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Towards an Integrated Environmental Modeling Platform for Sustainable Aviation and Urban Air Mobility

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Abstract

As aviation and urban air mobility (UAM) continue to expand, they create several challenges—ranging from environmental impact to infrastructure constraints—highlighting the urgent need for integrated and flexible solutions that can adapt to these evolving conditions. This paper presents the development of a Minimum Viable Product (MVP) that incorporates a selected subset of high-impact features from the broader RefMap platform—a modular suite of environmental modeling tools designed to support sustainability-oriented decision-making in both conventional aviation and UAM. Using a stakeholder-centered approach based on in-depth interviews, we identified and prioritized core functionalities across emissions reduction, noise mitigation, and trajectory optimization. The RefMap platform integrates real-time weather data, noise propagation modeling, CFD-based simulations, and multi-scale impact assessments to evaluate and enhance environmental performance. Findings reveal a strong demand for tools that bridge regulatory, operational, and environmental dimensions. This initial Minimum Viable Product (MVP) serves as a starting point for building a decision-support system that is easy to use, meets regulations, and potentially aligned with Europe's sustainability goals.

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Keywords: sustainable aviation, urban air mobility, environmental modelling, RefMap platform, noise and emissions, trajectory optimization, digital decision support

1. Introduction

Aviation is a key driver of economic growth and global connectivity but remains a major contributor to environmental degradation, particularly through greenhouse gas (GHG) emissions and noise pollution. In 2019[1], it

[1] 2019 is used as the latest available pre-pandemic baseline, as 2024 figures are not yet published, and traffic levels have nearly returned to pre-COVID conditions.

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accounted for 3.8% of the EU's total emissions, including CO_2, nitrogen oxides (NO_x), and contrails—significant non-CO_2 climate forcers, as reported by European Commission (2025). According to ICAO (2022), air transport is also considered the most carbon-intensive mode of transportation. Operational inefficiencies, such as suboptimal trajectories, further exacerbate its environmental footprint. As noted by Grollman (2020), aviation noise affects fewer people than road traffic, but it can still lead to severe health implications. With air traffic projected to grow by 86% by 2040, addressing these sustainability challenges has become a strategic priority, as highlighted by Amicarelli et al. (2021).

Despite growing environmental efforts—like carbon accreditation, SAF adoption, and offset schemes—current solutions often remain fragmented and fail to integrate dynamic operational conditions or optimize trajectories based on combined environmental factors, as observed by Rodoplu et al. (2022). Meanwhile, the rise of drones and urban air mobility (UAM) introduces new concerns, including cumulative noise, local air quality, and regulatory gaps. As the EU advances toward Green Deal targets, integrated digital tools for environmentally informed decision-making in both aviation and UAM are urgently needed, according to European Commission (2024).

This paper contributes to that need by presenting the initial development of a Minimum Viable Product (MVP) within the RefMap platform—a modular suite targeting emissions, noise, and trajectory optimization. The MVP serves as a strategic stepping stone toward a fully integrated digital decision-support tool, helping align environmental modeling capabilities with operational, regulatory, and stakeholder requirements, as noted by Stevenson et al. (2024). Based on semi-structured interviews, key stakeholder needs were identified and used to prioritize high-impact features most relevant to sustainability goals. The paper outlines related tools, the RefMap framework, applied methodology, findings, and next steps.

2. RefMap platform and tools description

A range of digital platforms has been developed in recent years to support various aspects of aviation and drone operations, including compliance management, fleet coordination, airspace integration, and environmental monitoring. Tools such as ANCON, developed by UK CAA, focus specifically on noise impact modeling, while platforms like Drone Suite by ITG Drone Solutions, FlyFreely, and Avision Flight emphasize operational efficiency and regulatory compliance. Others, such as Envirosuite and AirHub by Airspace Link, provide capabilities in environmental monitoring and airspace management. However, these tools typically address isolated functions and often lack the integration required to support comprehensive sustainability planning.

In contrast, the RefMap platform offers a multidimensional solution that integrates environmental performance analysis, noise-aware flight planning, and route optimization. Using CFD, climate modelling, and optimization algorithms, it enables multi-scale assessments of emissions, noise, and air quality. These capabilities support scenario-based simulations and predictive analyses for both conventional aviation and UAM, allowing stakeholders to assess environmental impacts under diverse operational and weather conditions. Table 1 outlines the platform's core components.

Table 1. Description of the tools of the RefMap platform.

Tool Name	Description
High-Fidelity Simulations	Describes flow fields around buildings with detailed velocity components and turbulence data.
UrbanUQ	Quantifies uncertainty in steady urban flow predictions due to urban fabric geometry and meteorological variability.
MFLOW (Multi-fidelity FLOW)	Predicts wind flow inside urban areas based on specified wind conditions.
CFDPerfOpt	Accelerates high-fidelity CFD simulations for airflow modeling, reducing infrastructure costs and enabling broader deployments.
CLIMaCCF	Evaluate climate impacts of aviation emissions using algorithmic climate change functions.
F-LAQA	Assesses air quality near airports for different aviation fuels and blending levels.
DLOpt	Optimizes RefMap AirFlow deep learning model performance for efficient deployment.
ROOST Library	Provides robust trajectory optimization under uncertainty conditions.

ANTAO	Models aircraft trajectories to reduce noise and emissions while complying with regulations.
UAV-Noise Tool	Models drone sound emissions and propagation to optimize flight paths for minimal noise impact.
Flight Dynamics Models (FDM)	Simulates dynamics for various aircraft types using tailored models for scenario analysis.

3. Methodology

This study aimed to gather in-depth insights from stakeholders engaged in both large-scale (aviation) and small-scale (drone/UAM) environmental modeling. A semi-structured interview approach was used to collect both qualitative and quantitative data. Stakeholders first participated in open-ended discussions and then evaluated specific system features numerically, following exposure to tailored scenarios. Interviews were conducted using a standardized format by researchers from Future Needs (FN) and ISCTE – University Institute of Lisbon, ensuring consistency across sessions.

4.1 *Stakeholders*

A total of twenty-three interviews were conducted with professionals from five stakeholder groups: Airports and Airport Operators (3), Technical Researchers (7), Airlines and Aviation Industry Representatives (4), Drone Industry Stakeholders (6), and Civil Aviation Authorities/Policymakers (3). Each 90–120-minute session explored user needs, challenges, and expectations regarding RefMap's potential applications across conventional aviation and UAM contexts.

4.2 *Interview Structure*

Interviews included both structured and unstructured components:

- Structured questions addressed system functionality, integration, and expected impact. Two discussion guides (aviation and drone-specific) were developed and implemented via the Qualtrics platform. Each guide introduced RefMap features through contextualized scenarios and asked participants to rate each on a 1–5 scale of usefulness.
- Unstructured questions encouraged participants to elaborate on their professional contexts, challenges, and suggestions for additional functionalities—allowing for deeper exploration beyond predefined criteria.

Scenarios were tailored to each stakeholder's domain: aviation participants focused on system-wide operations (e.g., airspace and flight planning), while drone stakeholders emphasized real-time mapping, urban logistics, and operational flexibility. All interviews were conducted with informed verbal consent, adhering to GDPR and ensuring confidentiality and data protection.

4. Results

4.1 *Stakeholder-Identified Challenges and Tool Landscape*

Stakeholders identified a range of challenges for sustainable aviation and UAM, spanning environmental, regulatory, operational, economic, and social domains. Key concerns included persistent airport noise, the climate impact of non-CO_2 emissions, and limited adoption of Sustainable Aviation Fuels (SAFs) and alternative propulsion systems. Regulatory constraints, certification bottlenecks, and high infrastructure costs were seen as major barriers to innovation and decarbonization.

In the UAM context, stakeholders cited integration challenges, infrastructure gaps, and low public acceptance. Issues of data quality, digital trust, and tool interoperability were common across both domains. While many tools exist—ranging from noise simulation to U-space and air traffic management—stakeholders noted their fragmentation and lack of integration, underscoring the need for cohesive, multifunctional platforms like RefMap.

4.2 *Quantitative Assessment of RefMap Features*

To complement the qualitative insights, participants rated the usefulness of RefMap feature sets in predefined large-scale (aviation) and small-scale (UAM) operational scenarios. Each scenario presented a statement—a curated bundle of tool functionalities—designed to simulate realistic applications of the RefMap platform. Participants rated each

statement on a Likert scale from 1 (not useful) to 5 (very useful), enabling comparison across domains and functionalities. These ratings help identify the most attractive tool combinations for MVP development.

Large Scale Scenario 1: To help airlines support sustainable aviation practices complying with new regulations

"Air transport is the largest contributor to transport-related emissions, and new EU Green Deal regulations require airlines to adapt or face financial penalties. Mrs. Smith, an airline manager, is already struggling with profitability on routes under 250 km and is concerned about the added pressure from upcoming environmental caps. She uses the platform to simulate different SAF blending levels for an Airbus A320 and explores alternative trajectories with lower environmental impact. Some routes trigger high fines due to emissions, while others meet regulatory thresholds. Through optimized planning, she can adjust operations to reduce environmental penalties and ensure compliance."

Figure 1 presents the aggregated results of participants' evaluations on the perceived usefulness of each individual characteristic included in Large Scale Scenario 1. Participants were asked to respond to the following prompt: "The RefMap solution is envisioned to offer the following statements, each representing a combination of tool functionalities. Please rate how much you agree with the usefulness of each statement on a scale from 1 to 5."

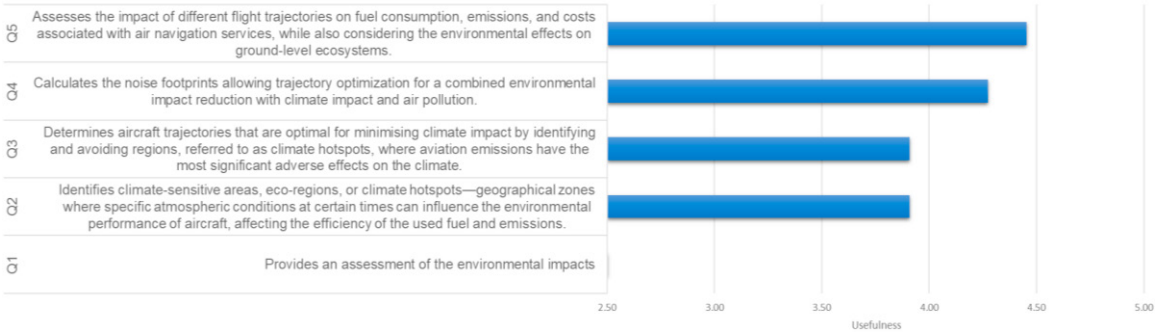


Fig. 1. Results of the participants' ratings on the usefulness of each characteristic for Large Scale Scenario 1.

Large Scale Scenario 2: Minimisation of citizens environmental impacts, while ensuring airport capacity expansion

"With increasing air transport volumes, there is a continuous need to expand airports around urban areas. However, emissions and noise impacts near airports are a growing concern among citizens, often leading to delays due to public demonstrations. As part of its 2030 capacity expansion plan, Schiphol Airport faces such challenges, driven by lower airfares and increased traffic. Airport managers use RefMap to simulate environmental emissions within the surrounding air traffic network. Given the limited land availability in the Netherlands and strong public opposition, it also supports the identification of meteorological conditions that can be leveraged to disperse emissions during approach, thereby reducing environmental impacts and enhancing community acceptance."

Figure 2 presents the participants' ratings on the perceived usefulness of each individual feature associated with Large Scale Scenario 2.

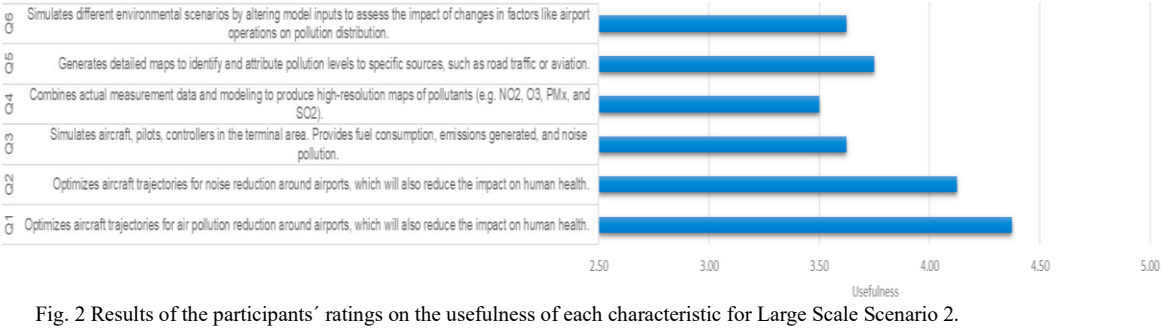


Fig. 2 Results of the participants´ ratings on the usefulness of each characteristic for Large Scale Scenario 2.

Large Scale Scenario 3: To empower EU regulators to oversee environmental footprints from the aviation industry

“By 2040, international aviation emissions are expected to increase by up to 150% compared to 2020 levels. While technological improvements may reduce fuel use, they will not fully offset aviation’s environmental impact, driving regulators to enforce stricter monitoring and introduce targeted environmental fees. To support these efforts, the RefMap platform enables evaluation of airspace use through AI-based trajectory optimization tools (TOP-AID) and integrates environmental impact constraints into flight planning, helping identify more sustainable operational pathways.”

Figure 3 presents the corresponding results for the perceived usefulness of each feature within Large Scale Scenario 3.

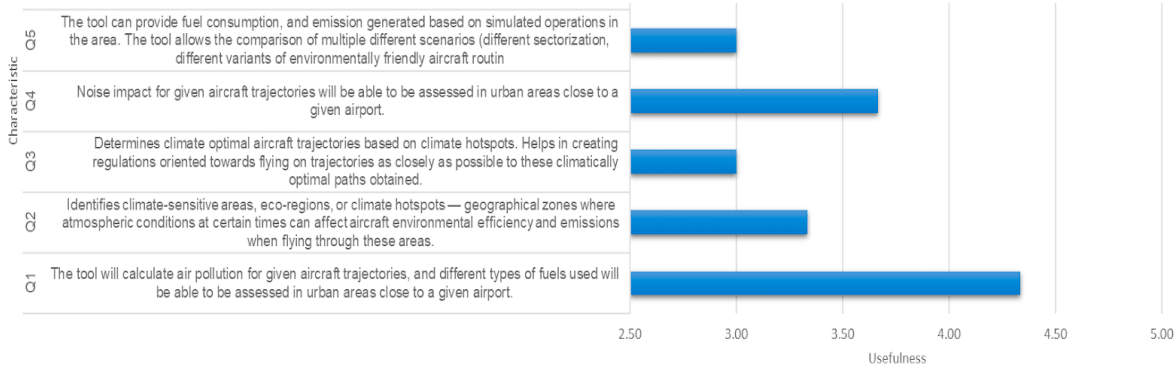


Fig. 3. Results of the participants' ratings on the usefulness of each characteristic for Large Scale Scenario 3.

Small Scale Scenario 1: Identification of locations in an inhabited environment where a drone fleet can operate

“Municipalities and drone operators use simulations to evaluate and minimize noise impacts, enabling the selection of locations that meet urban logistics needs while preserving residential quiet periods. The platform supports the identification of suitable and unsuitable areas, accounting for factors such as predominant winds, seasonal variations, and time-of-day constraints—enhancing service efficiency and community acceptance.”

Figure 4 summarizes feedback on the relevance of each feature within Small Scale Scenario 1.

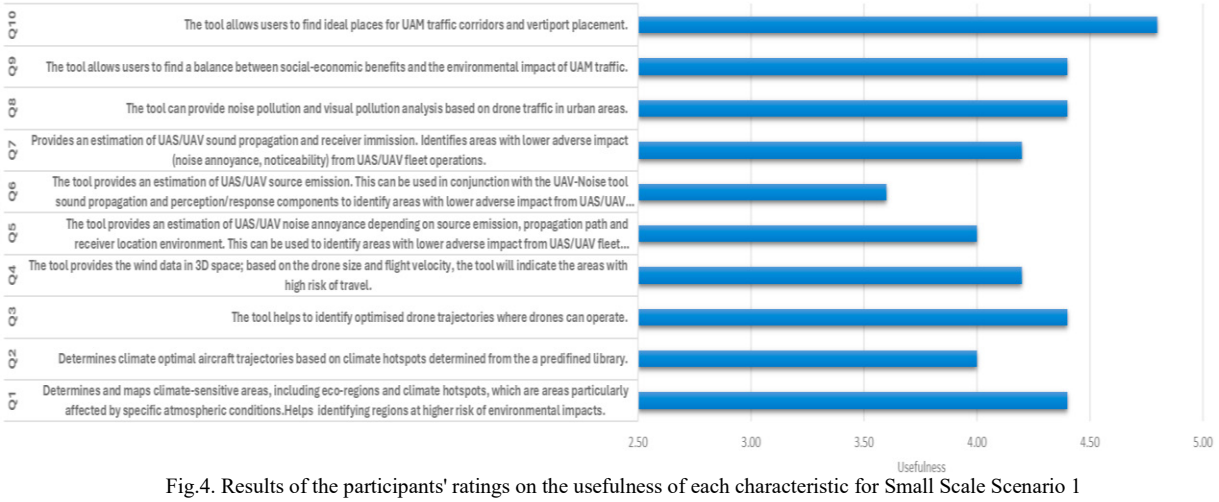


Fig.4. Results of the participants' ratings on the usefulness of each characteristic for Small Scale Scenario 1

Small Scale Scenario 2: Delivery of essential goods, complementing other forms of transportation

“In 2019, road transport accounted for 72% of transport-related GHG emissions. Electrically powered drones offer a way to reduce local emissions and ease road congestion. Mr. Montalban, a transport company owner in Spain,

struggles with rising fuel costs and declining demand. His competitor, Ms. Martinez, has shifted to electric vehicles and drones for deliveries. She uses the platform to plan drone routes with TOP-AID and assess daily weather conditions via MFLOW, ensuring safe and efficient operations."

Figure 5 shows participants' usefulness ratings for each feature in Small Scale Scenario 2.

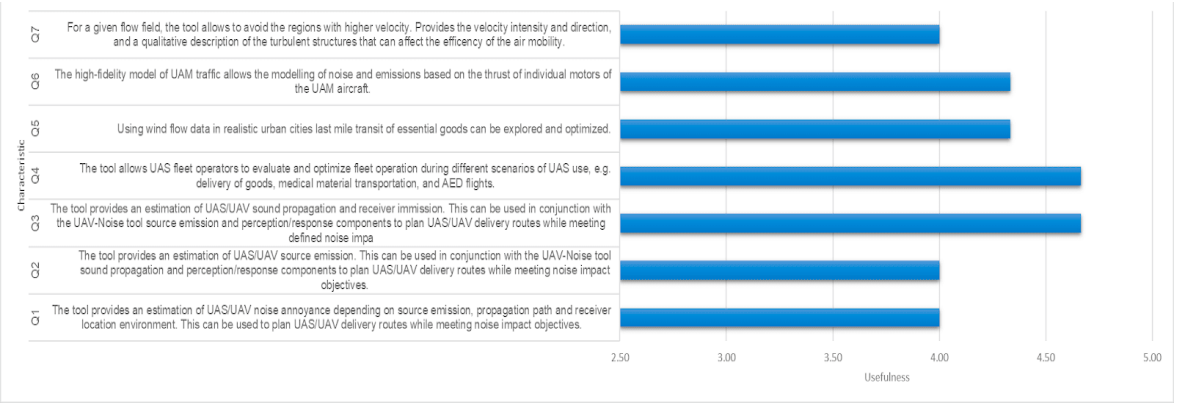


Fig. 5. Results of the participants' ratings on the usefulness of each characteristic for Small Scale Scenario 2.

The top-rated features—those scoring above 4 out of 5—are summarized below and grouped thematically under environmental impact assessment, noise management, and trajectory optimization for both large- and small-scale applications. The top-rated features for the Large-Scale Scenarios discussed during the interviews with ratings of more than 4 out of 5 were:

- L-SCE1-Q4: Calculates the noise footprints allowing trajectory optimization for a combined environmental impact reduction with climate impact and air pollution.
- L-SCE1-Q5: Assesses the impact of different flight trajectories on fuel consumption, emissions, and costs associated with air navigation services, while also considering the environmental effects on ground-level ecosystems.
- L-SCE1-Q1: Optimizes aircraft trajectories for air pollution reduction around airports, which will also reduce the impact on human health.
- L-SCE2-Q2: Optimizes aircraft trajectories for noise reduction around airports, which will also reduce the impact on human health.
- L-SCE3-Q1: The tool will calculate air pollution for given aircraft trajectories, and different types of fuels used will be able to be assessed in urban areas close to a given airport.

Moreover, the top-rated features for the Small-Scale Scenarios discussed during the interviews with ratings of more than 4 out of 5 were:

- S-SCE1-Q1: Determines and maps climate-sensitive areas, including eco-regions and climate hotspots, which are areas particularly affected by specific atmospheric conditions. This feature helps in identifying regions at higher risk of environmental impacts, aiding targeted decision-making.
- S-SCE1-Q3: The tool helps to identify optimised drone trajectories where drones can operate.
- S-SCE1-Q4: The tool provides the wind data in 3D space; based on the drone size and flight velocity, the tool will indicate the areas with high risk of travel.
- S-SCE1-Q7: The tool provides an estimation of UAS/UAV sound propagation and receiver immission. This can be used in conjunction with the UAV-Noise tool source emission and perception/response components to identify areas with lower adverse impact (noise annoyance, noticeability) from UAS/UAV fleet operations.
- S-SCE1-Q8: The tool can provide noise pollution and visual pollution analysis based on drone traffic in urban areas.

- S-SCE1-Q9: The tool allows users to find a balance between social-economic benefits and the environmental impact of UAM traffic.
- S-SCE1-10: The tool allows users to find ideal places for UAM traffic corridors and vertiport placement.
- S-SCE2-Q3: The tool provides an estimation of UAS/UAV sound propagation and receiver immission. This can be used in conjunction with the UAV-Noise tool source emission and perception/response components to plan UAS/UAV delivery routes while meeting defined noise impact objectives.
- S-SCE2-Q4: The tool allows UAS fleet operators to evaluate and optimize fleet operation during different scenarios of UAS use, e.g. delivery of goods, medical material transportation, and AED flights.
- S-SCE2-Q5: Using wind flow data in realistic urban cities, last mile transit of essential goods can be explored and optimized.
- S-SCE2-Q6: The high-fidelity model of UAM traffic allows the modelling of noise and emissions based on the thrust of individual motors of the UAM aircraft.

4.3 Discussion: Prioritized Features and Their Implications

The results from the quantitative assessment highlight a clear set of stakeholder priorities in both aviation and UAM contexts. Features related to environmental impact assessment, noise management, and trajectory optimization consistently received ratings above 4 out of 5, reflecting their perceived value in achieving sustainability and operational excellence.

- **Environmental Impact Assessment**: Highly rated features (e.g., L-SCE1-Q5, L-SCE3-Q1) enable simulation of emissions across fuels and trajectories, helping address both regulatory and climate objectives. Stakeholders valued the integration of fuel consumption, emissions, and cost to support data-driven decisions.
- **Noise Management**: Features like L-SCE1-Q4, L-SCE2-Q2, and S-SCE1-Q7/Q8 were prioritized due to increasing pressure to reduce noise—especially in urban settings. Accurate spatial noise modeling and flight path tuning were seen as key for regulatory compliance and public acceptance.
- **Trajectory Optimization**: Features such as S-SCE1-Q3 and S-SCE1-Q10 were favored for their ability to simulate safe, efficient routes under varying conditions (e.g., wind, noise, energy limits).
- **Contextual Awareness and Risk Mitigation**: Tools like S-SCE1-Q1 (climate-sensitive zones) and S-SCE2-Q6 (motor-level emissions) support localized planning and risk management, particularly in ecologically sensitive areas.
- **Socio-economic Integration**: Features such as S-SCE1-Q9—addressing community perception, urban planning, and noise/visual pollution—demonstrate the growing importance of social acceptance for UAM viability.

Beyond the quantitative feedback, open discussions emphasized the need for transparency, interpretability, and user-friendly interfaces—particularly in complex tools such as CFD-based noise simulations. Stakeholders also stressed alignment with certification processes, data governance, and evolving EU sustainability frameworks. While the environmental value of the platform was acknowledged, concerns about economic viability remain significant. Trade-offs between environmental performance and cost efficiency, shaped by certification complexity, infrastructure readiness, and regulatory alignment, must be considered, as emphasized by Raihan (2025).

These insights guide the ongoing refinement of the MVP, underscoring the need to balance sustainability gains with operational and financial feasibility to enable broader adoption across the aviation and UAM sectors.

5. Conclusion and Future Work

This study introduced RefMap as a modular, multi-scale platform designed for environmental modeling and operational optimization in both conventional aviation and Urban Air Mobility (UAM). Through stakeholder interviews, key features were identified and prioritized to support emissions reduction, noise mitigation, and optimized trajectory planning, emphasizing the demand for integrated, user-friendly tools that facilitate sustainability-oriented decision-making. Given the complex sustainability and economic challenges faced by the aviation and UAM sectors,

often stemming from knowledge gaps, infrastructure constraints, and fragmented technological development, a strategic approach to product development is essential.

The definition of RefMap's MVP serves as a critical step in this direction. To extend and validate the findings of this study, a follow-up online survey is being conducted with a broader stakeholder group across Europe. This next research phase will complement the qualitative insights and further refine the MVP. Future work will focus on improving usability, regulatory alignment, and iterative testing, positioning RefMap as a robust and widely adoptable decision-support system for environmental performance in air transport.

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