S A E C

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WIP:
A Transition-Centric Meta-Framework for Sustainability Challenges

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Overview

Why?
How?
What?
Questions?

Why?

A Strategic Approach to Sustainability Decision-Making

Sustainability transitions are messy. Think: conflicting goals, wicked trade-offs, uncertainty …

Interdisciplinarity vs. disciplinarity

Problem-Structuring Question: Where should MCDA focus within a sustainability transition?

Argument: Shift selection from disciplinary literature review → to a structured, transition-centric method.

What is Missing in Current Approaches

Literature reviews and expert-driven ad hoc approaches dominate …

Panaro et al. (2023); Afsar et al. (2023): Current MCDA problem structuring is driven by literature reviews or ad hoc expert opinion—lacking robustness, repeatability, and adaptability.

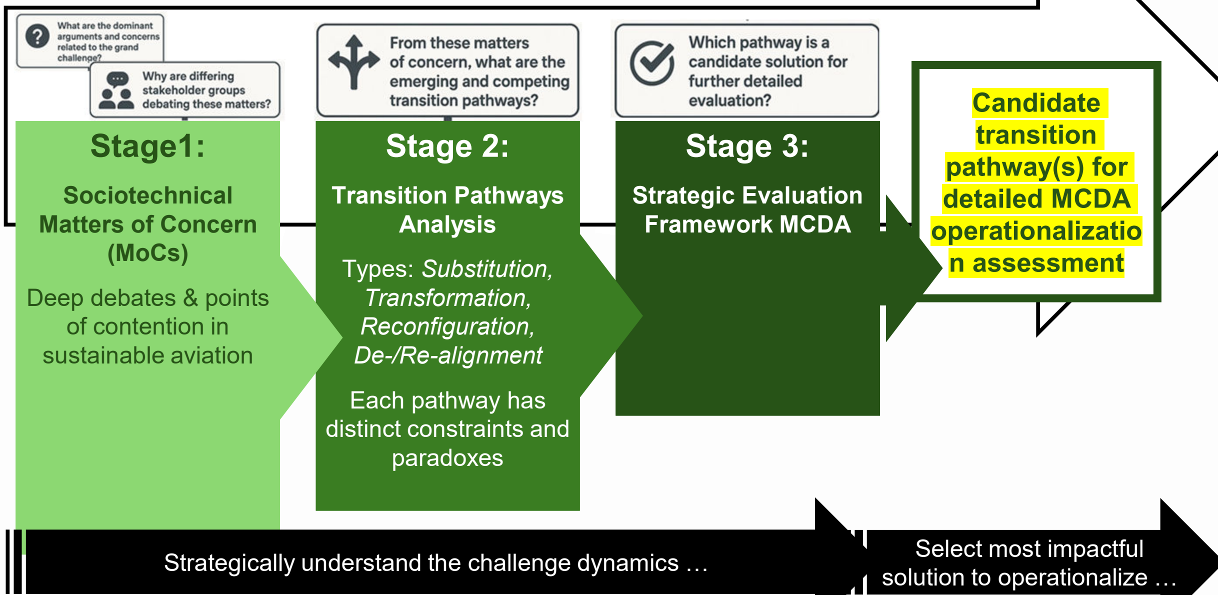
Result: Selection bias, lack of clarity, narrow disciplinary focus.

Sovacool et al. (2020): "Research must show greater attention to diversity, theoretical triangulation, and emerging concerns at the nexus of technology and society."

A Transition-Centric Meta-Framework

Objective: Build a decision-structuring meta-framework to guide MCDA use in complex sustainability transitions.

Transition-Centric Meta-Framework



How?

Method: Three Stages

- Stage 1: Identifies key sustainability Matters of Concern (Latour et al)
  - Defines key debates & trade-offs in sustainable aviation
  - Recognizes paradoxes (e.g., economic feasibility vs. sustainability trade-offs)
  - Calculates term frequences (TFIDFs) via computational text analysis using Quanteda
- Stage 2: Maps Transition Pathways (Geel's MLP)
  - Categorizes multiple, competing pathways within sustainability transitions: Substitution, transformation, reconfiguration, de-/re-alignment (Geels & Schot)
  - Derives pathways by clustering high-TFIDF MoCs and aligning them with Geels & Schot's four transition pathway types, ensuring both empirical grounding and theoretical coherence
- Stage 3: Introduces Robust Multi-Scenario Decision Analysis (RMSDA), offering:
  - Approach 1: Streamlined Analytical Hierarchy Process AHP-based ranking method
  - Approach 2: Comprehensive scenario-driven assessment integrating five transition scenarios
  - The AHP computations were performed in Excel using standard formulas for pairwise comparison normalization and weight derivation (consistent with Saaty's method)

How?

Method

https://docs.google.com/document/d/1Ppqa1wFJud95951VY9J7jBRaSaB37oSq7GfOUCSpgwY/edit?usp=sharing

Stage 3, Approach 1 Streamlined AHP-based ranking method

- Step 1: Define the Decision Criteria & Weighting: Technological Readiness, Data Availability, Policy Alignment, Computational Feasibility, Industry Adoption Potential
- Step 2: Conduct the AHP-Based Weighting Process (Saaty et al): Pairwise Comparisons & Expert Input Collection; Apply Weighted Scores to Each Pathway (Using Metrics & Literature-Based Inputs)
- Step 3: Rank Pathways & Interpret Results: Rankings are determined based on weighted scores
  - Sensitivity Analysis (Optional): Experts review ranking stability under minor AHP weight shifts
  - Rank Pathways: The highest-ranked pathway is selected for operationalizing MCDA integration

How?

Method

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Stage 3, Approach 2 Comprehensive scenario-driven assessment integrating five transition scenarios

- Step 1: Define Evaluation Criteria (same five key decision variables)
- Step 2: Weight Transition Scenarios
- Step 3: Adjust Weights Using Scenario Priorities: Short-Term Feasibility (2025–2035), Regulatory Priority (2035–2050), Net-Zero Carbon Priority (2050+), Economic Feasibility, Total Environmental Sustainability
  - Adjust original AHP-derived weights per scenario to reflect shifting priorities. Example: In the Net-Zero scenario, environmental impact receives greater weight; in Economic Feasibility, cost-related variables dominate.
- Step 4: Normalize Scores & Compute Weighted Rankings
  - Normalize Pathway Scores within each scenario using min-max normalization. Apply Scenario-Based Weights to normalized scores. Aggregate Weighted Scores to generate final rankings per scenario.
- Step 5: Aggregate Multi-Scenario Rankings
  - Compute Final Weighted Multi-Scenario Rankings to identify the most resilient MCDA candidate pathway.
- Step 6: Interpret Results & Select MCDA Focus

Method

Case Application

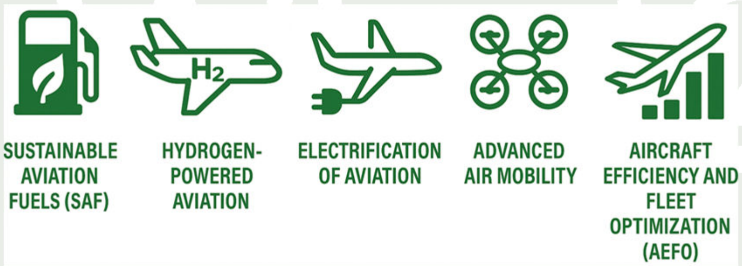
- The framework is applied to Sustainable Aviation transitions
- The study provides a scalable, generalizable methodology for selecting MCDM/A applications across sustainability domains

What?

Results: Stage 1

Matters of Concern (MoCs)	Concise Definition
Synchronizing TFIDF 17.71 (n=141)	Centers on public perception, consumer acceptance, and the alignment of investment funding with technological advancements to drive the successful adoption of green aviation solutions.
Operationalizing TFIDF 12.49 (n=141)	Examines the economic viability and operational efficiency of sustainable aviation, balancing environmental goals with airline profitability, fleet management, airport transformations, and fuel optimization.
Prognosticating TFIDF 9.34 (n=141)	Addresses the role of regulatory frameworks, global cooperation, and policy foresight in shaping the transition to sustainable aviation while mitigating risks of regulatory stagnation or market fragmentation.
Innovating TFIDF 7.03 (n=141)	Focuses on the development and integration of novel aviation technologies, such as electric and hydrogen propulsion, alongside the infrastructure challenges required for their scalability and widespread adoption.

Results: Stage 2 Pathways



Results: Stage 2 Pathways

Five Emerging Pathways with Type (Means) and Trajectory (Aim)

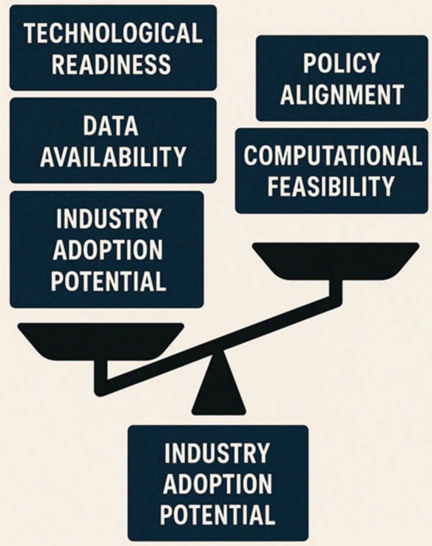
Pathway	Transition Pathway Type	Trajectory
Sustainable Aviation Fuels (SAFs)	**Substitution / Reconfiguration**	**Incremental to Evolutionary**
Hydrogen-Powered Aviation	**De- and Re-alignment**	**Disruptive to Radical**
Electrification of Aviation	**Substitution**	**Disruptive**
Advanced Air Mobility (AAM/UAM)	**Reconfiguration**	**Emergent to Disruptive**
Aircraft Efficiency and Fleet Optimization (AEFO)	**Transformation**	**Stabilizing to Incremental**

Results: Stage 3 Approach 1

Decision Variables

Static evaluation dimensions …

What?



Results: Stage 3 Approach 1

Decision Variable Definitions (for pathway evaluation)

Decision Variable	Definition	High Score (9)	Low Score (1)
Technological Readiness	Maturity of the technology and readiness for deployment.	Proven, market-ready tech; high TRL (≥ 8–9)	Early-stage, conceptual, or lab-based tech (TRL ≤ 4)
Data Availability	Accessibility and quality of supporting data.	Rich, robust datasets (e.g., LCA, field trials, policy models)	Sparse, unreliable, or missing data
Policy Alignment	Consistency with current/emerging regulations, incentives, and policy agendas.	Strong regulatory support, clear national/international alignment	No supportive policies or potential regulatory resistance
Computational Feasibility	Ease of modeling, simulation, and analysis using MCDA tools.	Simple to compute, stable models, few assumptions needed	Complex models, high uncertainty, or computational intractability
Industry Adoption Potential	Likelihood of acceptance and implementation by stakeholders and markets.	Strong market pull, supply chain readiness, infrastructure compatibility	Unclear demand, resistant incumbents, or lack of enabling infrastructure

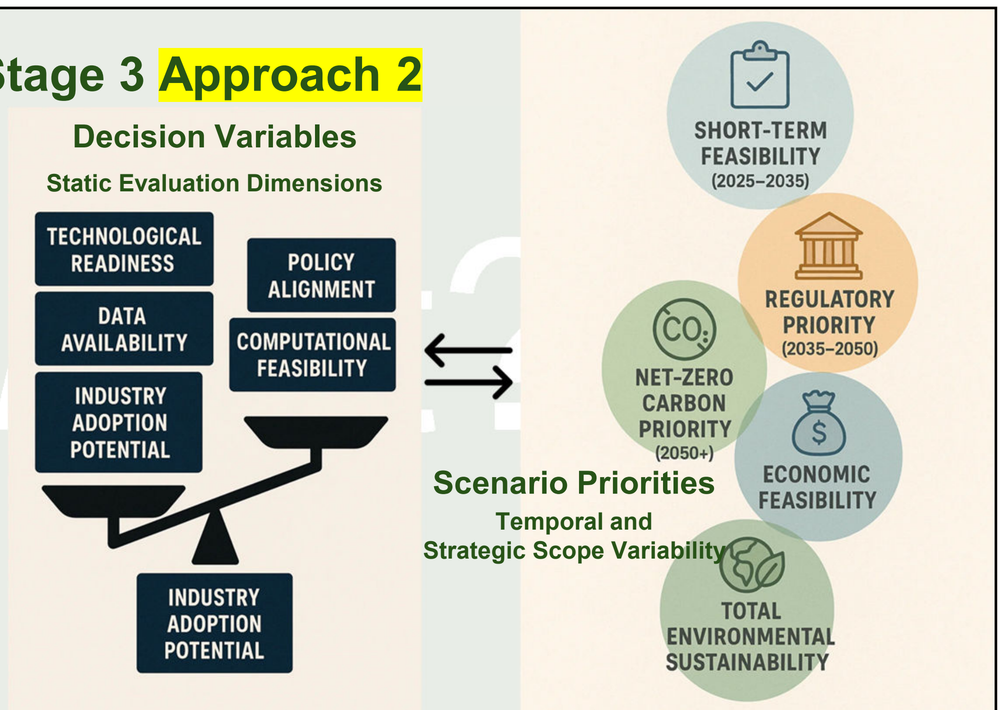
Results: Stage 3 Approach 1

Under a streamlined AHP ranking approach, Fleet Optimization emerged as the top-ranked pathway due to high scores in technological readiness, economic feasibility, industry adoption, and regulatory readiness—despite lower environmental impact.

Final Pathway Rankings

Pathway	Final Weighted Score	Rank
Fleet Optimization	**4.52**	🥇 1st
Sustainable Aviation Fuels (SAFs)	4.36	🥈 2nd
Advanced Air Mobility (AAM/UAM)	3.03	3rd
Electrification	2.84	4th
Hydrogen	2.34	5th

Results: Stage 3 Approach 2



Results: Stage 3 Approach 2

Scenario Definitions:

Scenario	*Description*
Short-Term Feasibility (2025–2035)	Focus on technologies that are immediately ready, scalable, and industry-compatible
Regulatory Priority (2035–2050)	Aligns with policy mandates, compliance frameworks, and infrastructure shifts
Net-Zero Carbon Priority (2050+)	Prioritizes full decarbonization and deep environmental performance
Economic Feasibility	Focuses on investment costs, return on investment, and cost-effectiveness
Total Environmental Sustainability	Encompasses emissions, resource use, and long-term ecological impact

These scenarios **shape the weighting** of the static Decision Variables' criteria and introduce **normative preferences** about what "success" looks like *under a specific temporal-scope lens*.

Results: Stage 3 Approach 2

This RMSDA approach shows that there's no single best solution across all scenarios—highlighting the trade-offs and context-dependency of sustainability decision-making in aerospace.

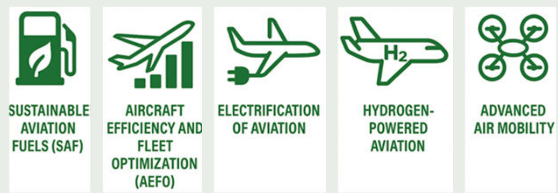
Final Scenario-Based RMSDA Ranking Matrix (*Table 5.1 – Using min-max normalization*)

Pathway	Short-Term Feasibility (2025–2035)	Regulatory Priority (2035–2050)	Net-Zero Carbon Priority (2050+)	Economic Feasibility	Environmental Sustainability
SAFs	🥇 1st	🥇 1st	2nd	2nd	4th
Fleet Optimization	2nd	3rd	5th	🥇 1st	2nd
AAM/UAM	3rd	2nd	3rd	4th	3rd
Electrification	4th	4th	🥇 1st	5th	🥇 1st
Hydrogen	5th	5th	4th	3rd	5th

Results: Stage 3 Approach 2

Key Scenario-Based Takeaways

- **SAFs** are the top performer in both **short-term feasibility** and **regulatory priority** due to current infrastructure compatibility, policy support, and industry momentum
- **Fleet Optimization** wins under **economic feasibility,** with its low-cost, high-readiness profile
- **Electrification** dominates under **environmental sustainability** and **net-zero carbon scenarios** but is held back in short-term and economic contexts due to infrastructure and technology maturity
- **Hydrogen** consistently ranks low due to readiness and infrastructure constraints—despite its long-term potential
- **AAM/UAM** only niche impacts
- WIP: Test used RAE judgements only.



Questions?

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