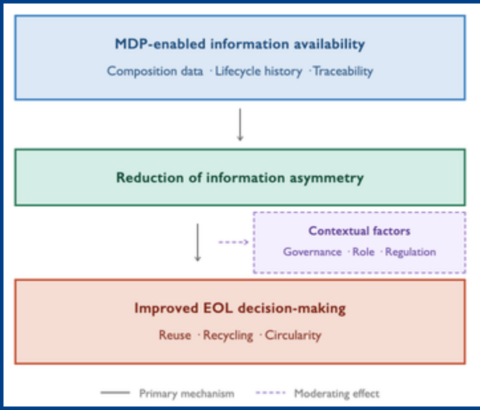
This study investigates how a Materials Digital Passport (MDP), as a material-level element of the EU Digital Product Passport framework, can reduce information asymmetry in Airbus' aircraft supply chain and unlock end-of-life circular opportunities. Drawing on 12 semi-structured interviews with actors spanning the full supply chain, the study maps current information flows, identifies governance barriers, and evaluates how improved material information availability could change reuse and recycling decision conditions at aircraft end-of-life.




*Conceptual framework*

## Findings & Recommendations

Material information is fully recorded internally but systematically filtered at each handoff. EOL players are structurally excluded from existing sharing practices.

Information asymmetry is governance-driven rather than technical. Actors share only what is strictly necessary to the next stage.

DPP awareness varies significantly across the supply chain. Only Airbus and raw materials suppliers actively anticipate compliance.

Actors expressed conditional willingness to participate in an MDP, contingent on role-based access control preventing sensitive data from reaching competitors.

Institutional guidance and OEM-level initiation are both seen as necessary. Airbus is widely identified as best positioned to lead implementation.

MDP-enabled traceability would expand the reuse pool beyond same-operator constraints and enable cross-airline airworthiness verification.

Composition tagging would improve recycling sort decisions and business case assessments, though circular outcomes also depend on economic viability and infrastructure.

Despite diverging views on information scope, material identification at EOL is considered both feasible and desirable across chain positions.

The findings suggest that an MDP aligned with the DPP framework could meaningfully reduce material-related information asymmetry in the aerospace supply chain, though realising circular outcomes at end-of-life will also require economic incentives, regulatory clarity, and coordinated governance across actors.

# Forced Landing: Greener but Less Competitive Skies in the EU?

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The European Green Deal has imposed a regulatory burden on EU air carriers. In this sense, the EU Emissions Trading System and the ReFuelEU Aviation Regulation do not extend in equal terms to their non-EU competitors. On international routes where EU and foreign carriers serve the same city pair, the resulting asymmetry generates potential competitive distortions that EU law is equipped to address. This research investigates the legally sound remedies available under EU law to balance that distortion, via the EU and Member States, focusing on operational State aid under Article 107(3)(b) TFEU, and examines the structural limitations of the existing soft-law architecture, whose eligibility criteria do not readily accommodate the kind of remedies that the aviation sector requires.

## Findings & Recommendations

**Asymmetric obligations between competing carriers.** EU ETS and ReFuelEU impose costs on EU carriers that their non-EU competitors do not equally bear on the same routes.

**A legally cognisable distortion, not merely political** Within the relevant market, the differential burden amounts to a competitive distortion under EU competition law.

**Article 107(3)(b) TFEU offers a sound treaty pathway** The derogation accommodates operational State aid to mitigate the distortion, consistent with EU competition law and climate goals.

**The bottleneck is the soft-law architecture** The Commission's IPCEI Communication sets criteria that do not readily accommodate operational, sector-wide remedies.

**Reform the soft law, not the Treaty**
A tailored soft-law instrument for climate-driven distortions would unlock the Treaty's full potential — no primary-law reform needed.

**ETS revenues can carry their fair share**
Earmarking auction proceeds and Art. 10a(6 of the EU RT, already used to compensate carbon-leakage risk in industry the same logic could be applicable to the Aviation Industry

# The EU Aviation Eco-Label

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The EU Aviation Eco-Label (Flight Emissions Label) is a new transparency-based environmental instrument established under ReFuelEU Aviation. Unlike the EU ETS, it does not directly regulate airline emissions. Instead, it provides standardized environmental information to consumers during the booking process.

This research examines whether the Eco-Label remains an information disclosure mechanism or gradually evolves into an indirect regulatory instrument. It analyses the legal framework under EU law, its interaction with international aviation law and ICAO, and the legal risks arising from consumer protection, market competition and environmental governance. Finally, the thesis proposes legal safeguards for its future development.

## Findings & Recommendations

Environmental scores are calculated using operational data, aircraft efficiency, load factors and SAF consumption

The scheme involves the EU, EASA, airlines, consumers, booking platforms and ICAO

Improves transparency, influences consumer behaviour and encourages better environmental performance

The Eco-Label is expected to create gradual long-term market and behavioural changes rather than immediate regulatory effects

Limited direct compliance costs, but additional administrative, reporting and reputational costs for airlines

Environmental ratings simplify complex emissions data but may strongly influence airline visibility and purchasing decisions

Main concerns include jurisdiction, regulatory fragmentation, consumer protection, greenwashing and competition law

Maintain the informational nature of the Eco-Label, improve methodological transparency, prevent market distortion and strengthen coordination with ICAO

The principal challenge is not whether the Eco-Label is legal today, but whether it can remain a transparency-based information instrument without gradually becoming an indirect mechanism of market regulation.

# Shared Take-Aways and Recommendations...

1 Regulatory fragmentation is a common brake on progress

→ Harmonize and future-proof rules across instruments and jurisdictions

2 Trust and transparent information-sharing are key

→ Treat trust-building and data governance as core principles

3 Single, flight-based metrics such as $CO_2$ or cost do not capture all effects

→ Work towards multi-dimensional, lifecycle-based indicators in all disciplines

4 No single actor can decarbonize aviation or introduce novel concepts alone

→ Invest in formal coordination mechanisms rather than relying on parallel individual efforts

# ... Leading to New Research Questions

? How can aviation's climate regulations be harmonized across instruments and jurisdictions, and what role can non-regulatory stakeholders perform?

? How can regulation stay effective as aviation technology and markets keep changing?

? What would allow trust and acceptance to be designed into aviation's data and information systems, not just assumed?

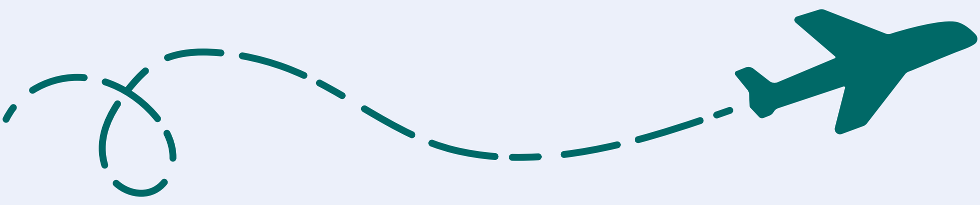
? How can we enable data sharing across stakeholders to help decision making and trust building, without losing the competitive edge?

? How to fairly evaluate and select new technologies, operations, regulations, and other solutions under uncertainty?

? What indicators allow measuring sustainability consistently across aviation's full value chain for new technologies and processes?

? How to capture the interdependencies between different stakeholders in decision-making processes?

? Who should lead, and who should follow, in aviation's sustainability transition?



# Enrichment Sessions

During the lab, students joined a series of enrichment sessions to dig into the many challenges and opportunities shaping the future of sustainable aviation and related industries.

*Kick-off LDE Thesis labs in Leiden*



*Visit to TU Delft, Faculty of Aerospace Engineering*

*Lecture by John-Alan Pascoe and visit to the Aerospace Study Collection*

## *Visit to NLR*


## *Visit to Airbus Netherlands*

*A look inside the manufacturing of space components and exploring the tangents to aviation*

*Pressure Cooker*

*Creating an overview of the system we are considering in the lab*

*Round Table Discussion*

*Discussing the research with experts from airports, airlines, policy, manufacturers, research organisations, and branch organisations*




*Bootcamp*

*Communicating your research*

*Visit to BlueCity*

*Investigating how startups contribute to blue and circular economy*


*Visit to Leiden University, Faculty of Law*

*Lecture by Garry Pratama on Regulatory Frameworks Governing Aviation Emissions*


*Erasmus University*

*Bringing all puzzle pieces together*

# Final Words

And with this overview of the enrichtment sessions, we already close off this booklet on the LDE thesis lab “Wings of the Future”! We hope that you enjoyed reading the booklet and that you are inspired by the many different research questions, research areas, and disciplines that play a role in the transition towards sustainable aviation.

Last, we would like to thank everyone involved in organizing this lab: The overarching Thesis Labs organization, the coordinators of last year, Flying Vision Accelerator, NLR, Airbus, and all experts participating in the enrichment sessions for their time, active involvement, and practical help. And last, but not least, we would like to thank all the participating students: Without your enthusiasm, input, creativity, and hard work, we could not have organized this lab.

Kind regards,

**Ingeborg de Pater, Pieter-Jan Proesmans, and Prem Sundaramoorthy**
Coordinators of the LDE Thesis Lab “Wings of the Future”

Noor Maijers

*“Technological advancement and regulatory development can create the aviation industry of the future. Disruptiveness does not have to be negative if innovation is looked upon with a positive attitude and research is endorsed.”*

Xinyi Zhang

*“May our commitment to balancing environmental protection and the sustainable development of civil aviation inspire laws that are both effective and forward-looking.”*

Luke Willigenburg

*“Even in times of adversity, don't give up hope on the ambitions to reach net-zero. It's never easy to make a change amidst such a complex industry, but I'm sure we can do it. Together.”*

# Coordination Team

*“Solving aviation’s greatest sustainability challenges requires more than just technical innovation. It demands a collective, interdisciplinary ecosystem that the LDE Thesis Lab uniquely provides.”*


Dr. Ingeborg de Pater
Network Coordinator

Dr.ir. Pieter-Jan Proesmans
Network Coordinator

Dr. Prem Sundaramoorthy
Academic Coordinator

# Useful Links

**LDE Thesis Labs**
https://www.leiden-delft-erasmus.nl/nl/sustainable-aviation-wings-of-the-future

**Flying Vision Accelerator**
https://luchtvaartintransitie.nl/en/project-item/flying-vision-accelerator/

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