An Evaluation Framework for Aviation Decarbonization Strategies and Policies

Marina Efthymiou(✉)

Dublin City University Business School, Dublin, Ireland
marina.efthymiou@dcu.ie

Abstract. Achieving net-zero emissions in aviation requires a coherent mix of policy instruments that are environmentally effective, economically efficient, politically durable, and socially equitable. This paper develops a sector-specific evaluation framework grounded in multi-criteria decision analysis and environmental policy evaluation, designed to enable systematic, transparent, and replicable assessment of aviation decarbonization policies. The framework identifies six evaluation dimensions—mitigation potential, economic efficiency, feasibility and scalability, implementation speed, policy credibility, and equity and just transition—and provides measurement guidance. Applying the framework to two European instruments, the EU Emissions Trading System (EU ETS) and the Sustainable Aviation Fuel (SAF) mandate (ReFuelEU), demonstrates comparative assessment without collapsing complex trade-offs into a single score. The analysis highlights complementarities between pricing and mandates, the need for temporal sequencing of instruments, and the integration of non-CO_2 effects and equity safeguards. The framework offers a practical tool for policymakers, regulators, and researchers to design, evaluate, and adapt aviation decarbonization strategies.

Keywords: aviation decarbonization · Sustainable aviation · policy evaluation · EU ETS · sustainable aviation fuel · multi-criteria analysis · net zero

1 Introduction

The decarbonization of the global aviation sector constitutes one of the most intractable challenges in climate policy. Aviation contributes approximately 2–3% of anthropogenic CO_2 emissions, yet its total radiative forcing is significantly higher when non-CO_2 effects such as contrail-induced cloudiness are included. While the International Civil Aviation Organization (ICAO) has adopted a Long-Term Aspirational Goal (LTAG) of net-zero carbon emissions by 2050, and the European Union (EU) has embedded aviation within its "Fit for 55" and ReFuelEU Aviation packages, the pathway to net zero remains contested in both technical and political terms [1].

Aviation's structural dependence on high energy-density liquid fuels, the slow turnover of fleets, and the projected post-pandemic rebound in demand exacerbate the difficulty of achieving deep and rapid decarbonization. Policy instruments have proliferated, ranging from market-based measures (e.g., the EU Emissions Trading System,

© The Author(s) 2027
D. Esztergár-Kiss et al. (Eds.): TRAconference 2026, LNMOB, pp. 73–81, 2027.
https://doi.org/10.1007/978-3-032-37207-9_9

CORSIA) to blending mandates, R&D subsidies, and demand management tools. Yet systematic, comparative evaluation of these policies remains underdeveloped.

Existing scholarship tends to assess individual instruments in isolation, often privileging either techno-economic modelling or qualitative policy analysis. This fragmentation hampers the ability to compare policy effectiveness across jurisdictions and to synthesize insights for integrated decarbonization strategies. The absence of a coherent, transparent, and reproducible evaluation methodology risks policy lock-in to suboptimal measures and undermines international coordination.

This paper responds to that gap by proposing a structured evaluation framework tailored to aviation decarbonization. The framework draws on multi-criteria decision analysis (MCDA) methodologies developed in transport appraisal [2], integrates principles from environmental policy evaluation [3], and incorporates insights from political economy analyses of climate policy durability [4]. The framework is designed to enable rigorous, cross-contextual comparison of decarbonization policies, to enhance policy design, and to provide a replicable tool for future empirical studies.

2 Literature Review

Multi-criteria decision analysis (MCDA) provides a formalised approach to evaluating alternatives against a set of heterogeneous criteria, both quantitative and qualitative. In transport policy, MCDA has been employed to reconcile trade-offs between environmental objectives, economic efficiency, and social acceptability [2, 5]. Unlike purely cost-benefit approaches, MCDA accommodates dimensions that resist monetisation, such as political feasibility or distributional equity. Yet it remains critical to the viability of decarbonisation measures.

While MCDA frameworks are widely used in infrastructure planning (e.g., the UK's WebTAG, the EU's TEN-T evaluation guidelines), their application to policy instruments—as opposed to physical projects—is comparatively limited. Aviation decarbonisation presents a particularly complex domain for MCDA because of (a) multiple interacting emissions sources (CO_2, NO_x, contrails), (b) heterogeneous stakeholder interests across borders, and (c) high uncertainty in technology cost and performance trajectories.

A small but growing body of scholarship evaluates aviation decarbonisation policies. Studies of the EU ETS [6, 7] often focus on marginal abatement costs and leakage effects but do not systematically compare the ETS to alternative instruments. Research on the ReFuelEU Aviation Regulation [8] examines supply chain readiness and lifecycle emissions of sustainable aviation fuels (SAF) but rarely integrates these findings into a multi-instrument comparative framework. Analyses of CORSIA [9] highlight issues of offset quality and additionality but treat these in isolation from broader policy portfolios.

Given aviation's unique characteristics, such as slow technological turnover, stringent energy density requirements, governance under a global regime, and substantial non-CO_2 climate impacts, policy evaluation in this sector must adopt a tailored approach [10]. This requires technological specificity to capture sectoral constraints and opportunities; sensitivity to policy design that considers enforceability, adaptability, and long-term political durability; global applicability that aligns with ICAO-led frameworks while remaining responsive to diverse regional contexts; and explicit integration of uncertainty

to account for contested cost and performance trajectories of decarbonisation options, including SAF, hydrogen, and demand elasticity.

3 Evaluation Framework

The framework follows four principles (see Table 1): transparency (explicit definitions, indicators, sources), comparability (like-for-like assessment across instruments), adaptability (criteria updated as science and costs evolve, including non-CO_2), and policy-design sensitivity (enforceability, durability, fairness).

Table 1. Core design principles

Principle	Description	Example in aviation policy context
Transparency	All criteria definitions, indicators, and data sources are explicit and documented for replication.	Publishing the exact MRV methodology used to assess ETS aviation emissions reductions.
Comparability	Enables side-by-side assessment across diverse policy types.	Evaluating SAF mandates and ticket taxes on common dimensions such as cost-effectiveness and mitigation potential.
Adaptability	Criteria and weightings can evolve with new evidence and technologies.	Updating framework to include contrail mitigation metrics once operational protocols mature.
Policy-design sensitivity	Captures enforceability, political durability, and fairness beyond technical metrics.	Analysing how legislative embedding of SAF mandates affects long-term compliance.

The policy taxonomy (Table 2) groups aviation decarbonisation instruments into four categories: market-based measures, which create price signals to internalise environmental costs (e.g., emissions trading schemes, carbon or ticket taxes); mandate or regulatory measures, which set binding standards or quotas to drive specific outcomes (e.g., SAF blending mandates, aircraft performance standards); enabling or support measures, which reduce barriers and accelerate innovation through funding, infrastructure, or procurement; and demand-management measures, which aim to moderate or shift air travel demand through pricing reforms, behavioural interventions, or targeted restrictions. This classification helps ensure that different policy types—each with distinct mechanisms, strengths, and risks—are compared on a consistent basis within the evaluation framework.

The framework operationalises "what good looks like" for aviation decarbonisation policy through six evaluation dimensions (Table 3): mitigation potential, assessing the

Table 2. Policy Taxonomy

Category	Definition	Typical instruments	Primary mechanism	Key benefits	Principal risks/bottlenecks	Typical evidence needed
Market-based	Puts a price on emissions or flying.	EU ETS, CORSIA, carbon/ticket taxes.	Price signal; internalises external costs.	Cost-effective abatement; revenue for recycling	Volatile/low prices; partial coverage; leakage.	MRV flight-level data; ex-post econometrics; revenue/incidence analysis.
Regulatory/mandate	Sets a standard or quota.	SAF blending mandates; aircraft performance standards; NOx limits.	Quantity/standard – forces fuel/tech switch.	High certainty on volumes; investment signal.	Supply capacity; high near-term costs; certification lags.	LCA/TEA of fuels; supply chain projections; compliance data.
Enabling/support	Lowers barriers to adoption	R&D grants, PtL infrastructure finance, green public procurement.	Cost de-risking; network effects.	Accelerates innovation and scale-up.	Picking winners; lock-in; fiscal cost.	Programme evaluations; CGE/IO modelling; cost-learning evidence.
Demand-management	Moderates demand or shifts behaviour.	Frequent-flyer levies; VAT/ticket tax reforms; advertising limits.	Price/choice architecture	Immediate impact; complements supply-side.	Equity concerns; substitution/leakage.	Elasticity estimates; distributional incidence; cross-border effects.

scale of emissions reduction (including non-CO_2 impacts) relative to a defined baseline; economic efficiency, evaluating the cost-effectiveness and wider welfare effects of the policy; feasibility and scalability, examining the capacity to deploy and expand the intervention at sectoral level; implementation speed, measuring how quickly meaningful impacts can be realised; policy credibility, considering enforceability, stability, and adaptability over time; and equity and just transition, analysing how costs and benefits are distributed across stakeholders and regions. Together, these dimensions provide a balanced lens that integrates environmental, economic, technical, political, and social performance.

In practical terms, equity in aviation decarbonisation policy can be assessed by combining distributional incidence analysis with qualitative stakeholder perspectives. Quantitatively, this can include:

- Income decile analysis. Use national or EU household expenditure surveys to estimate air travel demand by income group, apply estimated ticket price changes from the policy, and calculate the relative burden (as % of disposable income) for each decile.
- Geographic incidence. Map effects by region using input–output tables or regional accounts to capture employment gains/losses (e.g., in SAF production hubs vs. non-production regions) and changes in connectivity for remote areas.
- Employment transition metrics. Track job creation in low-carbon aviation supply chains and job losses in fossil-fuel-dependent sectors; adjust for skill-matching potential.

Table 3. Evaluation Dimensions and Indicators

Dimension	Definition	Preferred indicators (units)	Minimum acceptable methods	Reporting notes
Mitigation potential	Expected CO_2e reduction vs. baseline by 2050.	% sector reduction; $MtCO_2e$; CO_2e per RPK.	Robust LCA or ex-post econometrics; IAM/sector models with documented assumptions.	State baseline, horizon, and whether non-CO_2 included.
Economic efficiency	Cost per tonne avoided and welfare effects.	€/tCO_2e; ΔGDP; consumer surplus; airline cost pass-through.	MACCs; CGE/PE models; audited cost data.	Report ranges and price assumptions; show sensitivity to fuel and EUA prices.
Feasibility & scalability	Ability to deploy at sector scale.	TRL; certified fuel capacity (Mt/y); infrastructure readiness milestones.	Supply-chain analysis; certification status; programme audits.	Flag critical inputs (renewable electricity, CO_2, feedstocks).
Implementation speed	Time from adoption to measurable reductions.	Years to first impact; abatement profile (early vs. late).	Documented regulatory/industry timelines; ex-post case histories.	Separate legislative lead time from physical ramp-up.
Policy credibility	Likelihood the instrument endures and bites.	Compliance rates; penalty stringency; mandated ratchets.	Legal analysis; governance audits; historical stability.	Note derogations, free allocations, or carve-outs.
Equity & just transition	Distribution of costs/benefits.	Incidence by income/region; employment effects; revenue recycling share.	Microsimulation or incidence analysis; regional IO studies.	Report design of compensations and who gains/losses.

- Revenue recycling impacts. Model how hypothecating ETS or other policy revenues to targeted rebates, public transport subsidies, or green skills training changes the net distributional outcome.
- Accessibility indicators. Monitor changes in affordability of essential air services for low-income or peripheral communities.

The evaluation process begins with (1) defining the scope of the analysis, specifying the jurisdiction, baseline year, time horizon, and coverage of the policy under review; this stage produces a scope note, a baseline dataset, and, where relevant, a policy logic model. (2) The evaluator then collects evidence for each of the six framework dimensions, ensuring that all data sources are fully documented and quality-checked; outputs at this stage include an evidence matrix, a data dictionary, and quality assurance records. (3) Next, the evaluation criteria are applied, either qualitatively or in a semi-quantitative form, with explicit justifications for each assessment and sensitivity tests to account for uncertainty; this typically results in dimension-by-dimension assessments and a sensitivity analysis appendix. (4) Finally, the evaluator synthesises and reports the findings, comparing the performance of different policy instruments, identifying synergies and trade-offs, and highlighting evidence gaps; the deliverables include a comparative results table, a narrative synthesis, and an uncertainty register to inform policy refinement.

Key uncertainties in aviation decarbonization policy include variability in lifecycle assessment (LCA) results by feedstock, process inputs, and co-product crediting; these should be tested using parameter ranges, Monte Carlo simulations, and sensitivity checks for ILUC, grid carbon intensity, and refinery efficiency. Price volatility for EUAs, fossil jet fuel, and SAF/PtL fuels warrants scenario analysis with ±1–2 standard deviation shocks. Demand elasticity varies by market and income, requiring meta-analytic or market-specific estimates with ±25–50% sensitivity tests. Non-CO_2 impacts, such as contrail radiative forcing, NO_x chemistry, and CO_2-equivalence choices, should be assessed using alternative metrics and time horizons. Compliance risks from enforcement limits, exemptions, or free allocations can be modelled using historical rates and partial-compliance scenarios.

4 Discussion and Conclusion

The evaluation framework developed in this paper addresses a persistent methodological gap in assessing aviation decarbonization policies. While most studies examine individual instruments in isolation, such as the EU ETS [6] or SAF mandates [8, 11], this framework enables structured cross-instrument comparison, incorporating both quantitative performance indicators and qualitative policy design features. By operationalizing six dimensions—mitigation potential, economic efficiency, feasibility and scalability, implementation speed, policy credibility, and equity—it moves beyond conventional evaluations to reflect aviation-specific dynamics.

Application of the framework shows that the central policy risk in aviation decarbonization is not selecting the "wrong" instrument but relying on any single instrument in isolation. Market-based measures such as the ETS perform strongly in economic efficiency, scalability, and implementation speed, but at plausible carbon price levels are insufficient to induce large-scale structural fuel switching. Regulatory mandates such as ReFuelEU provide greater mitigation certainty and long-term investment signals, including potential non-CO_2 benefits, yet are constrained by near-term supply chain limits, high costs, and distributional impacts. The main policy-relevant result is therefore that complementarity and sequencing of instruments are more decisive for mitigation outcomes than the relative performance of individual policies.

The framework consequently supports a sequenced portfolio approach to aviation decarbonization. First, strengthened pricing instruments can deliver immediate operational efficiencies, modest demand responses, and revenue generation. Second, supply-building measures, including SAF mandates and enabling infrastructure and innovation support, should be deployed in parallel to create the conditions for deeper long-term emissions reductions. Third, revenue recycling and explicit distributional safeguards are required to maintain political durability and social legitimacy, particularly where policies increase ticket prices. This shifts policy design from optimizing single instruments to stress-testing portfolios across mitigation, feasibility, credibility, and equity dimensions.

Equity considerations are therefore critical. Both instruments can increase ticket prices and disproportionately affect lower-income travelers. ETS revenues, however, create opportunities for socially progressive investment, unlike mandates. Including equity as a core dimension ensures these distributional effects are addressed at the design stage. Non-CO_2 effects also remain poorly integrated despite their significant warming impact [12]. The framework's focus on CO_2e rather than CO_2 alone enables future evaluations to incorporate contrail avoidance and operational measures as methodologies develop.

Decarbonising aviation in line with net-zero targets requires policies that combine environmental effectiveness, economic efficiency, political durability, and social equity [13–16]. This paper proposes a sector-specific framework that operationalises these aims through six measurable dimensions. Grounded in multi-criteria decision analysis and environmental policy evaluation theory, it provides a transparent, replicable method for comparing policy types, from carbon pricing to fuel mandates and demand management. The framework is intended as both an assessment tool for existing policies and a design guide for future measures.

The framework therefore supports a sequenced portfolio approach: (1) immediate strengthening of pricing instruments to drive operational and demand-side efficiencies; (2) parallel deployment of supply-building measures (SAF mandates, infrastructure support) with clear scale-up pathways; and (3) mandatory integration of revenue recycling and distributional safeguards to maintain political durability. Policymakers should use the framework ex-ante to stress-test instrument portfolios across all six dimensions, rather than optimising policies on mitigation or cost alone.

Nevertheless, the framework has some limitations. Its use depends on data availability and quality, which vary across jurisdictions and instruments. Semi-quantitative scoring can introduce subjectivity without transparent justification and sensitivity testing. Cross-jurisdictional application may also require adapting weightings and indicators to different governance and market contexts.

References

1. Martín-Domingo, L., Efthymiou, M., Mújica-Mota, M.: Airline sustainability reportingin Europe: progress, compliance and challenges. Environ. Sustain. Indic. **28**, 101008 (2025)
2. Yannis, G., Kopsacheili, A., Dragomanovits, A., Petraki, V.: State-of-the-art review on multi-criteria decision-making in the transport sector. J. Traffic Transp. Eng. (English edition). **7**(4), 413–431 (2020)
3. Huang, I.B., Keisler, J., Linkov, I.: Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Sci. Total Environ. **409**(19), 3578–3594 (2011)
4. Greening, L.A., Bernow, S.: Design of coordinated energy and environmental policies: use of multi-criteria decision-making. Energy Policy. **32**(6), 721–735 (2004)
5. Macharis, C., Bernardini, A.: Reviewing the use of multi-criteria decision analysis for the evaluation of transport projects: time for a multi-actor approach. Transp. Policy. **37**, 177–186 (2015)
6. Efthymiou, M., Papatheodorou, A.: EU emissions trading scheme in aviation: policy analysis and suggestions. J. Clean. Prod. **237**, 117734 (2019)
7. Dominioni, G., Efthymiou, M.: Market-based measures for international aviation and shipping: lessons learned from a cross-sectoral analysis of EU ETS. In: Transport Research Arena Conference, pp. 117–124. Springer Nature Switzerland, Cham (2025)
8. Breen, M., Carton, J.G., Efthymiou, M.: Sustainable aviation fuel (SAF) supply. In: Transport Research Arena Conference, pp. 646–651. Springer Nature Switzerland, Cham (2025)
9. Prussi, M. et al.: CORSIA: the first internationally adopted approach to calculate life-cycle GHG emissions for aviation fuels. Renew. Sust. Energ. Rev. **150**, 111398 (2021)
10. Efthymiou, M., Papatheodorou, A.: Environmental policies in European aviation: a stakeholder management perspective. In: Sustainable Aviation: Greening the Flight Path, pp. 101–125. Springer International Publishing, Cham (2019)
11. Efthymiou, M., Ryley, T.: Governance and policy developments for sustainable aviation fuels. In: Sustainable Alternatives for Aviation Fuels, pp. 201–214. Elsevier (2022)
12. Scheelhaase, J., Maertens, S., Grimme, W.: Options for improving the EU emissions trading scheme (EU ETS) for aviation. Transp. Res. Procedia. **59**, 193–202 (2021)
13. Sun, X. et al.: From hero to zero: barriers to achieving IATA's 2050 sustainability targets. Transp. Policy. **174**, 103830 (2025)
14. Efthymiou, M., Martín-Domingo, L., Mújica-Mota, M.: Aviation decarbonisation: a bibliometric analysis of productivity, research trends, and gaps. Transp. Res. Procedia. **94**, 26–35 (2026)
15. Agarwal, S., Efthymiou, M.: Market reactions to ESG sanctions in the European airline industry. J. Air Transp. Res. Soc. **5**, 100087 (2025)
16. Efthymiou, M., Papatheodorou, A.: Environmental considerations in the single European sky: a Delphi approach. Transp. Res. A Policy Pract. **118**, 556–566 (2018)

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

