Aviation Net-Zero Pathways:

A Comparative Study of Sustainable Aviation Fuels (SAF) vs. Hydrogen in Hong Kong

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Abstract

The aviation sector is vital to Hong Kong's economy but is a significant source of carbon emissions. This study investigates which fuel pathway (Sustainable Aviation Fuel or Hydrogen) demonstrates greater overall feasibility for adoption at scale in Hong Kong's aviation sector before 2040. The study utilises a comparative framework to evaluate both pathways across five weighted dimensions where the analysis is grounded in a review of technical literature, industry reports, and a detailed case study of Cathay Pacific's decarbonization strategies and initiatives. SAF achieves a higher pre-2040 feasibility score (7.6/10) due to its compatibility with existing infrastructure, despite facing economic and feedstock challenges, whereas hydrogen scores only (4.35/10) as its superior long-term potential is outweighed by the need for a costly, systemic overhaul that is unlikely to be completed before 2040. For the pre-2040 horizon, SAF presents a more practical near-term solution, while hydrogen remains a longer-term prospect. The study concludes that SAF is the more viable pathway for achieving significant emission reductions in Hong Kong by 2040.

Keywords: Sustainable Aviation Fuel (SAF), Hydrogen Aviation, Decarbonization, Hong Kong Aviation, Cathay Pacific

1.Introduction

1.1 Background

Hong Kong stands as a cornerstone of the global aviation network, its international airport being one of the world's busiest cargo passenger hubs. The aviation sector is a critical part of the city's economy, facilitating trade, tourism, and financial connectivity. However, it is also a significant and growing source of carbon emissions, contributing substantially to Hong Kong's overall carbon footprint and leading to mounting pressure to transform. The goal is not only about reducing emissions, but to do so while preserving Hong Kong's competitive operational reliability and thereby retaining its title as Asia's World city.

The decarbonization of aviation is challenging due to both underlying technical and operational constraints. Aircraft require fuels with extremely high energy density to achieve the necessary range and payload for long-haul travel: Hong Kong in particular is known for its vast long haul network, connecting major hubs across the globe. While battery-electric propulsion is advantageous for short-haul flights, its current energy density cannot support the intercontinental routes that Hong Kong's aviation depends on. This problem thus turns to an alternative solution, namely, Sustainable Aviation Fuel (SAF) or Hydrogen.

1.2 Literature Review and Research Gap

Produced from sustainable feedstocks such as used cooking oil, agricultural waste, or synthesized from green hydrogen and captured carbon (e-fuels), SAF has the capability to blend with or directly replace conventional jet fuel without modifying existing aircraft or fuel infrastructure (ICAO, n.d.). SAF can reduce lifecycle carbon emissions by up to 80% compared to fossil kerosene. Its primary advantage lies in its compatibility with existing engines and airport hydrant systems. This seems highly promising, however, global SAF production remains at less than 0.1% of total jet fuel demand due to high costs, limited feedstock availability, and complex sustainability certification (Wang, M., & Yu, X, 2024).

On the other hand, hydrogen-powered aviation offers the potential for true zero-carbon flight when produced via renewable electrolysis. It can be used either by combustion directly in modified gas turbine engines or conversion to electricity via fuel cells to power electric propulsion (Gutiérrez-Antonio, C., Gómez-Castro, F. I., de Lira-Flores, J. A., & Hernández, S., 2017). Hydrogen boasts a superior gravimetric energy density but a very low volumetric density, requiring either cryogenic storage as a liquid at -253°C or high-pressure storage as a gas. This requires a complete change of current aircraft designs, airport fueling infrastructure, and ground handling procedures. While several major aerospace manufacturers have announced hydrogen aircraft concepts targeting entry-into-service around 2035, the technology remains at a development/demonstration phase.

Previous studies on aviation decarbonization have established several critical dimensions for comparing fuel pathways. The Technical Dimension considers the energy density, aircraft range and payload implications, and technology readiness level (TRL). The Economic Dimension considers the fuel production (cost per gallon), total cost of ownership, and the capital expenditure (CapEx) required for new supply chain infrastructure. The Environmental Dimension considers the Well-to-Wake lifecycle emissions assessment, considering the entire process from feedstock cultivation, fuel production, transport, and combustion. And the Feasibility Dimension considers supply chain scalability, regulatory and safety certification timelines, and social acceptance.

Existing literature often evaluates SAF and hydrogen at a global scale with significant gaps in contextualizing such pathways within the specific constraints of a major, densely populated aviation hub like Hong Kong. These constraints include: Severe Land Scarcity (Limiting the potential for on-site, large-scale fuel production or storage facilities); Dependence on Imports (Making fuel security and its supply chain a top priority); Safety and Urban Proximity (Concerns around the storage and handling of new energy carriers like liquid hydrogen near populated areas); and Operational Continuity (The necessity to avoid disruptions to the 24/7 operations of one of the world's busiest airports). Therefore, there is a need for a structured analysis for decarbonization pathways in Hong Kong's unique realities, using a major local case study as a point of analysis.

1.3 Research Objectives and Questions

This study aims to conduct a comparative analysis to identify the more viable net-zero fuel pathway for Hong Kong's aviation sector before the year 2040: Using Cathay Pacific Airways and

Hong Kong International Airport (HKIA) as a central case study. This research focus on the following questions:

1. Between Sustainable Aviation Fuel (SAF) and hydrogen, which aviation fuel pathway demonstrates greater overall feasibility for adoption at scale in Hong Kong before 2040?
2. What are the technical, economic, and supply chain barriers for Cathay Pacific and Hong Kong International Airport under each decarbonization pathway?
3. Based on the comparative analysis, what phased transition strategy should stakeholders in Hong Kong adopt to achieve long-term decarbonization while ensuring short-term operational and economic stability?

1.4 Contribution and Structure of the Study

By integrating a detailed comparison across technical, economic, environmental, and feasibility dimensions of SAF's and Hydrogen Fuels with the practical context of Cathay Pacific's existing initiatives and Hong Kong's infrastructural and geographic constraints, this paper's primary contribution is to provide a grounded framework and/or solution for Hong Kong's aviation decarbonization.

2.Methodology

2.1 Comparative Framework and Feasibility Index

To address the research questions in a structured manner, this study utilises a comparative framework to evaluate the feasibility of Sustainable Aviation Fuel (SAF) and hydrogen pathways for Hong Kong's aviation sector before 2040. Each dimension (refer to table 3) is assigned a weight (refer to table 1) based on its perceived criticality for Hong Kong's specific context. The scoring (from 0-10) for each dimension will be derived from a qualitative assessment of literature data, case study evidence, and logical inference (refer to table 2)

Table 1: Justification of weighting to the dimensions of Feasibility Index

Dimension	Weight	Justification
Technical Viability	25%	Drop-in compatibility is critical to avoid premature fleet retirement and is therefore given a high weighting.
Economic Feasibility	25%	SAF can be 2-5x more expensive than jet fuel. Lower costs are very important for commercialisation and scaling. This includes both fuel costs and infrastructure Capital Expenditure (CapEx).
Environmental Impact	25%	Reduction in emissions is the primary objective of SAFs. A Well-to-Wake approach ensures all emissions including production are accounted for. A fuel pathway must be both green and feasible.
Supply Chain	15%	Land scarcity prohibits massive new infrastructure. A fuel requiring entirely new infrastructure faces severe barriers here. This is however a secondary concern compared to the technical, economic and environmental factors of the fuel.

Technology	10%	For the pre-2040 horizon, pathways must be beyond demonstration and able to enter commercial scalability. Lower weighting acknowledges that readiness can improve within this timeframe.

Table 2: Scoring Criteria for Feasibility Index

Score Range	Qualitative Representation of Score Range
0-2	N/A to Very Poor
3-4	Poor to Mediocre
5-6	Average to Decent
7-8	Good to Great
9-10	Excellent to Perfect

Table 3: Feasibility Index, its dimensions and components including explanations for its given weighting

Dimension	Weighting	Explanation	Components
Technical Viability	25%	Assesses the physical and engineering suitability of the fuel for Hong Kong's aviation operations.	1. Gravimetric & Volumetric Energy Density 2. Compatibility with Existing Fleet & Infrastructure:
Economic Feasibility	25%	Evaluates the cost implications which is important for commercial adoption.	1. Fuel Cost per Energy Unit 2. Infrastructure Capital Expenditure (CapEx)
Environmental Impact	25%	Well-to-Wake (WtW) Life Cycle Assessment (LCA) approach.	1. Lifecycle GHG (Green House Gas) Emission Reduction Potential:
Supply Chain & Operational Feasibility	15%	Tailored to Hong Kong's unique constraints of land scarcity and import dependency.	1. Import Logistics & Storage Feasibility 2. Integration with Airport Operations
Technology & Commercial Readiness	10%	Assesses the proximity to market deployment	1. Technology Readiness Level (TRL) 2. Regulatory Certification & Commercial Scalability

2.2 Data Sources

Given the nature of this investigation, the analysis will draw upon multiple sources of evidence to base the comparative framework. This allows for more professionally reasoned arguments that gives rise to more accurate qualitative based scores (refer to table 4):

Table 4: Type of data and its derived source

Data Type	Sources
Technical & Environmental Data	US Department of Energy (DOE). International Civil Aviation Organization (ICAO) Life Cycle Assessment (LCA) methodologies, and peer-reviewed academic LCA studies.
Economic Data	Fuel cost projections from industry reports (IATA, BloombergNEF), corporate disclosures, and infrastructure cost estimates from engineering and consultancy studies.
Hong Kong & Regional Context	Hong Kong International Airport Authority and Civil Aviation Department publications for traffic and fuel consumption statistics. Analysis of regional SAF production capacity will rely on corporate announcements, government energy plans, and trade reports.
Cathay Pacific Case Study	Cathay Pacific's annual sustainability reports, press releases on SAF procurement, corporate partnerships, and fleet renewal plans.

2.3 Scenario Design for Sensitivity Analysis

To contextualize the comparative analysis, three possible scenarios are constructed.

Scenario A: Accelerated Hydrogen Development
This scenario assumes a 40% reduction in green hydrogen production costs by 2035, successful certification of a commercial liquid hydrogen aircraft by 2038, and moderate progress in cryogenic shipping infrastructure.

Scenario B: Constrained SAF Scale Up
This scenario assumes persistent feedstock limitations for HEFA pathways, delays in commercializing Power-to-Liquid (PtL) e-fuels, and no significant policy intervention in Hong Kong by 2028.

Scenario C: Strong Policy Intervention
This scenario assumes binding Hong Kong SAF production and consumption mandates, tax incentives or subsidies, and active regional supply agreements.

3. Analysis and Discussion

3.1 Case Study: Cathay Pacific

Cathay Pacific has positioned itself as a regional leader in aviation decarbonization, establishing clear, public commitments for its long-term economic and environmental strategy. The airline has committed to achieving net-zero carbon emissions by 2050, aligning with IATA's global target. A critical interim goal is the use of 10% Sustainable Aviation Fuel (SAF) for its total fuel consumption by 2030. Table 5 outlines Cathay Pacific's SAF recent action timeline.

Table 5: Cathay Pacific SAF Action Timeline (2022-2025)

Year	Action	Partners	Significance
2022	First corporate SAF programme launched. (Swire Pacific & Cathay Pacific, 2022)	AIA, Airport Authority Hong Kong, DHL Global Forwarding, HSBC, Kintetsu World Express, PwC China, Standard Chartered, and Swire Pacific	Engage other like-minded organisations, and a first step in sending an important demand signal to the SAF supply chain that there is firm interest in the region.
2022	Major long-term SAF supply agreement signed, beginning deliveries in 2025. (Cathay Pacific Airways Limited, 2022)	Aemetis (US biorefinery) and One World Alliance.	Secured a substantial future supply (up to 38 million gallons over 7 years), produced at Aemetis Carbon Zero plant. The SAF purchased can reduce more than 80,000 tonnes of lifecycle carbon emissions.
2023	Signing a Memorandum of Understanding (MoU). (Cathay Pacific Airways Limited, 2023)	State Power Investment Cooperation (SPIC)	MoU will use a multitude of different technologies for SAF production, including a pathway similar to power-to-liquid (PtL) to convert renewable electricity into liquid fuels. (Schmidt, P. R., Habersetzer, A., & Raksha, T, 2022).
2024	Purchased agreement for around 3400 tonnes of SAF produced by EcoCeres	HSBC Hong Kong and EcoCeres	EcoCeres' SAF is derived from 100% waste-based biomass feedstock, which can deliver an estimated reduction of up to 90% in GHG emissions compared to conventional jet fuel.

2024	Launched Hong Kong Sustainable Aviation Fuel Coalition (HKSAFC) (Cathay Pacific Airways Limited, 2024)	Business Environmental Council (BEC) along with 13 other founding partners including Shell Aviation, Sinopec and PetroChina.	A multi-stakeholder platform in the region that brings together the aviation industry, to collaborate on advancing the development, supply and use of SAF.
2025	Cathay and Airbus form co-investment partnership (up to $70 million) for scaling sustainable aviation fuel adoption. (Cathay Pacific Airways Limited, 2025)	Airbus	Cathay and Airbus aim to leverage their global experience to help shape policies that make SAF more accessible and affordable in this part of the world.

3.2 Technical, Economical and Environmental Fuel Data

Table 6 provides comparative technical, economic, and environmental data of Sustainable Aviation Fuel (SAF) and hydrogen, highlighting key advantages and trade-offs between them.

Table 6: Qualitative technical, economical and environmental literature Data of SAF and Hydrogen

Category	Parameter	SAF	Hydrogen
Technical	Energy Density (Mass)	43 MJ/kg	120 MJ/kg
	Energy Density (Volume)	35 MJ/kg	9 MJ/kg
	Production Efficiency (Well-to-wing)	50%-60% (Power to Liquid)	60%-70% (Electrolysis to H_2)
	TRL	TRL 8-9 (Commercial)	TRL 3-6 (Mid stage development)
Economical	Current Cost (Production)	USD $5000-$8000/tonne	USD $5-6/kg
	Cost per energy unit	USD $0.14-$0.22/MJ	USD $0.10-$0.13/MJ
Environmental	Lifecycle CO_2 Reduction vs conventional jet fuel	50%-89% (Depending on feedstock)	Up to 100% (If produced Via renewable electrolysis)
	Absolute Lifecycle Emissions	As low as 8 gCO_2e/MJ	0 g CO_2e/MJ

	Production Energy Input (per Kg fuel)	1 kg SAF; requires ~ 40-50 kWh electricity	50-55 kWh electricity per kg H_2; liquefaction adds ~10-12 kWh/kg

Note. Technical, Economical and Environmental data are from (ICAO, 2024), (Braun, M., Grimme, W., & Oesingmann, K, 2024), (Wang, M., & Yu, X. ,2024) and (US Department of Energy, n.d)

3.3 Hong Kong Fuel Supply Chain

The feasibility of a decarbonization pathway for Hong Kong not only depends on the fuel's technical aspects, but also on the practicality of its end-to-end supply chain. Table 7 summarises the SAF vs. Hydrogen Supply Chain comparison for Hong Kong. The SAF Supply Chain begins with production in regional hubs ; Shipment via standard marine tankers; Storage at Hong Kong's existing fuel terminals; Blending with conventional jet fuel at the airport and finally fueling of aircraft using the existing hydrant system (US Department of Energy, n.d). The primary strength of the SAF pathway is its flexibility with existing systems. Hong Kong's status as a global shipping hub means that import infrastructure is not a problem. The existing Airport Fuel Receiving Facility and the underground hydrant pipeline to HKIA can handle blended SAF. This means existing capital investment and decades of operational expertise can be easily utilised and therefore minimizing cost. The main limitation is Hong Kong's external supply dependency as the city has no space for large-scale local SAF production. Security of supply thus relies entirely on long-term offtake contracts with producers in foreign countries while the blending process requires careful quality control and certification which may become complicated.

Table 7: End-to-End SAF vs. Hydrogen Supply Chain Comparison for Hong Kong

Category	SAF Pathway	Hydrogen Pathway
Production	Regional or foreign Biorefinery or e-fuel plant.	Green hydrogen plant (location outside of Hong Kong)
Primary Transport	Maritime shipment via chemical/product tanker	Specialized cryogenic tanker ship (liquid H_2) or high-pressure ISO containers (compressed H_2)
Receipt & Storage	At the Tsing Yi Fuel Terminal or direct into HKIA's existing fuel farm	Requires a new, segregated cryogenic (-253°C) or high-pressure storage facility at/near HKIA. Significant land and safety buffer zones needed.
Blending	Blended with conventional Jet A-1 to specified ratio (10%) using existing infrastructure	Requires complex cryogenic pumping and vapor management systems.

Distribution & Uplift	Pumped via the existing underground hydrant system to aircraft using standard refueling trucks.	Dedicated, insulated refueling trucks or fixed refueling points at specific gates/stands.

The Hydrogen Supply Chain begins with production of green hydrogen; Transportation via specialized cryogenic tankers or high-pressure containers; Storage in new, high-security, cryogenic tanks at the airport and finally fueling of aircraft using completely separate, dedicated refueling trucks and systems (US Department of Energy, n.d). There are however some main barriers of the hydrogen supply chain. A reliable import supply requires the existence of a global green hydrogen trade that still hasn't been fully developed, requiring specialized cryogenic tanker ships that are rare and expensive. Additionally, liquid hydrogen must be stored at -253°C and the infrastructure required for this is massive, expensive, and requires significant safety exclusion zones due to hydrogen's wide flammability range and potential for embrittlement (Bauen, A., Bitossi, N., German, L., Harris, A., & Leow, K, 2020). Furthermore, integrating hydrogen requires the construction of a completely new system which includes dedicated storage, a separate distribution network and specialized refueling positions. The CapEx would be enormous, and the construction and integration phase would significantly impact the 24/7 operation of the hub. Unlike SAF, which can be stored for longer periods, liquid hydrogen experiences evaporation, requiring intensive re-liquefaction (Prussi, M., O'Connell, A., & Lonza, L., 2019).

3.4 Discussion

SAF's advantage is its immediate technical and operational compatibility, delivering measurable emissions reductions within the current fleet and infrastructure lifecycle. The trade-off is economic and resource-based. High costs of SAF impact airline competitiveness and ticket prices, while dependency on sustainable feedstocks like used cooking oil or agricultural waste limits scalability due to limited supply.

Hydrogen, particularly green hydrogen, offers near-zero Well-to-Wake emissions in the long run. The trade-off, however, is the need for a full scale system and infrastructure transformation. This does not just includes the aircraft itself, but the entire aviation ecosystem: global green hydrogen production, cryogenic shipping, revolutionary airport infrastructure, and new safety protocols. The timeline for this system to become a mature operation likely extends well beyond 2040.

Based on the Data and case study analysis, SAF procurement can only succeed in its intended impact by evolving from a sustainability project to a commercial process. This involves negotiating long-term offtake agreements to secure SAF supply volume and hedge against future price volatility, while diversifying the supplier base geographically and across production pathways. Also, Cathay Pacific must be a lead advocate and partner in shaping the Hong Kong and regional SAF ecosystem. This can be achieved by actively lobbying the HKSAR government for a clear SAF mandate and support policies. Working alongside the Airport Authority on the technical specifications and investment plans for airport blending and storage infrastructure (IATA, 2025). Cathay Pacific must play a leadership role in the Sustainable Aviation Fuel Alliance for Asia and similar consortia to drive standardization, sustainability certification, and collective purchasing power. While the next generation of aircraft will still be conventional, Cathay Pacific should engage manufacturers to understand the roadmap for hydrogen or hybrid-hydrogen aircraft and assess the long-term implications for its network and hub operations (Ng, K. S., Farooq, D., & Yang, A., 2021).

4. Results

4.1 Indicator Comparison Summary

The following section synthesizes the comparative analysis of SAF and Hydrogen across the five key dimensions established in the methodology.

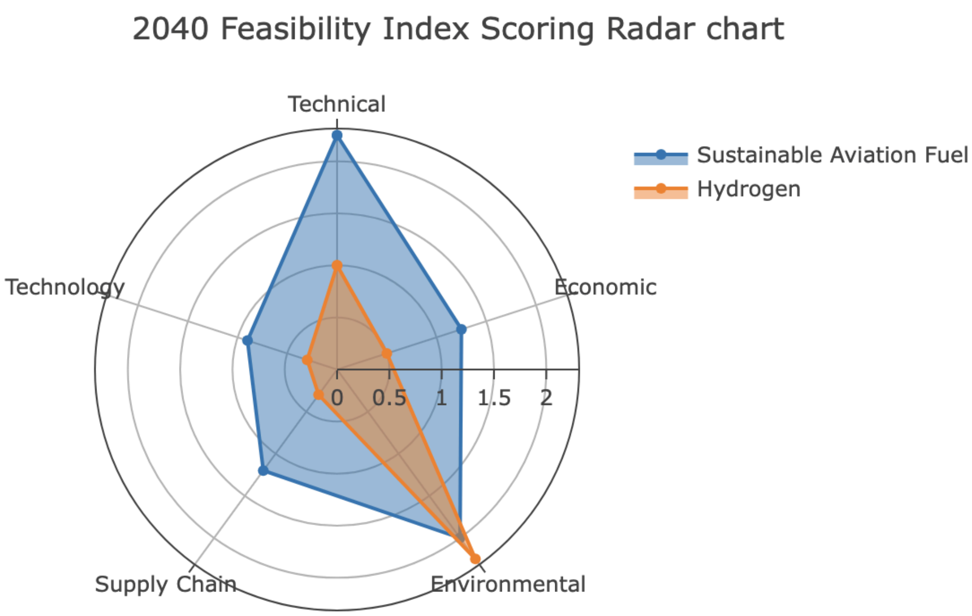

Figure 1: 2040 Feasibility Index Radar Chart

The results are visualized in figure 1 clearly illustrating SAF’s dominant overall feasibility profile for the specified timeframe. The data table and reasoning for figure 1 are illustrated in table 8 and table 9. *Note: the axis of figure 1 has been condensed by a factor of 4 from (0-10) to (0-2.5)*

Table 8: Comparative Summary of SAF vs. Hydrogen Aviation Pathways (Pre-2040 Horizon)

Feasibility Index Dimension	Sustainable Aviation Fuel	Hydrogen Liquid	Implication For Hong Kong
Technical Viability	*Excellent.* Near-identical gravimetric & volumetric density to Jet A-1. Fully compatible as "drop-in" fuel for existing fleet.	*Mediocre.* Superior gravimetric density but very poor volumetric density. Requires new aircraft designs with cryogenic tanks.	SAF imposes no harm on Hong Kong's long-haul operations. Hydrogen forces a trade-off between passenger/cargo capacity and range with current tech.

Economic feasibility	*Average.* High cost premium (2-5x Jet A-1) is the major barrier. Infrastructure CapEx is low-to-moderate (blending, storage upgrades).	*Very Poor.* Fuel cost is very high, and infrastructure CapEx is extremely high (new import terminals, cryogenic storage, dedicated distribution).	SAF costs are manageable with scale and policy support. Hydrogen requires unfeasibly high investment for city-scale deployment before 2040.
Environmental Impact	*Good.* Up to 80% emission reduction for best pathways such as HEFA from waste. E-fuels can approach 100% but are not yet scalable.	*Excellent.* Near-zero emissions from green hydrogen. However, upstream emissions depend entirely on renewable electricity sources.	Both offer deep decarbonization potential. SAF delivers immediate, verifiable reductions. Hydrogen's benefit is future-dependent.
Supply Chain Feasibility	*Good.* Leverages existing global fuel trading, maritime transport, and airport hydrant systems. Constrained by feedstock production scale.	*Very Poor.* Requires a nascent global liquid H2 shipping network, bespoke import terminals, and massive on-airport storage with safety buffers.	The SAF supply chain is an evolution of the current system. Hydrogen supply chain is hypothetical that does not yet exist at the required scale.
Technology and Readiness	*Excellent.* Fully certified for use up to 50% blends. Commercial production is scaling globally.	*Poor.* No commercially existing airport infrastructure and no commercial hydrogen airliner exists.	SAF is a commercially ready technology. Hydrogen is an R&D and demonstration technology for the 2040+ horizon.

4.2 2040 Feasibility Index Scoring

Applying the weighted framework from the methodology (Technical 25%, Economic 25%, Environmental 25%, Supply Chain 15%, Readiness 10%) yields the following comparative feasibility scores for the pre-2040 period. Scores are on a 0-10 scale, based on the analysis.

Table 9: 2040 Feasibility Index (FI) Scoring

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)	Weighted SAF Score	Weighted H_2 Score
Technical	25%	9	4	2.25	1.00
Economic	25%	5	2	1.25	0.50
Environmental	25%	8	9	2.00	2.25

Supply Chain	15%	8	2	1.20	0.30
Technology	10%	9	3	0.90	0.30
Total	100%			7.60/10	4.35/10

Note: Hydrogen's environmental score assumes green hydrogen; grey/blue hydrogen would score significantly lower.

4.3 Sensitivity Analysis

To test the robustness of the 2040 Feasibility Index, a sensitivity analysis was conducted by adjusting key uncertain variables: technological readiness, feedstock maturity and regulation where the analysis can be found in table 10, 11 and 12 respectively. The three scenarios explained in section 2.3 were modelled against the baseline findings presented in Section 4.2.

Table 10: Scenario A Accelerated Hydrogen Breakthrough

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)	Change to H_2	Rationale for adjustment
Technical	25%	9	5	+1	Improved aircraft design maturity, but volumetric density penalty remains.
Economic	25%	5	5	+3	40% cost reduction makes green H2 more competitive.
Environmental	25%	8	9	0	Already at near-zero; no change needed.
Supply Chain	15%	8	4	+2	Moderate progress in LH2 shipping, but HKIA land constraints persist.
Technology	10%	9	7	+4	Certification of commercial H2 aircraft by 2038 significantly raises TRL.
Total	100%	7.60	5.80	+1.45	

Table 11: Scenario B Constrained SAF Scale Up

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)	Change to SAF	Rationale for adjustment
Technical	25%	9	4	0	Drop-in compatibility unaffected.
Economic	25%	4	2	-1	Sustained green premium (4-5x Jet A-1) due to lack of policy

					support.
Environmental	25%	7	9	-1	Feedstock constraints force reliance on lower-grade pathways.
Supply Chain	15%	6	2	-2	Limited feedstock availability constrains scalable supply.
Technology	10%	9	3	0	TRL remains high; constraint is commercial, not technical.
Total	100%	6.30	4.35	-1.30	

Table 12: Scenario C Strong Intervention Policy

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)	Change to SAF	Rationale for adjustment
Technical	25%	9	4	0	No change.
Economic	25%	7	2	+2	Subsidies and mandates reduce the effective cost premium for airlines.
Environmental	25%	9	9	+1	Mandate drives investment in higher-grade PtL pathways.
Supply Chain	15%	9	2	+1	Policy certainty encourages supplier investment and regional agreements.
Technology	10%	9	3	0	No change.
Total	100%	8.40	4.35	+0.80	

Table 13: Summary of Sensitivity Analysis Data

Scenario	Key Assumptions	Revised SAF Score	Revised H_2 Score	**Change From Baseline**
Baseline	Projections from table 2	7.60/10	4.35/10	-
A:Accelerated Hydrogen Breakthrough	40% reduction in H2 cost by 2035; commercial H2 aircraft certified by 2038; moderate progress in cryogenic shipping	7.60/10	5.80/10	+1.45 (H_2)
B: Constrained	Persistent	6.30/10	4.35/10	-1.30 (SAF)

SAF Scale Up	feedstock limitations; e-fuels delayed; no HK mandate by 2028.			
C: Strong Policy Intervention	Binding HK SAF mandates; increase in tax incentives; regional supply agreements.	8.40/10	4.35/10	+0.80 (SAF)

The sensitivity analysis confirms that SAF remains the more viable pathway for Hong Kong before 2040 under all plausible scenarios. Even under optimistic assumptions for hydrogen, its feasibility score rises to only 5.80/10 , still trailing SAF's baseline of 7.60/10 due to persistent supply chain and land constraints at HKIA. However, the analysis also reveals that SAF's feasibility is not automatic, In a pessimistic scenario without support, SAF's score falls to 6.30/10. Conversely, strong government intervention (blending mandates and incentives) boosts SAF to 8.40/10 , the highest score across all scenarios.

4.4 Proposed 2040 Adoption Roadmap for Hong Kong

Based on the Feasibility Index and the strategic discussion, a phased, actionable roadmap is proposed to guide Hong Kong's aviation decarbonization (refer to figure 2).

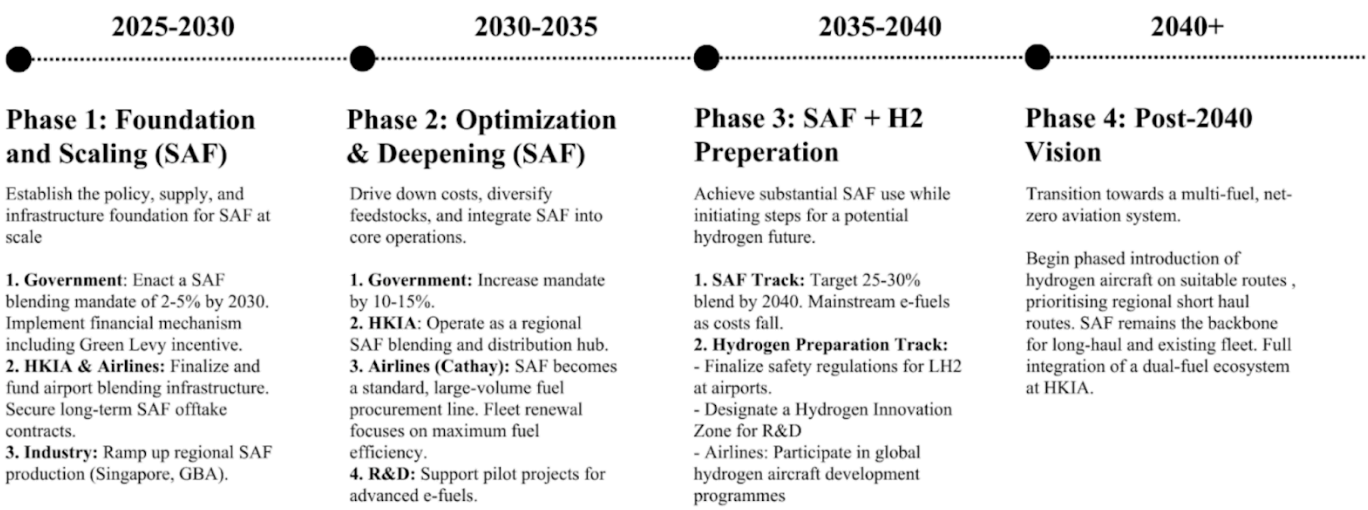

figure 2: Proposed 2040 Adoption Roadmap

Based on the results, The Sustainable Aviation Fuel (SAF) pathway is significantly more feasible for Hong Kong, with a Feasibility Index score nearly double that of hydrogen. The optimal roadmap should be to scale SAF to its maximum potential this decade, coupled with strategic planning to keep the hydrogen option viable for the future.

5. Conclusion

This study set out to evaluate the comparative feasibility of Sustainable Aviation Fuel (SAF) and hydrogen as decarbonization pathways for Hong Kong's aviation sector before 2040. The 2040 Feasibility Index underscores that SAF represents the viable pathway for achieving significant short-to-medium term emission reductions, while hydrogen remains a technologically promising but commercially and logistically uncertain option best suited for post-2040 planning. For an aviation hub with long-haul operations, land scarcity, and a need for operational continuity, the "drop-in" nature of SAF is advantageous. Hong Kong's decarbonization strategy should be a phased approach by initially scaling SAF deployment as the primary pillar, while undertaking preparatory, low-cost actions to keep future hydrogen options open. This unique perspective of SAF in the context of Hong Kong adds depth and further elevates the broader implications in this field of research.

6. Acknowledgement

The author would like to thank and acknowledge the guidance and encouragement of their mentor, Dr. Minnie Yu, in the development of this manuscript. The mentor's contributions were advisory and supervisory, which included the reviewing of the manuscript for logical consistency, formatting standards and alignment with the stated research objective. The use of large language model tools (LLM) were only for minor editing tasks which include grammar correction, punctuation, and formatting consistency.

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Decision: Desk revise and resubmit. The paper shows potential, the core contributions are solid, and the topic is clearly relevant, but the methodological transparency and rigor need to be considerably improved before the paper is sent to external peer review.

Review: All in all, I enjoyed reading the paper and thought it covered a unique topic. The manuscript is well-structured, well-written, and policy-relevant, with a focused research question and a coherent analytical framework. The Hong Kong-centered perspective and incorporation of a real-world institutional context (e.g., Cathay Pacific) are especially valuable.

However, the paper's primary limitations lie in the methodological rigor and transparency of the comparative framework, as presented in the current draft. The Feasibility Index relies on qualitative judgments that are insufficiently formalized or reproducible, which undermines the credibility of the numerical results and limits the paper's contribution beyond a structured literature synthesis. Hence, in the paper's current form, the methodological foundations are not sufficiently rigorous to support publication.

Major comments:

- The Feasibility Index is the central contribution of the study, yet it is not well enough defined to support the quantitative conclusions drawn. A "qualitative assessment of literature data, case study evidence, and logical inference" based on seemingly subjective scores seems rather ad hoc and not sufficiently rigorous, at least without further details.
  - Is there an explicit criterion mapping the evidence/sources to the scores? What is the justification for specific numerical assignments, aside from seemingly purely subjective assessments? This scoring system needs to be replicable, because otherwise it seems easily influenced by political inclinations, economic views, etc.
  - Maybe define explicit scoring rules (e.g., certain cost ranges lead to scores), and clearly clarify whether scores are derived from data, expert judgements, or synthesis.
- The core conclusion seems well-established already: SAF is more viable in the near term while hydrogen is a longer-term solution. The Hong Kong-specific framing is valuable, but the paper does not sufficiently explain what new insight is generated beyond contextual application and whether this framework yields non-obvious or decision-relevant insights.
  - Identify which conditions might change the conclusions, as well as the underlying mechanisms (e.g., costs and policy shifts)
  - Maybe reframe your results as a decision-making framework rather than just static results. This would make your methods seem a lot more powerful and impactful.
  - When making global conclusions, would context-specific constraints change your results?
- My statistical intuition tells me that these scores should have some uncertainty associated with them, since different experts or datasets might provide different scores.

    - Are you handling uncertainty at all here? Are there at least some *statistics* associated with each score?
    - How robust are these scores? How much do scores change under changes in weights? You should include some sort of sensitivity analysis here, alongside a discussion on how rankings might change under alternative assumptions.
- I am concerned that your Feasibility Index might suffer from double-counting. For instance, Technical Viability and Tech + Commercial Readiness seem to overlap, as would Supply Chain and Economic Feasibility.
    - Clarify how you're defining each evaluation dimension.
    - Could you justify their independence in your analysis? If not, you might consider consolidating or restructuring these categories.
- As is often an issue with early-stage submissions, the paper tends to summarize rather than critically evaluate the literature, along with assuming some sort of consensus without at least addressing or hearkening to disagreement when it occurs. For instance, hydrogen timelines, cost, and infrastructural feasibility are highly contested topics in media and literature. Moreover, lifecycle emissions of SAF can vary widely depending on the methodology used.
    - You should engage more with ongoing tension and debates rather than assume that the reader might already be on the same page. Some of these facts are *not* settled, either because scholars and policymakers disagree on them, or because we literally just do not know yet (so there's a lot of uncertainty)

Minor comments:

- Prose can be repetitive or "fluffy" at times; consider staying more focused and focusing on the flow throughout the paper overall rather than constantly having to regurgitate certain points (think like Spock)
- Check for awkward phrasing overall. (Sounds rather formulaic at times; was this due to LLM-generated revisions?)
- Consider adding a visual summary (e.g., a decision map/tree) for readability and to track the flow of ideas

Aviation Net-Zero Pathways:

A Comparative Study of Sustainable Aviation Fuels (SAF) vs. Hydrogen in Hong Kong

[Author name redacted]

Abstract

The aviation sector is vital to Hong Kong's economy but remains a significant source of carbon emissions. This study investigates which fuel pathway (Sustainable Aviation Fuel (SAF) or hydrogen) demonstrates greater overall feasibility for adoption at scale in Hong Kong's aviation sector before 2040. Using a comparative feasibility index with dimensions weighted 40% technical, 40% economic, and 20% environmental, reflecting Hong Kong's long-haul dependency, land scarcity, and import reliance, the analysis is grounded in technical literature, industry reports, and a detailed case study of Cathay Pacific's decarbonization initiatives. SAF achieves a pre-2040 feasibility score of 8.12/10, driven by high technical readiness (9.00) and economic compatibility (7.80), despite facing feedstock and cost challenges. Hydrogen scores 4.94/10, as its superior environmental potential (9.00) is outweighed by poor volumetric energy density and prohibitive infrastructure compatibility and costs. Sensitivity analysis confirms that SAF remains the winner across all plausible weight and parameter scenarios for the 2040 horizon; hydrogen only outperforms SAF under an extreme long-term weighting (80% environmental, 10% technical, 10% economic) that is unrealistic for pre-2040 decision-making in Hong Kong. The study concludes that SAF is the more viable near-to-medium term pathway for Hong Kong, while hydrogen should be developed strategically, aligning with post-2040 decarbonization efforts.

Keywords: Sustainable Aviation Fuel (SAF), Hydrogen Aviation, Decarbonization, Hong Kong Aviation, Cathay Pacific

1.Introduction

1.1 Background

Hong Kong stands as a cornerstone of the global aviation network, its international airport being one of the world's busiest cargo passenger hubs. The aviation sector is a critical part of the city's economy, facilitating trade, tourism, and financial connectivity. However, it is also a significant and growing source of carbon emissions, contributing substantially to Hong Kong's overall carbon footprint, leading to mounting pressure to transform. The goal is not merely reducing emissions, but to do so while preserving Hong Kong’s competitive operational reliability and thereby retaining its title as Asia’s World city.

The decarbonization of aviation is challenging due to both underlying technical and operational constraints. Aircraft require fuels with extremely high energy density to achieve the necessary range and payload for long-haul travel: Hong Kong in particular is known for its vast long haul network, connecting major hubs across the globe. While battery-electric propulsion may seem as a plausible substitute, its current low energy density cannot support the intercontinental routes that Hong Kong's aviation depends on. Therefore, the problem turns to an alternative solution, namely, Sustainable Aviation Fuel (SAF) or Hydrogen (H_2).

1.2 Literature Review and Research Gap

Produced from sustainable feedstocks such as used cooking oil, agricultural waste, or synthesized from green hydrogen and captured carbon (e-fuels), SAF has the capability to blend with or directly replace conventional jet fuel without modifying existing aircraft or fuel infrastructure (ICAO, n.d.). SAF can reduce lifecycle carbon emissions by up to 80% compared to fossil kerosene. Its primary advantage lies in its compatibility with existing engines and airport hydrant systems. This seems highly promising, however, global SAF production remains at less than 0.1% of total jet fuel demand due to high costs, limited feedstock availability, and complex sustainability certification (Wang, M., & Yu, X, 2024).

On the other hand, hydrogen-powered aviation offers the potential for true zero-carbon flight when produced via renewable electrolysis. It can be used either by combustion directly in modified gas turbine engines or conversion to electricity via fuel cells to power electric propulsion (Gutiérrez-Antonio, C., Gómez-Castro, F. I., de Lira-Flores, J. A., & Hernández, S., 2017). Hydrogen boasts a superior gravimetric energy density but a very low volumetric density, requiring either cryogenic storage as a liquid at -253°C or high-pressure storage as a gas. This requires a complete change of current aircraft designs, airport fueling infrastructure, and ground handling procedures.

Previous studies on aviation decarbonization have established several critical dimensions for comparing fuel pathways. These dimensions include the Technical Dimension, which considers the energy density, aircraft range and payload implications, and technology readiness level (TRL); the Economic Dimension, which considers the fuel production (cost per gallon), total cost of ownership, and the capital expenditure (CapEx) required for new supply chain infrastructure; The Environmental Dimension, which considers the Well-to-Wake lifecycle emissions assessment, considering the entire process from feedstock cultivation, fuel production, transport, and combustion; And the Feasibility Dimension, that considers supply chain scalability, regulatory and safety certification timelines, and social acceptance.

Existing literature often evaluates SAF and hydrogen at a global scale with significant gaps in contextualizing such pathways within the specific constraints of a major, densely populated aviation hub like Hong Kong. These constraints include: Severe Land Scarcity, Dependence on Imports, Safety and Urban Proximity and Operational Continuity. Therefore, there is a need for a structured analysis for decarbonization pathways in Hong Kong’s unique realities, using a major local case study as a point of analysis.

1.3 Research Objectives and Questions

This study aims to conduct a comparative analysis to identify the more viable net-zero fuel pathway for Hong Kong's aviation sector before the year 2040: Using Cathay Pacific Airways and Hong Kong International Airport (HKIA) as a central case study. This research focus on the following questions:

1. Between Sustainable Aviation Fuel (SAF) and hydrogen, which aviation fuel pathway demonstrates greater overall feasibility for adoption at scale in Hong Kong before 2040?
2. What are the technical, economic, and supply chain barriers for Cathay Pacific and Hong Kong International Airport under each decarbonization pathway?
3. Based on the comparative analysis, what phased transition strategy should stakeholders in Hong Kong adopt to achieve long-term decarbonization while ensuring short-term operational and economic stability?

1.4 Contribution and Structure of the Study

By integrating a detailed comparison across technical, economic and environmental dimensions of SAF and Hydrogen within the practical context of Cathay Pacific's existing initiatives and Hong Kong's infrastructural and geographic constraints, this paper's primary contribution is to provide a grounded framework and/or solution for Hong Kong's aviation decarbonization.

2.Methodology

2.1 Comparative Framework and Feasibility Index

To address the research questions in a structured manner, this study constructs and utilises a comparative framework/feasibility index to evaluate the feasibility of Sustainable Aviation Fuel (SAF) and hydrogen pathways for Hong Kong's aviation sector before 2040. The index is based on three carefully constructed dimensions (refer to table 1) that are each assigned a weighting (refer to table 2) based on its perceived criticality for Hong Kong's specific context. Each dimension includes subcomponents that are also given a weight based on its perceived criticality as analysed in the analysis and discussion (refer to table 15). The scoring for each dimension and its subcomponents will be derived from a detailed assessment of literature data, case study evidence, and logical inference that ensures replicability. All subcomponent scoring and its dimension are scored from 1-10 based on specific scoring rubrics.

Table 1: Feasibility Index, its dimensions and components including explanations for its given weighting

Dimension	Weighting	Explanation	Subcomponents
Technical and Operational Readiness	40%	Assesses whether the fuel can enable Hong Kong's long-haul aviation operations without large performance disadvantages.	A. Gravimetric & Volumetric Energy Density B. Compatibility with Existing Fleet & Infrastructure (Drop-in capability) C. Technological Readiness Level (TRL) of the entire system

Economic and Supply Chain Feasibility	40%	Assesses the total cost of adopting the fuel pathway in Hong Kong's unique context.	A. Fuel Cost Production and per Energy Unit (USD/MJ) B. Capital Expenditure (CapEx) for new infrastructure, the import supply chain and potential aircraft modifications C. Import Logistics, Storage Feasibility and fuel delivery given Hong Kong's land scarcity and import dependance.
Environmental Impact	20%	Assesses the Well-to-Wake lifecycle greenhouse gas emissions (GHG) of the fuel pathway from feedstock cultivation/production, fuel manufacturing to transport and combustion.	A. Lifecycle CO_2 Reduction vs. Jet A as a percentage B. Absolute Lifecycle Emissions (g CO_2e/MJ)

Table 2: Justification of weighting to the dimensions of Feasibility Index

Dimension	Weight	Justification
Technical and Operational Readiness	40%	Hong Kong's long-haul hub cannot compromise on range or payload, making technical compatibility and readiness critical for operational continuity, especially within a pre-2040 decision framework.
Economic and Supply Chain Feasibility	40%	As a near 100% fuel importer with severe land scarcity, cost and supply chain practicality determine whether any pathway can be commercially sustained before 2040.
Environmental Impact	20%	Emissions reduction is the fundamental objective of decarbonization. However, for the 2040 horizon in Hong Kong, a pathway that delivers deep lifecycle CO_2 reductions though remaining technically or economically infeasible cannot be deployed, hence lower weighting for a near term index.

2.2 Scoring Protocol

To ensure transparency and replicability, all scores in the Feasibility Index were derived using the following methodological protocol:

1. For each sub-component , the peer-reviewed literature and industry reports were reviewed to identify the range of reported values and/or descriptions in its respective scoring rubric found in tables 3-10.

2. The reported value was then mapped to either the lower or upper bound of the scoring rubric (or to the upper and lower extremes) defined in Tables 3-10. If the value was a reported range, the median of the range was taken for score assignment.
3. Each score was reported in the Master Justification Table (Table 16) accompanied by justification. The literature review in the analysis and discussion section will have mapped out the evidence to formulate and justify each score.
4. Where a dimension contains multiple sub-components, sub-component scores were weighted across a 100% to give an overall dimension score of 1-10. Weights were assigned based on the dimension's definition and criticality in Hong Kong's specific context (refer to table 15).
5. The final scores of each fuel were calculated by multiplying each dimension specific scores by its given weight (table 2) and summed up to produce the final score from 1-10.

Note: This protocol produces scores that represent the author's synthesis of the evidence. Different researchers might assign slightly different scores based on the evidence, though most of the components rely on quantitative data and highly attributable qualitative descriptions that mitigates that issue. However, to address this potential uncertainty, Section 4.3 presents a sensitivity analysis that varies key parameters and shows how scores change under alternative assumptions.

Rubric 1: Technical And Operation Readiness Scoring Criteria

Table 3: Sub Component A: Energy Density (Volumetric and Gravimetric)

Score Range	Volumetric Energy Density (MJ/L)	Gravimetric Energy Density (MJ/kg)	Percentage Reduction vs. Traditional Jet Fuel (43MJ/kg and 35MJ/L)
9-10	31-35+	38-45	<10%
7-8	26-30	32-37	10-25%
5-6	18-25	22-31	25-50%
3-4	9-17	11-21	50-75%
0-2	<9	<11	>75%

Note: if percentage reduction between volumetric and gravimetric energy density lies in a different score range, the mean score between the two are taken.

Table 4: Sub Component B: Compatibility With Existing Fleet

Score Range	Description
9-10	Full drop-in capability with no modifications and certified for 50-100% blends
7-8	Drop-in for blends ≤50%; with minor modifications for higher blends
5-6	Requires new fuel system components (tanks, seals, pumps)
3-4	Requires new engine or airframe design
0-2	Incompatible; requires entirely new fleet

Table 5: Sub Component C: Technological readiness Level (TRL)

Score Range	Description and TRL Level
9-10	Commercial production and operation; multiple suppliers (TRL 9-10)
7-8	System demonstration in operational environment (TRL 7-8)
5-6	Technology validated in relevant environment (TRL 5-6)
3-4	Proof of concept to component validation (TRL 3-4)
0-2	Basic research to concept formulation (TRL 1-2)

Rubric 2: Economic and Supply Chain Feasibility

Table 6: Sub Component A: Fuel Cost

Score Range	Cost Multiple vs. Traditional Jet Fuel	Approximate USD/tonne	Approximate USD/MJ
9-10	<1.5x	$1500	<$0.035
7-8	1.5-2.5x	$1500-2500	$0.035–0.058
5-6	2.5-4x	$2500-4000	$0.058–0.093
3-4	4-6x	$4000-6000	$0.093–0.140
0-2	>6x	>$6000	>$0.140

Table 7: Sub Component B: Infrastructure Capital Expenditure (CapEx)

Score Range	CapEx Relative to Mainstream Jet A System	Estimated Absolute Supplemental Cost in USD for Hong Kong
9-10	<10% additional	$100M
7-8	10-50% additional	$100-500M
5-6	50-100% additional	$500M-$1B
3-4	100-300% additional	$1B-3B
0-2	>300% additional	>$3B

Table 8: Sub Component C: Import Logistics and Storage Feasibility

Score Range	Description
9-10	Uses existing shipping and storage infrastructure; no new land required
7-8	Minor modifications to existing terminals; small land footprint

5-6	New equipment at existing facilities; moderate land use
3-4	Requires new facility type; significant land needed
0-2	Requires infrastructure that does not yet exist globally; massive land and safety exclusion zones required

Rubric 3: Environmental Impact

Table 9: Sub Component A: Lifecycle CO_2 Reduction vs. Jet A

Score Range	Reduction vs Jet A
9-10	>90%
7-8	70-90%
5-6	50-70%
3-4	30-50%
0-2	<30%

Table 10: Sub Component B: Absolute Lifecycle Emissions

Score Range	g CO_2e/MJ
9-10	5
7-8	5-15
5-6	15-25
3-4	25-35
0-2	>35

Note: Jet A baseline is ~80-90 g CO_2e/MJ

2.3 Data Sources

Given the nature of this investigation, the analysis will draw upon multiple sources of evidence to base the comparative framework. This allows for more professionally reasoned arguments that gives rise to more accurate qualitative based scores (refer to table 11):

Table 11: Type of data and its derived source

Data Type	Sources
Technical & Environmental Data	US Department of Energy (DOE). International Civil Aviation Organization (ICAO) Life Cycle Assessment (LCA) methodologies, and peer-reviewed academic LCA studies.

Economic Data	Fuel cost projections from industry reports (IATA, BloombergNEF), corporate disclosures, and infrastructure cost estimates from engineering and consultancy studies.
Hong Kong & Regional Context	Hong Kong International Airport Authority and Civil Aviation Department publications for traffic and fuel consumption statistics. Analysis of regional SAF production capacity will rely on corporate announcements, government energy plans, and trade reports.
Cathay Pacific Case Study	Cathay Pacific's annual sustainability reports, press releases on SAF procurement, corporate partnerships, and fleet renewal plans.

3. Analysis and Discussion

3.1 Case Study: Cathay Pacific

Cathay Pacific has positioned itself as a regional leader in aviation decarbonization, establishing clear, public commitments for its long-term economic and environmental strategy. The airline has committed to achieving net-zero carbon emissions by 2050, aligning with IATA's global target. A critical interim goal is the use of 10% Sustainable Aviation Fuel (SAF) for its total fuel consumption by 2030. Table 12 outlines Cathay Pacific's SAF recent action timeline.

Table 12: Cathay Pacific SAF Action Timeline (2022-2025)

Year	Action	Partners	Significance
2022	First corporate SAF programme launched. (Swire Pacific & Cathay Pacific, 2022)	AIA, Airport Authority Hong Kong, DHL Global Forwarding, HSBC, Kintetsu World Express, PwC China, Standard Chartered, and Swire Pacific	Engage other like-minded organisations, and a first step in sending an important demand signal to the SAF supply chain that there is firm interest in the region.
2022	Major long-term SAF supply agreement signed, beginning deliveries in 2025. (Cathay Pacific Airways Limited, 2022)	Aemetis (US biorefinery) and One World Alliance.	Secured a substantial future supply (up to 38 million gallons over 7 years), produced at Aemetis Carbon Zero plant. The SAF purchased can reduce more than 80,000 tonnes of lifecycle carbon emissions.
2023	Signing a Memorandum of	State Power Investment Cooperation (SPIC)	MoU will use a multitude of different technologies for SAF

	Understanding (MoU). (Cathay Pacific Airways Limited, 2023)		production, including a pathway similar to power-to-liquid (PtL) to convert renewable electricity into liquid fuels. (Schmidt, P. R., Habersetzer, A., & Raksha, T, 2022).
2024	Purchased agreement for around 3400 tonnes of SAF produced by EcoCeres	HSBC Hong Kong and EcoCeres	EcoCeres' SAF is derived from 100% waste-based biomass feedstock, which can deliver an estimated reduction of up to 90% in GHG emissions compared to conventional jet fuel.
2024	Launched Hong Kong Sustainable Aviation Fuel Coalition (HKSAFC) (Cathay Pacific Airways Limited, 2024)	Business Environmental Council (BEC) along with 13 other founding partners including Shell Aviation, Sinopec and PetroChina.	A multi-stakeholder platform in the region that brings together the aviation industry, to collaborate on advancing the development, supply and use of SAF.
2025	Cathay and Airbus form co-investment partnership (up to $70 million) for scaling sustainable aviation fuel adoption. (Cathay Pacific Airways Limited, 2025)	Airbus	Cathay and Airbus aim to leverage their global experience to help shape policies that make SAF more accessible and affordable in this part of the world.

Cathay Pacific's active SAF procurement commitments show that near-term feasibility is driven by technical compatibility and economic practicality, not environmental potential alone, conforming with the study's dimension weightings. This case study also helps to identify Hong Kong specific priorities through the perspective of a local stakeholder, enhancing the legitimacy of the weightings and assigned scores of the comparative framework.

3.2 Technical, Economical and Environmental Fuel Data

Table 6 provides comparative literature synthesis of technical, economic, and environmental data of Sustainable Aviation Fuel (SAF) and hydrogen, highlighting key advantages and trade-offs between them. This allows for accurate mapping of reported literature values to the corresponding assigned score ranges as mentioned in tables 3-10.

Table 13: Quantitative technical, economical and environmental literature Data of SAF and Hydrogen

Category	Parameter	SAF	Hydrogen
Technical	Gravimetric Energy Density	43 MJ/kg	120 MJ/kg
	Volumetric Energy Density	35 MJ/kg	9 MJ/kg
	Production CapEx	Approximately USD 1,500 per tonne of annual capacity for greenfield plants.	Large-scale electrolyzer systems cost between US$2,100 – US$3,200 per kW
	Airport Infrastructure	Near zero. It is 100% compatible with existing pipelines, fuel trucks, and airport storage tanks.	Specialized cryogenic storage and new refueling equipment. Supply infrastructure costs are estimated at US$3.83 – US$5.03 per kg of H_2 handled.
	TRL	TRL 8-9 (Commercial)	TRL 4-6 (Mid stage development)
Economical	Current Cost (Production)	USD $2000-$3500/tonne	USD $2280-7390/ tonne
	Cost per energy unit	USD $0.14-$0.22/MJ	USD $0.10-$0.13/MJ
Environmental	Lifecycle CO_2 Reduction vs conventional jet fuel	50%-89% (Depending on feedstock)	Up to 100% (If produced Via renewable electrolysis)
	Absolute Lifecycle Emissions	10-15 gCO_2e/MJ	0 g CO_2e/MJ
	Production Energy Input (per Kg fuel)	1 kg SAF; requires ~ 40-50 kWh electricity	50-55 kWh electricity per kg H_2; liquefaction adds ~10-12 kWh/kg

Note. Technical, Economical and Environmental data are from (ICAO, 2024), (Braun, M., Grimme, W., & Oesingmann, K, 2024), (Wang, M., & Yu, X. ,2024) and (US Department of Energy, n.d)

3.3 Hong Kong Fuel Supply Chain

An analysis of the fuel supply chain in Hong Kong is crucial given its heavy weighting in the comparative short term feasibility index. The feasibility of a decarbonization pathway for Hong Kong not only depends on the fuel's technical aspects, but also on the practicality of its end-to-end supply chain with Table 7 summarising the SAF vs. Hydrogen Supply Chain comparison for Hong Kong.

The SAF Supply Chain begins with production in regional hubs;Shipment via standard marine tankers; Storage at Hong Kong's existing fuel terminals; Blending with conventional jet fuel at the airport and finally fueling of aircraft using the existing hydrant system (US Department of Energy, n.d). The primary strength of the SAF pathway is its flexibility with existing systems. The existing Airport Fuel Receiving Facility and the underground hydrant pipeline to HKIA can handle blended SAF, meaning existing capital investment and decades of operational expertise can be easily utilised and therefore minimizing cost. However, Hong Kong has an external supply dependency as the city has no space for large-scale local SAF production. Security of supply thus relies entirely on long-term offtake contracts with producers in foreign countries.

Table 14: End-to-End SAF vs. Hydrogen Supply Chain Comparison for Hong Kong

Category	**SAF Pathway**	**Hydrogen Pathway**
Production	Regional (Greater Bay Area) or foreign Biorefinery or e-fuel plant.	Green hydrogen plant (location outside of Hong Kong)
Primary Transport	Maritime shipment via chemical/product tanker	Specialized cryogenic tanker ship (liquid H_2) or high-pressure ISO containers (compressed H_2)
Receipt & Storage	At existing surrounding fuel Terminals or directly into HKIA's existing fuel network.	Requires a new, segregated cryogenic (-253°C) or high-pressure storage facility at/near HKIA. Significant land and safety buffer zones needed.
Blending	Blended with conventional Jet A-1 to specified ratio using existing infrastructure	Requires complex cryogenic pumping and vapor management systems.
Distribution & Uplift	Pumped via the existing underground hydrant system to aircraft using standard refueling trucks.	Dedicated, insulated refueling trucks or fixed refueling points at specific gates/stands.

The Hydrogen Supply Chain begins with production of green hydrogen; Transportation via specialized cryogenic tankers or high-pressure containers; Storage in new, high-security, cryogenic tanks at the airport and finally fueling of aircraft using completely separate, dedicated refueling trucks and systems (US Department of Energy, n.d). However, there are some main barriers of the hydrogen supply chain. First, a reliable import supply of hydrogen requires the existence of a global green hydrogen trade that still hasn't been fully developed, requiring specialized cryogenic tanker ships that are rare and expensive. Additionally, liquid hydrogen must be stored at -253°C and the infrastructure required for this is massive, expensive, and requires significant safety exclusion zones due to hydrogen's wide flammability range and potential for embrittlement (Bauen, A., Bitossi, N., German, L., Harris, A., & Leow, K, 2020). Furthermore, integrating hydrogen requires the construction of a completely new system which includes dedicated storage, a separate distribution network and specialized refueling positions. The CapEx would be enormous, and the construction and integration phase would significantly impact the 24/7 operation of the hub, which is crucial to Hong Kong. Unlike SAF, which can be stored for longer periods, liquid hydrogen experiences evaporation, requiring intensive re-liquefaction (Prussi, M., O'Connell, A., & Lonza, L., 2019).

3.4 Discussion

SAF's advantage is its immediate technical and operational compatibility, delivering measurable emissions reductions within the current fleet and infrastructure lifecycle. However, high costs of SAF impact airline competitiveness and ticket prices, while dependency on sustainable feedstocks like used cooking oil or agricultural waste limits scalability due to limited supply. Hydrogen, particularly green hydrogen, offers near-zero Well-to-Wake emissions in the long run. However, there is the need for a full scale system and infrastructure transformation which not only includes the aircraft itself, but the entire aviation ecosystem from global green hydrogen production, cryogenic shipping, new airport infrastructure, and new safety protocols.

Based on the Data and case study analysis, SAF procurement in the short run can be advanced by considering the following protocols. This involves negotiating long-term offtake agreements to secure SAF supply volume and hedge against future price volatility, while diversifying the supplier base geographically and across production pathways. This is a key insight gained from Cathay's case study. Given the experience and expertise, Cathay Pacific must be a lead advocate and partner in shaping the Hong Kong and regional SAF ecosystem. This can be achieved by actively lobbying the HKSAR government for a clear SAF mandate and support policies, working alongside the Airport Authority on the technical specifications and investment plans for airport blending and storage infrastructure (IATA, 2025). Cathay Pacific should lead and influence the Sustainable Aviation Fuel Alliance for Asia and similar consortia to drive standardization, sustainability certification, and collective purchasing power. Cathay Pacific should also engage manufacturers to understand the roadmap for hydrogen or hybrid-hydrogen aircraft and assess the long-term implications for its network and hub operations (Ng, K. S., Farooq, D., & Yang, A., 2021).

While the technical parameters of SAF and hydrogen are well-documented, several critical issues remain actively contested. Industry proponents usually project commercial hydrogen aircraft entry-into-service by 2035, with airport infrastructure following shortly thereafter. However, there is conflict on how these timelines are unrealistic. There are currently no commercial airports that handle liquid hydrogen at scale, with some sources estimating that a full hydrogen aviation system requires 20-30 years to develop, pushing commercial viability to 2045-2055. (Braun, M., Grimme, W., & Oesingmann, K , 2024)

In general, SAF reduces lifecycle emissions by 70-80% (HEFA pathways) compared to conventional jet fuel. However, experts often argue that indirect land-use change (ILUC), where biofuel feedstock cultivation displaces food crops, leading to forest clearing elsewhere, can erode or reverse claimed emissions benefits. Furthermore, different life cycle assessments may produce different lifecycle emission results, though such data remains in a range largely accepted by the industry. In addition, Green hydrogen costs are often projected to fall 40-60% by 2030, driven by falling electrolyzer prices and renewable electricity costs. However, previous energy technology cost forecasts have consistently been too optimistic (Schmidt, P. R., Habersetzer, A., & Raksha, T, 2022).

These debates and ongoing tensions provide more evidence to the weight or relative importance of each of the dimensions and its subcomponents in the feasibility index.

3.5 Subcomponent Weighting (Hong Kong Context)

Based on the discussion surrounding the Cathay Pacific Case Study and Hong Kong's specific contextual priorities, the following weights are assigned to each subcomponent as illustrated by table 15.

Table 15 : Justification of weighting to the subcomponents of the dimensions of the Feasibility Index

Dimension	Subcomponent	Weight	Justification
Technical and Operational Readiness	A: Energy Density	35%	Hong Kong's long-haul dependent hub cannot accept the range penalties of low-density fuels.
	B: Compatibility with Exiting Fleet	40%	Drop-in compatibility avoids loss of assets and high costs from premature fleet retirement, which is critical for Cathay Pacific's future fleet horizon.
	C: TRL	25%	For pre-2040 deployment, fuels must be commercial (TRL 8-9), not demonstration-stage, to avoid operational risk to Hong Kong's global hub status.
Economic and Supply Chain Feasibility	A: Fuel Cost	40%	As a 100% fuel importer, Hong Kong's aviation competitiveness depends directly on fuel cost.
	B: CapEx	35%	Land scarcity at HKIA makes hydrogen's expensive cryogenic storage near impossible, while SAF's blending fits existing infrastructure, which is economically very advantageous.
	C: Import and Storage Logistics	25%	SAF leverages Hong Kong's existing liquid fuel shipping network, whereas hydrogen requires a non-existent global H_2 supply chain.
Environmental Impact	A: Lifecycle CO_2 Reduction vs. Jet A	60%	Percentage reduction is the primary policy metric used by ICAO CORSIA, IATA, and Cathay Pacific's net-zero targets.
	B: Absolute Lifecycle Emissions	40%	Absolute emissions provide a clear comparison, accounting for the entire life cycle from well to wake.

4. Results

4.1 Indicator Comparison Summary

The following section synthesizes the comparative analysis of SAF and Hydrogen across the three key dimensions established in the methodology.

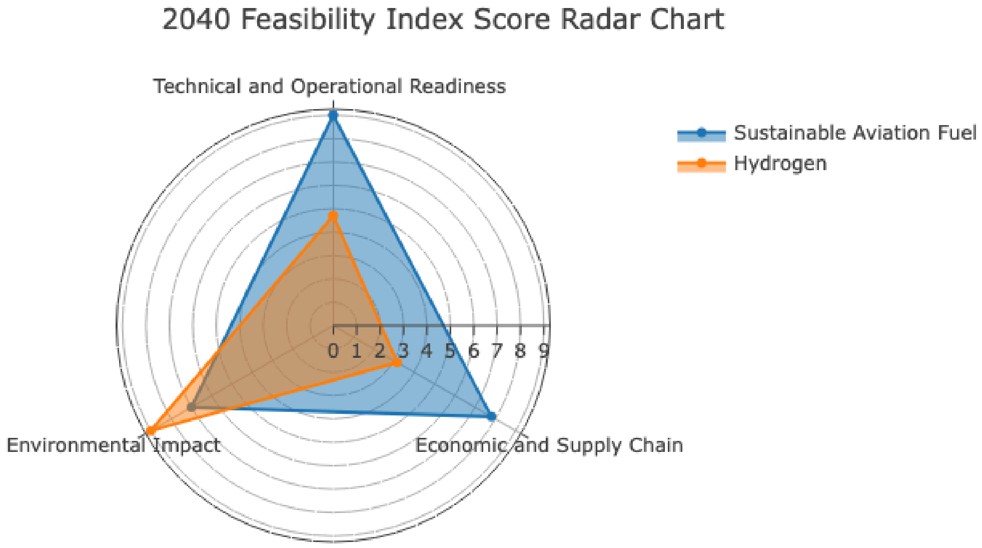

Figure 1: 2040 Feasibility Index Radar Chart

The results are visualized in figure 1 clearly illustrating SAF's dominant overall feasibility profile for the specified timeframe, especially for the technical and economic dimensions. The Master Scoring Table with the assigned scores based on the feasibility index scoring methodology is illustrated by table 16.

Table 16: Master Scoring Table based on methodology, comparing SAF vs Hydrogen for Hong Kong

Dimension and Weight	Subcomponent and Weight	Supporting Evidence (SAF)	SAF Scoring	Supporting Evidence (Hydrogen)	Hydrogen Scoring
Technical and Operational Readiness (40%)	A: Energy density (35%)	Mass: 43 MJ/kg; Vol: 35 MJ/L (near identical to Jet A)	9	Mass: 120 MJ/kg; Vol: 9 MJ/L (74% decrease in volumetric)	6
	B: Compatibility (45%)	Full drop-in; 100% compatible with existing pipelines, fuel trucks, and storage tanks	9	Requires specialized cryogenic storage and new refueling equipment; supply infrastructure costs	3

				$3.83-5.03/kg H_2 handled	
	C: TRL (25%)	TRL 8-9 (Commercial)	9	TRL 4-6 (Mid-stage development)	5
	Sub Total (Weighed)		9.00		4.70
Economic and Supply Chain (40%)	A: Fuel Cost (40%)	$2,000-3,500/tonne = 2-3.5 x Jet A	6	$2,280-7,390 /tonne = 2.3-7.4x Jet A	4
	B: Infrastructure CapEx (35%)	Uses existing Jet A infrastructure with minor or no modifications. Certification already exists	9	Requires completely new cryogenic storage tanks, piping, vaporizers, safety systems, and refueling vehicles. Estimated extra cost: $1–3B for a major hub.	3
	C: Import and Storage Feasibility (25%)	Uses existing shipping, pipelines, and airport storage; zero new infrastructure required	9	Requires new facility type ; significant land needed and global LH_2 shipping network does not yet exist	2
	Sub Total (Weighed)		7.80		3.15
Environmental Impact (20%)	A: Reduction vs Jet A (60%)	50-89% depending on feedstock.	7	Up to 100% if produced via renewable electrolysis	9
	B: Absolute Emissions (40%)	As low as 8 g CO_2e/MJ	7	0g CO_2e/MJ at combustion; Only emissions from construction/maintenance; can approach zero with fully renewable grid	9
	Sub Total (Weighed)		7.00		9.00

4.2 2040 Feasibility Index Scoring

A summarised table of results is represented by table 17, underscoring the weighting of each dimension and the weighted scores for each dimension and total score for each fuel.

Table 17: 2040 Feasibility Index (FI) Scoring

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)
Technical and Operational Readiness	40%	9.00	4.70
Economic and Supply Chain	40%	7.80	3.15
Environmental Impact	20%	7.00	9.00
Total	100%	8.12	4.94

Note: Hydrogen's environmental score assumes green hydrogen; grey/blue hydrogen would score significantly lower.

Table 17 shows that SAF benefits from high technical readiness (9.00) and economic compatibility (7.80), enabling near-term deployment. Hydrogen, while environmentally superior (9.00), is held back by low technical (4.70) and economic (3.15) scores due to poor volumetric energy density, fleet incompatibility, and high infrastructure costs. However, hydrogen's strong environmental performance suggests that if technical and economic barriers are overcome post-2040 (through advanced aircraft design, cost reductions, and global supply chain development) it could very well become the dominant long-term solution.

4.3 Sensitivity Analysis and Uncertainty

To test the robustness of the 2040 Feasibility Index, a sensitivity analysis was conducted by adjusting key parameters and weighting , as presented by table 18 and 19 :

Table 18: Weight Sensitivity Analysis

Scenario	Technical weight (%)	Economic weight (%)	Environmental Weight (%)	SAF Score	Hydrogen Score	Winner
Baseline	40	40	20	8.12	4.94	SAF
Heavy Technical	50	25	25	8.20	5.39	SAF
Heavy Economic	25	50	23	7.90	5.00	SAF
Heavy Environmental	25	25	50	7.70	6.47	SAF
Equal Weights	33	33	33	7.92	5.64	SAF

Extreme Environmental (long-term)	10	10	80	7.28	7.99	Hydrogen

From the weighting sensitivity analysis, SAF has a narrow score range (7.70-8.20), highlighting its robustness under various circumstances. On the other hand, hydrogen has a wide score range (5.94-7.99), heavily influenced by environmental weighting. Under a long-term, extreme environmental weighting, hydrogen marginally outperforms SAF (7.99 vs. 7.28). This is also the only scenario where hydrogen outperforms SAF. However, for a pre-2040 feasibility assessment where technical and economic barriers remain binding, such a weighting is unrealistic.

Table 19: Parameter Sensitivity Analysis

Parameter Varied	SAF Score Change	Hydrogen Score Change	New SAF Score	New Hydrogen Score	Winner
Baseline	-	-	8.12	4.94	SAF
H_2 cost drops 50% (to $1,140-3,700/tonne)	0	+0.32	8.12	5.26	SAF
SAF production CapEx increases 50%	-0.48	0	7.64	4.94	SAF
H_2 TRL advances to 7	0	+0.20	8.12	5.14	SAF
SAF feedstock constrained (emission reduction falls to 40-60%)	-0.38	0	7.74	4.94	SAF
Green Hydrogen absolute emissions become net zero 0 CO_2e/MJ	0	+0.20	8.12	5.14	SAF
SAF supply chain disruption	-0.64	0	7.48	4.94	SAF
Combined: H_2 optimistic + SAF pessimistic	-1.50	+0.72	6.62	5.66	SAF

SAF remains the winner under every single scenario tested. Even when combining the most optimistic hydrogen assumptions with the most pessimistic SAF assumptions, the gap narrows to 0.96 points but never closes, validating the conclusion that SAF is more feasible for pre 2040 operations in Hong Kong. The robustness of SAF's advantage across parameter and weight variations suggests that detailed point-uncertainty quantification for individual subcomponents would not alter the study's primary conclusion.

5. Conclusion

This study evaluated SAF and hydrogen for Hong Kong's aviation sector before 2040. The Feasibility Index (Section 4.2) shows SAF scoring 8.12/10 versus hydrogen's 4.94/10. From this investigation, three valuable insights can be concluded:

Firstly, for hydrogen to compete with SAF in Hong Kong before 2040, it must cross four independent thresholds. First, green hydrogen production costs must fall below USD $3,000 per tonne. Second, a commercial hydrogen aircraft must be certified and operating from HKIA by 2038 at the earliest. Third, cryogenic storage requires approximately 5-10 acres of land with 100-200m safety exclusion zones and this does not currently exist at Hong Kong International Airport. Fourth, a liquid hydrogen shipping network to Hong Kong must be established from scratch. Crossing all four thresholds are required simultaneously which is extremely unlikely before 2040. Therefore, Hong Kong should not delay SAF deployment and depend on a potential breakthrough of hydrogen.

Secondly, no single mechanism alone can influence SAF's clear advantage over hydrogen in the short run. The only winning scenario for hydrogen requires four simultaneous advancements which includes cost reduction, early certification, SAF feedstock collapse, and strong hydrogen policy. This combined scenario has very low probability before 2040. Therefore, Policymakers and local stakeholders should collaborate and focus on SAF specific policies instead such as mandates, offtake incentives, regional partnerships.

Thirdly, Hong Kong's constraints and this study cannot be used to deem generic global conclusions. Land scarcity, import dependency, long-haul network requirements, and the absence of mandates make hydrogen significantly less feasible in Hong Kong than in regions like Europe or the United States. A study conducted in a country such as the Netherlands might conclude hydrogen is viable by 2040 where the same conclusion does not hold for Hong Kong. This study's contribution is not to declare a global conclusion for SAF and Hydrogen, but to provide a context-sensitive methodology that other hubs can adapt to their own constraints.

For Hong Kong, this study recommends a phased approach as illustrated by figure 2:

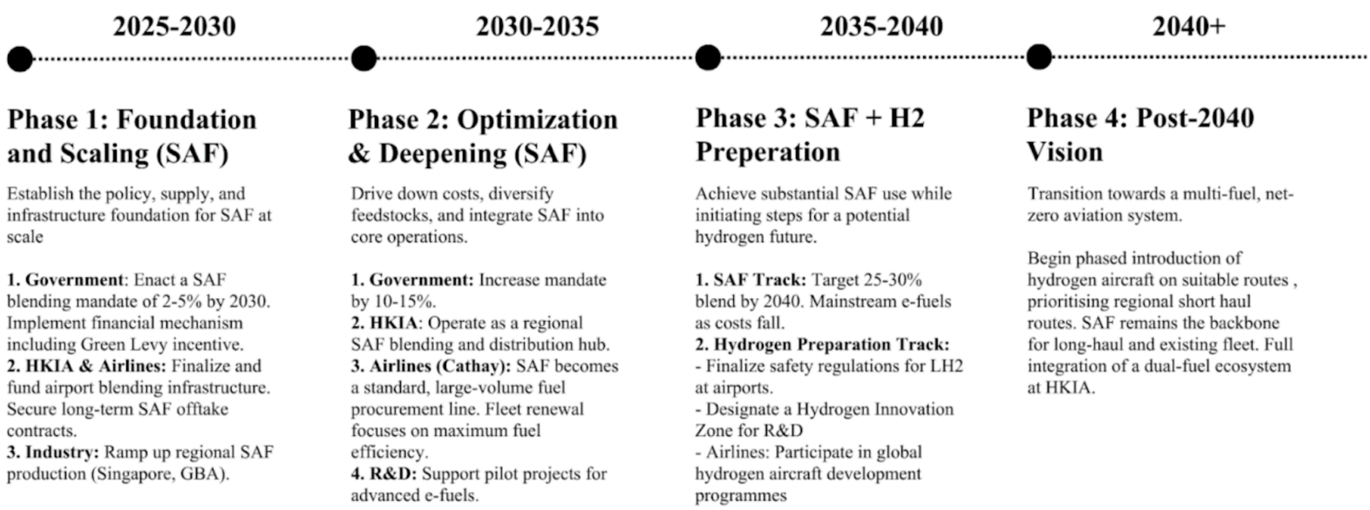

figure 2: Proposed 2040 Adoption Roadmap

For researchers, this study contributes a replicable, context-sensitive methodology. Future work should apply this framework to other Aviation hubs to identify region-specific thresholds and to refine hydrogen cost and TRL projections as new data emerge.

5.1 Limitations and Uncertainty

The Feasibility Index presented in this study is subject to several limitations that readers should consider when interpreting the results. Fuel cost projections for both SAF and hydrogen vary widely across sources depending on electricity prices, electrolyzer efficiency, and scale. The assigned scores use median estimates which may give rise to statistical uncertainty, but the sensitivity analysis shows that even under optimistic hydrogen cost assumptions, SAF has a competitive feasibility advantage given the weighting and dimensions of this index. In addition, the weights and scoring criteria were developed specifically for Hong Kong's unique constraints which may not generalize to aviation hubs with different characteristics. Researchers applying this framework to other contexts should recalibrate weights accordingly.

While the scoring rubrics (Tables 3-10) and master justification table (Table 16) provide transparency, the synthesis of evidence into numerical scores ultimately involves researcher judgment where different experts might assign slightly different scores. The sensitivity analysis addresses this by showing that moderate score variations (±1-2 points) do not change the overall conclusion that SAF is more feasible before 2040. Hydrogen's feasibility score would increase substantially for a post-2050 horizon as infrastructure matures and costs decline. This study does not conclude that hydrogen is infeasible indefinitely, instead that it is not the optimal pathway for Hong Kong's near-term decarbonization efforts.

6. Acknowledgement

The author would like to thank and acknowledge the guidance and encouragement of [mentor name redacted] in the development of this manuscript. The mentor's contributions were advisory and supervisory, which included the reviewing of the manuscript for logical consistency, formatting standards and alignment with the stated research objective. The use of large language model tools (LLM) were only for minor editing tasks which include grammar correction, punctuation, and formatting consistency.

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Dear Editorial Team, Convergence Journal,

I have addressed the major comments from the review. Below is a summary of the key revisions.

Major Comment 1: Scoring system lacks transparency and replicability

I restructured the methodology to ensure replicability:

- Consolidated overlapping dimensions into three non-overlapping categories (Technical & Operational Readiness, Economic & Supply Chain Feasibility, Environmental Impact)
- Created explicit scoring rubrics with 0-10 thresholds anchored to observable data ranges
- Added a Master Justification Table tracing every score to a specific citation (ICAO, IATA, DOE, etc.)
- Added Scoring Protocol methodology so others scholars can replicate the process

Major Comment 2: Core conclusion

I reframed the results more as a decision framework rather than static scores from the comparative framework:

- Wrote a short threshold analysis in the conclusion that identified four specific conditions hydrogen must meet to become competitive, emphasising that all four are required simultaneously.
- Wrote a short mechanism analysis in the conclusion that explained how no single policy or breakthrough can change the pre-240 outcome. Only an unlikely combination of four simultaneous advancements can change the results.
- Reemphasised the Phased decision framework for policymakers across four phases from 2025-2040+
- Explained the adaptability of the comparative index and how it can be varied and adapted for analysis of a different region. Explained why Hong Kong's constraints show that global conclusions cannot be defined for hydrogen and SAF.

Major Comment 3: Uncertainty

I added comprehensive sensitivity analysis:

- Added a Weight sensitivity analysis that showed SAF wins in all plausible scenarios where only an unrealistic 90% environmental weight changes the outcome.
- Added a Parameter sensitivity analysis that showed SAF wins in six of seven variations where only a highly unlikely combination of H_2 breakthroughs and SAF collapse changes the outcome.
- Added a subsection in the conclusion that explains how statistical uncertainty is mitigated by the sensitivity analysis and how individual scoring uncertainty propagation is beyond the scope of the investigation. Explained the potential weaknesses that future researchers might consider when employing this comparative framework.

Major Comment 4: Double-counting among dimensions

Addressed by consolidating the five original dimensions into three non-overlapping categories (technical, economic and environmental), with explicit definitions of what each dimension includes and excludes.

Major Comment 5: Engaging with scholarly disagreement

Added a new section in the analysis and discussion that identified several active ongoing debates (hydrogen timelines, SAF lifecycle emissions, cost projections). Both optimistic and pessimistic positions are cited, enhancing scholars' understanding.

I hope the new changes in the manuscript are identifiable and able to offer a replicable decision framework and is suitable for peer review.

Sincerely,

Adrian Lau

Review Title: A Comparative Study of Sustainable Aviation Fuels (SAF) vs. Hydrogen in Hong Kong

Overall Decision: Accept with Minor Revisions

General Review

Overall, this is a strong paper with a very relevant research topic and well-developed analysis. However, there are some things that need to be addressed before proceeding with the publication process. The structure and organization of the manuscript need some improvements because the current order of sections is somehow confusing, disrupting the native flow of the study.

Right now, discussion of the initial analysis appears before the results which makes the overall argument difficult to follow. Additionally, the sensitivity analysis should be moved into the methodology section while the corresponding output and findings from the sensitivity analysis should be moved into the results sections since they are part of the analytical framework of the study.

You may combine your results and analysis sections if you prefer, but the manuscript should only contain one discussion section, even if that section becomes relatively long. Similarly, the subsection on weighting currently appears after the discussion and before the results which interrupt the narrative structure and should instead be incorporated into the methodology section.

I also wanted to highlight that the tables and graphs in the paper are very strong and contribute greately to understanding each step of your methodology. However, remember to always specify the software used to generate the graphs within the figure description or caption. Additionally, several tables are currently missing citations in their descriptions thus a good amount of the information presented in the tables cannot be traced back to the original sources because citations are not consistently included.

I also wanted to congratulate you on including numbering. You are only the second student submission I have reviewed using this format, and it's tremendously helpful for reviewers. However, the line number formatting is currently inconsistent throughout the documents. If you are unable to maintain continuous numbering across the entire paper, it may be better not to include it because reviewer comments referring specific lines (for example lines 11-12) become confusing where numbers reappear across sections.

Conceptual comments

First, within the sensitivity analysis, you explore multiple weighting scenarios such as technically focused, economically focused, environmentally focused, and equal-weight configurations. However, the reason behind the selected weighting percentages is currently unclear. For example, the manuscript does not explain why a technically focused scenario was represented using a 50% weighting rather than 70% or 80%. Providing a justification for how these weighting was selected would strengthen the methodological transparency of the analysis.

Second, the policy recommendations proposed in the paper would benefit from a clearer comparison with Hong Kong's current aviation decarbonization strategies. In other words, it is important to explicitly explain how your recommendations differ from the current policy trajectory and why, based on your findings, these proposed strategies could enhance the existing governmental approach. This would significantly strengthen the policy relevance and practical applicability of your study.

Section specific Comments

Abstract

Overall, your abstract clearly explains the subject you are studying as well as your research question. The background and methodology are also clearly presented. However, make sure the presentation of your results is consistent across both technologies. In this sentence, SAF is supported with specific numerical values and clearly identified drivers, while hydrogen is described more generally. Presenting both using the same structure and level of detail would make the comparison clearer and reinforce that the same evaluation criteria were used to assess each technology "SAF achieves a pre-2040 feasibility score of 8.12/10, 14 driven by high technical readiness (9.00) and economic compatibility (7.80), despite facing feedstock 15 and cost challenges. Hydrogen scores 4.94/10, as its superior environmental potential (9.00) is 16 **outweighed by poor volumetric energy density and prohibitive infrastructure compatibility and costs"**. Lastly, the overall findings are strong and do not require major changes. However, the abstract is currently missing one or two concluding sentences discussing the broader implications of the study. This is important because abstracts should not only summarize findings but also explain why those findings matter.

Introduction

Remember that, in the same way you include citations throughout your literature review, your introduction should also contain citations supporting factual claims. Statements such as: "The decarbonization of aviation is challenging due to both underlying technical and operational constraints" should always be cited. Additionally, you do not need separate subsections for "Contribution" and "Structure of the Study." These ideas can be integrated naturally into the introduction. The research questions can also be incorporated directly into the introduction without requiring separate subsection headers.

Literature Review / Background

You are missing several citations in this section. These references need to be properly cited. Your literature review does a good job discussing the global challenges associated with both Hydrogen and SAF pathways. However, the local Hong Kong should be more emphasized. Since this paper is a Hong Kong case study, the literature review should include more discussion regarding Hong Kong's specific aviation infrastructure, policy priorities, energy transition goals, or regional limitations. You discuss it in different sections but is mostly missing here.

Methodology

Remember that methodology sections should generally be written consistently in past tense. There are a few tense inconsistencies that should be corrected. For Tables 3, 4, 5, 6, 7, 8, 9, and 10, where are the citations supporting the ranges selected for each classification category? These references should be included within the table descriptions or captions. Table 4 also needs formatting corrections in its description.

Results / Analysis

Great job with your analysis. Please just look at my comments about the order your study shows follow.

Conclusion

In general, in most journal is best not to introduce more tables in your conclusion or discussion sections. Although there are exemptions, please try to keep results tables to your methods and results. The 2040 proposed adoption map makes sense in the Conclusion section, but other tables related to your results should not be in the discussion or conclusion sections. Lastly, please check your table numbers, they seem to be inconsistent, for example table 2 in the conclusion.

Note: Overall, great job. Remember all these comments are focused on making your manuscript even better. Please do not be discouraged by the long review. Addressing these comments will make your manuscript an even better representation of your research abilities.

I. Appropriateness of the Topic				
Inappropriate ______	Doubtful ______	Marginal ______	Suitable ______	Highly Appropriate __x___

II. Conceptual Adequacy				
Inadequate ______	Weak ______	Marginal ______	Good ______	Outstanding __x___

III. Mastery of Relevant Literature				
Inadequate	Weak	Marginal	Good x	Outstanding

IV. Technical Adequacy				
Completely Inadequate ______	Major Problems ______	Minor Problems ______	Good ______	Outstanding __x___

V. Clarity of Presentation				
Unclear, requires extensive rewriting	Major Problems ______	Minor Problems ___x__	Good ______	Outstanding ______

VI. Significance of Contribution to the Field				
None ______	Trivial ______	Modest ______	Good __x___	Outstanding ______

VII. Reviewer Recommendation				
REJECT	REJECT, DESPITE MERIT	INVITE REVISION	CONDITIONAL ACCEPTANCE	ACCEPT

Almost no chance that problems can be resolved. ____	Although parts of the manuscript have merit, it is unlikely that the problems can be resolved. _____	Possibly publishable if problems noted in my review are resolved. _____	Publishable if the minor problems noted in my review are resolved. __x___	Subject only to normal copy editing, if any.

KEY ASSESSMENTS OF THE PAPER

- **Originality & Significance**

This paper provides a timely and insightful comparative analysis of Sustainable Aviation Fuel (SAF) and Hydrogen pathways within the Hong Kong aviation sector. The author effectively identifies critical “binding constraints,” particularly land scarcity and infrastructure compatibility, which are highly relevant to Hong Kong’s pursuit of its 2040 net-zero aviation goals. The study successfully contextualizes global aviation decarbonization debates within Hong Kong’s unique operational and geographical limitations, making the research paper highly valuable for local stakeholders such as Cathay Pacific and aviation policymakers.

- **Clarity & Structure**

The manuscript is well-structured and logically organized. The application of a Multi-Criteria Decision Analysis (MCDA) framework provides a clear and systematic approach for evaluating both fuel pathways. Additionally, the inclusion of a Sensitivity Analysis significantly strengthens the study’s methodological rigor by demonstrating how varying environmental priorities influence overall outcomes. The results remain relatively stable across a range of assumptions, reinforcing the credibility of the findings and the dominance of SAF under current operational conditions.

- **Use of Evidence & Research Methods**

The methodology is robust and transparent, particularly in its weighted evaluation system of 40% Technical Feasibility, 40% Economic Feasibility, and 20% Environmental Impact. The scoring framework is clearly presented and easy to follow. Furthermore, the integration of the Cathay Pacific case study enhances the research's practical relevance by linking theoretical analysis to real-world corporate sustainability initiatives, such as the airline’s 10% SAF adoption target by 2030. Technical data relating to energy density, Technology Readiness Levels (TRL), and fuel performance are also supported by credible industry sources, including ICAO and IATA.

- **Engagement with Literature**

Despite the strengths highlighted above, several areas require revision to further improve the paper's academic quality and accessibility. First, some technical terminologies need clearer explanations when first introduced. Terms such as "drop-in capability," "cryogenic storage," and even "decarbonization" may not be immediately accessible to all readers, particularly interdisciplinary audiences. Providing concise definitions within the introduction or literature review would improve readability and broaden the paper's accessibility.

The major area requiring attention is the referencing and citation format. There are noticeable inconsistencies in the in-text citations and reference list formatting, especially concerning multi-author citations. Worth noting, **in the second paragraph, lines 20 and 21 under the literature review and research gap section**, the in-text citations of "**Gutiérrez-Antonio, C., Gómez-Castro, F. I., de Lira-Flores, J. A., & Hernández, S., 2017**" were not properly formatted as an in-text citation, hence, should be revised and standardized according to the required academic referencing style by the authors. Similar inconsistencies appear within the Discussion and Analysis sections. The author should carefully revise all citations to ensure scientific and professional consistency. Additionally, all technical claims, particularly those concerning fuel energy densities (MJ/L), should be directly supported with corresponding citations to maintain academic integrity and traceability of information.

The 20% weighting for "Environmental Impact" also requires further justification. Although the author explains that operational continuity and economic practicality are priorities, this weighting appears comparatively low for a study centered on achieving "Net-Zero" aviation goals. To strengthen this methodological choice, the author should provide a clearer rationale supported by relevant policy frameworks, such as the HKSAR Climate Action Plan 2050 or other governmental sustainability directives. This would help readers better understand why Economic and Technical Feasibility are prioritized over Environmental Impact within the Hong Kong context.

- ❖ **<u>Other issues</u>**

The paper's visual presentation is strong overall, particularly the "2040 Adoption Roadmap," which offers practical insights for policymakers and industry stakeholders. However, the paper could benefit further from the inclusion of a simple comparative diagram illustrating the "drop-in" infrastructure compatibility of SAF versus the specialized cryogenic storage and transportation infrastructure required for Hydrogen. Such a visual aid would help readers better understand the significant economic and operational disparities between the two pathways.

The conclusion is balanced and avoids overgeneralization by acknowledging that findings may vary across regions with different infrastructural and geographical realities. This demonstrates scholarly maturity and strengthens the credibility of the research.

- ❖ **Summary of all critiques**

Overall, this is a high-quality, original, and context-specific study that contributes meaningfully to ongoing discussions on aviation sustainability. By refining citation formatting, clarifying technical terminology, and further justifying the environmental weighting within the MCDA framework, the author can significantly enhance the manuscript's clarity, professionalism, and academic impact. **My recommendation is to accept with minor revisions**.

Aviation Net-Zero Pathways:

~~A Comparative~~ AComparative Study of Sustainable Aviation Fuels (SAF) vs. Hydrogen in Hong Kong

~~By Adrian Lau~~[Author name redacted]

Abstract

The aviation sector is vital to Hong Kong's economy but remains a significant source of carbon emissions. This study investigates which fuel pathway (Sustainable Aviation Fuel (SAF) or hydrogen) demonstrates greater overall feasibility for adoption at scale in Hong Kong's aviation sector before 2040. Using a comparative feasibility index with dimensions weighted 40% technical, 40% economic, and 20% environmental, reflecting Hong Kong's long-haul dependency, land scarcity, and import reliance, the analysis is grounded in technical literature, industry reports, and a detailed case study of Cathay Pacific's decarbonization initiatives. SAF achieves a pre-2040 feasibility score of 8.12/10, driven by high technical readiness (9.00) and economic compatibility (7.80), despite facing feedstock and cost challenges. Hydrogen scores 4.94/10, as its superior environmental potential (9.00) is outweighed by poor volumetric energy density and prohibitive infrastructure compatibility and costs. Sensitivity analysis confirms that SAF remains the winner across all plausible weight and parameter scenarios for the 2040 horizon; hydrogen only outperforms SAF under an extreme long-term weighting (80% environmental, 10% technical, 10% economic) that is unrealistic for pre-2040 decision-making in Hong Kong. The study concludes that SAF is the more viable near-to-medium term pathway for Hong Kong, while hydrogen should be developed strategically, aligning with post-2040 decarbonization efforts.

Keywords: Sustainable Aviation Fuel (SAF), Hydrogen Aviation, Decarbonization, Hong Kong Aviation, Cathay Pacific

1.Introduction

1.1 Background

Hong Kong stands as a cornerstone of the global aviation network, its international airport being one of the world's busiest cargo passenger hubs. The aviation sector is a critical part of the city's economy, facilitating trade, tourism, and financial connectivity. However, it is also a significant and growing source of carbon emissions, contributing substantially to Hong Kong's overall carbon footprint, leading to mounting pressure to transform. The goal is not merely reducing emissions, but to do so while preserving Hong Kong's competitive operational reliability and thereby retaining its title as Asia's World city.

The decarbonization of aviation is challenging due to both underlying technical and operational constraints. Aircraft require fuels with extremely high energy density to achieve the necessary range and payload for long-haul travel: Hong Kong in particular is known for its vast long haul network, connecting major hubs across the globe. While battery-electric propulsion may seem as a plausible substitute, its current low energy density cannot support the intercontinental routes that Hong Kong's aviation depends on. Therefore, the problem turns to an alternative solution, namely, Sustainable Aviation Fuel (SAF) or Hydrogen (H_2).

1.2 Literature Review and Research Gap

Produced from sustainable feedstocks such as used cooking oil, agricultural waste, or synthesized from green hydrogen and captured carbon (e-fuels), SAF has the capability to blend with or directly replace conventional jet fuel without modifying existing aircraft or fuel infrastructure (ICAO, n.d.). SAF can reduce lifecycle carbon emissions by up to 80% compared to fossil kerosene. Its primary advantage lies in its compatibility with existing engines and airport hydrant systems. This seems highly promising, however, global SAF production remains at less than 0.1% of total jet fuel demand due to high costs, limited feedstock availability, and complex sustainability certification (Wang, M., & Yu, X, 2024).

On the other hand, hydrogen-powered aviation offers the potential for true zero-carbon flight when produced via renewable electrolysis. It can be used either by combustion directly in modified gas turbine engines or conversion to electricity via fuel cells to power electric propulsion (Gutiérrez-Antonio, C., Gómez-Castro, F. I., de Lira-Flores, J. A., & Hernández, S., 2017). Hydrogen boasts a superior gravimetric energy density but a very low volumetric density, requiring either cryogenic storage as a liquid at -253°C or high-pressure storage as a gas. This requires a complete change of current aircraft designs, airport fueling infrastructure, and ground handling procedures.

Previous studies on aviation decarbonization have established several critical dimensions for comparing fuel pathways. These dimensions include the Technical Dimension, which considers the energy density, aircraft range and payload implications, and technology readiness level (TRL); the Economic Dimension, which considers the fuel production (cost per gallon), total cost of ownership, and the capital expenditure (CapEx) required for new supply chain infrastructure; The Environmental Dimension, which considers the Well-to-Wake lifecycle emissions assessment, considering the entire process from feedstock cultivation, fuel production, transport, and combustion; And the Feasibility Dimension, that considers supply chain scalability, regulatory and safety certification timelines, and social acceptance.

Existing literature often evaluates SAF and hydrogen at a global scale with significant gaps in contextualizing such pathways within the specific constraints of a major, densely populated aviation hub like Hong Kong. These constraints include: Severe Land Scarcity, Dependence on Imports, Safety and Urban Proximity and Operational Continuity. Therefore, there is a need for a structured analysis for decarbonization pathways in Hong Kong’s unique realities, using a major local case study as a point of analysis.

1.3 Research Objectives and Questions

This study aims to conduct a comparative analysis to identify the more viable net-zero fuel pathway for Hong Kong's aviation sector before the year 2040: Using Cathay Pacific Airways and Hong Kong International Airport (HKIA) as a central case study. This research focus on the following questions:

1. Between Sustainable Aviation Fuel (SAF) and hydrogen, which aviation fuel pathway demonstrates greater overall feasibility for adoption at scale in Hong Kong before 2040?
2. What are the technical, economic, and supply chain barriers for Cathay Pacific and Hong Kong International Airport under each decarbonization pathway?
3. Based on the comparative analysis, what phased transition strategy should stakeholders in Hong Kong adopt to achieve long-term decarbonization while ensuring short-term operational and economic stability?

1.4 Contribution and Structure of the Study

By integrating a detailed comparison across technical, economic and environmental dimensions of SAF and Hydrogen within the practical context of Cathay Pacific's existing initiatives and Hong Kong's infrastructural and geographic constraints, this paper's primary contribution is to provide a grounded framework and/or solution for Hong Kong's aviation decarbonization.

2.Methodology

2.1 Comparative Framework and Feasibility Index

To address the research questions in a structured manner, this study constructs and utilises a comparative framework/feasibility index to evaluate the feasibility of Sustainable Aviation Fuel (SAF) and hydrogen pathways for Hong Kong's aviation sector before 2040. The index is based on three carefully constructed dimensions (refer to table 1) that are each assigned a weighting (refer to table 2) based on its perceived criticality for Hong Kong's specific context. Each dimension includes subcomponents that are also given a weight based on its perceived criticality as analysed in the analysis and discussion (refer to table 15). The scoring for each dimension and its subcomponents will be derived from a detailed assessment of literature data, case study evidence, and logical inference that ensures replicability. All subcomponent scoring and its dimension are scored from 1-10 based on specific scoring rubrics.

Table 1: Feasibility Index, its dimensions and components including explanations for its given weighting

Dimension	Weighting	Explanation	Subcomponents
Technical and Operational Readiness	40%	Assesses whether the fuel can enable Hong Kong's long-haul aviation operations without large performance disadvantages.	A. Gravimetric & Volumetric Energy Density B. Compatibility with Existing Fleet & Infrastructure (Drop-in capability) C. Technological Readiness Level (TRL) of the entire system

Economic and Supply Chain Feasibility	40%	Assesses the total cost of adopting the fuel pathway in Hong Kong's unique context.	A. Fuel Cost Production and per Energy Unit (USD/MJ) B. Capital Expenditure (CapEx) for new infrastructure, the import supply chain and potential aircraft modifications C. Import Logistics, Storage Feasibility and fuel delivery given Hong Kong’s land scarcity and import dependance.
Environmental Impact	20%	Assesses the Well-to-Wake lifecycle greenhouse gas emissions (GHG) of the fuel pathway from feedstock cultivation/production, fuel manufacturing to transport and combustion.	A. Lifecycle CO_2 Reduction vs. Jet A as a percentage B. Absolute Lifecycle Emissions (g CO_2e/MJ)

Table 2: Justification of weighting to the dimensions of Feasibility Index

Dimension	Weight	Justification
Technical and Operational Readiness	40%	Hong Kong's long-haul hub cannot compromise on range or payload, making technical compatibility and readiness critical for operational continuity, especially within a pre-2040 decision framework.
Economic and Supply Chain Feasibility	40%	As a near 100% fuel importer with severe land scarcity, cost and supply chain practicality determine whether any pathway can be commercially sustained before 2040.
Environmental Impact	20%	Emissions reduction is the fundamental objective of decarbonization. However, for the 2040 horizon in Hong Kong, a pathway that delivers deep lifecycle CO_2 reductions though remaining technically or economically infeasible cannot be deployed, hence lower weighting for a near term index.

2.2 Scoring Protocol

To ensure transparency and replicability, all scores in the Feasibility Index were derived using the following methodological protocol:

1. For each sub-component , the peer-reviewed literature and industry reports were reviewed to identify the range of reported values and/or descriptions in its respective scoring rubric found in tables 3-10.

2. The reported value was then mapped to either the lower or upper bound of the scoring rubric (or to the upper and lower extremes) defined in Tables 3-10. If the value was a reported range, the median of the range was taken for score assignment.
3. Each score was reported in the Master Justification Table (Table 16) accompanied by justification. The literature review in the analysis and discussion section will have mapped out the evidence to formulate and justify each score.
4. Where a dimension contains multiple sub-components, sub-component scores were weighted across a 100% to give an overall dimension score of 1-10. Weights were assigned based on the dimension's definition and criticality in Hong Kong's specific context (refer to table 15).
5. The final scores of each fuel were calculated by multiplying each dimension specific scores by its given weight (table 2) and summed up to produce the final score from 1-10.

Note: This protocol produces scores that represent the author's synthesis of the evidence. Different researchers might assign slightly different scores based on the evidence, though most of the components rely on quantitative data and highly attributable qualitative descriptions that mitigates that issue. However, to address this potential uncertainty, Section 4.3 presents a sensitivity analysis that varies key parameters and shows how scores change under alternative assumptions.

Rubric 1: Technical And Operation Readiness Scoring Criteria

Table 3: Sub Component A: Energy Density (Volumetric and Gravimetric)

Score Range	Volumetric Energy Density (MJ/L)	Gravimetric Energy Density (MJ/kg)	Percentage Reduction vs. Traditional Jet Fuel (43MJ/kg and 35MJ/L)
9-10	31-35+	38-45	<10%
7-8	26-30	32-37	10-25%
5-6	18-25	22-31	25-50%
3-4	9-17	11-21	50-75%
0-2	<9	<11	>75%

Note: if percentage reduction between volumetric and gravimetric energy density lies in a different score range, the mean score between the two are taken.

Table 4: Sub Component B: Compatibility With Existing Fleet

Score Range	Description
9-10	Full drop-in capability with no modifications and certified for 50-100% blends
7-8	Drop-in for blends ≤50%; with minor modifications for higher blends
5-6	Requires new fuel system components (tanks, seals, pumps)
3-4	Requires new engine or airframe design
0-2	Incompatible; requires entirely new fleet

Table 5: Sub Component C: Technological readiness Level (TRL)

Score Range	Description and TRL Level
9-10	Commercial production and operation; multiple suppliers (TRL 9-10)
7-8	System demonstration in operational environment (TRL 7-8)
5-6	Technology validated in relevant environment (TRL 5-6)
3-4	Proof of concept to component validation (TRL 3-4)
0-2	Basic research to concept formulation (TRL 1-2)

Rubric 2: Economic and Supply Chain Feasibility

Table 6: Sub Component A: Fuel Cost

Score Range	Cost Multiple vs. Traditional Jet Fuel	Approximate USD/tonne	Approximate USD/MJ
9-10	<1.5x	$1500	<$0.035
7-8	1.5-2.5x	$1500-2500	$0.035–0.058
5-6	2.5-4x	$2500-4000	$0.058–0.093
3-4	4-6x	$4000-6000	$0.093–0.140
0-2	>6x	>$6000	>$0.140

Table 7: Sub Component B: Infrastructure Capital Expenditure (CapEx)

Score Range	CapEx Relative to Mainstream Jet A System	Estimated Absolute Supplemental Cost in USD for Hong Kong
9-10	<10% additional	$100M
7-8	10-50% additional	$100-500M
5-6	50-100% additional	$500M-$1B
3-4	100-300% additional	$1B-3B
0-2	>300% additional	>$3B

Table 8: Sub Component C: Import Logistics and Storage Feasibility

Score Range	Description
9-10	Uses existing shipping and storage infrastructure; no new land required
7-8	Minor modifications to existing terminals; small land footprint

5-6	New equipment at existing facilities; moderate land use
3-4	Requires new facility type; significant land needed
0-2	Requires infrastructure that does not yet exist globally; massive land and safety exclusion zones required

Rubric 3: Environmental Impact

Table 9: Sub Component A: Lifecycle CO_2 Reduction vs. Jet A

Score Range	Reduction vs Jet A
9-10	>90%
7-8	70-90%
5-6	50-70%
3-4	30-50%
0-2	<30%

Table 10: Sub Component B: Absolute Lifecycle Emissions

Score Range	g CO_2e/MJ
9-10	5
7-8	5-15
5-6	15-25
3-4	25-35
0-2	>35

Note: Jet A baseline is ~80-90 g CO_2e/MJ

2.3 Data Sources

Given the nature of this investigation, the analysis will draw upon multiple sources of evidence to base the comparative framework. This allows for more professionally reasoned arguments that gives rise to more accurate qualitative based scores (refer to table 11):

Table 11: Type of data and its derived source

Data Type	Sources
Technical & Environmental Data	US Department of Energy (DOE). International Civil Aviation Organization (ICAO) Life Cycle Assessment (LCA) methodologies, and peer-reviewed academic LCA studies.

Economic Data	Fuel cost projections from industry reports (IATA, BloombergNEF), corporate disclosures, and infrastructure cost estimates from engineering and consultancy studies.
Hong Kong & Regional Context	Hong Kong International Airport Authority and Civil Aviation Department publications for traffic and fuel consumption statistics. Analysis of regional SAF production capacity will rely on corporate announcements, government energy plans, and trade reports.
Cathay Pacific Case Study	Cathay Pacific's annual sustainability reports, press releases on SAF procurement, corporate partnerships, and fleet renewal plans.

3. Analysis and Discussion

3.1 Case Study: Cathay Pacific

Cathay Pacific has positioned itself as a regional leader in aviation decarbonization, establishing clear, public commitments for its long-term economic and environmental strategy. The airline has committed to achieving net-zero carbon emissions by 2050, aligning with IATA's global target. A critical interim goal is the use of 10% Sustainable Aviation Fuel (SAF) for its total fuel consumption by 2030. Table 12 outlines Cathay Pacific's SAF recent action timeline.

Table 12: Cathay Pacific SAF Action Timeline (2022-2025)

Year	Action	Partners	Significance
2022	First corporate SAF programme launched. (Swire Pacific & Cathay Pacific, 2022)	AIA, Airport Authority Hong Kong, DHL Global Forwarding, HSBC, Kintetsu World Express, PwC China, Standard Chartered, and Swire Pacific	Engage other like-minded organisations, and a first step in sending an important demand signal to the SAF supply chain that there is firm interest in the region.
2022	Major long-term SAF supply agreement signed, beginning deliveries in 2025. (Cathay Pacific Airways Limited, 2022)	Aemetis (US biorefinery) and One World Alliance.	Secured a substantial future supply (up to 38 million gallons over 7 years), produced at Aemetis Carbon Zero plant. The SAF purchased can reduce more than 80,000 tonnes of lifecycle carbon emissions.
2023	Signing a Memorandum of	State Power Investment Cooperation (SPIC)	MoU will use a multitude of different technologies for SAF

	Understanding (MoU). (Cathay Pacific Airways Limited, 2023)		production, including a pathway similar to power-to-liquid (PtL) to convert renewable electricity into liquid fuels. (Schmidt, P. R., Habersetzer, A., & Raksha, T, 2022).
2024	Purchased agreement for around 3400 tonnes of SAF produced by EcoCeres	HSBC Hong Kong and EcoCeres	EcoCeres' SAF is derived from 100% waste-based biomass feedstock, which can deliver an estimated reduction of up to 90% in GHG emissions compared to conventional jet fuel.
2024	Launched Hong Kong Sustainable Aviation Fuel Coalition (HKSAFC) (Cathay Pacific Airways Limited, 2024)	Business Environmental Council (BEC) along with 13 other founding partners including Shell Aviation, Sinopec and PetroChina.	A multi-stakeholder platform in the region that brings together the aviation industry, to collaborate on advancing the development, supply and use of SAF.
2025	Cathay and Airbus form co-investment partnership (up to $70 million) for scaling sustainable aviation fuel adoption. (Cathay Pacific Airways Limited, 2025)	Airbus	Cathay and Airbus aim to leverage their global experience to help shape policies that make SAF more accessible and affordable in this part of the world.

Cathay Pacific's active SAF procurement commitments show that near-term feasibility is driven by technical compatibility and economic practicality, not environmental potential alone, conforming with the study's dimension weightings. This case study also helps to identify Hong Kong specific priorities through the perspective of a local stakeholder, enhancing the legitimacy of the weightings and assigned scores of the comparative framework.

3.2 Technical, Economical and Environmental Fuel Data

Table 6 provides comparative literature synthesis of technical, economic, and environmental data of Sustainable Aviation Fuel (SAF) and hydrogen, highlighting key advantages and trade-offs between them. This allows for accurate mapping of reported literature values to the corresponding assigned score ranges as mentioned in tables 3-10.

Table 13: Quantitative technical, economical and environmental literature Data of SAF and Hydrogen

Category	Parameter	SAF	Hydrogen
Technical	Gravimetric Energy Density	43 MJ/kg	120 MJ/kg
	Volumetric Energy Density	35 MJ/kg	9 MJ/kg
	Production CapEx	Approximately USD 1,500 per tonne of annual capacity for greenfield plants.	Large-scale electrolyzer systems cost between US$2,100 – US$3,200 per kW
	Airport Infrastructure	Near zero. It is 100% compatible with existing pipelines, fuel trucks, and airport storage tanks.	Specialized cryogenic storage and new refueling equipment. Supply infrastructure costs are estimated at US$3.83 – US$5.03 per kg of H_2 handled.
	TRL	TRL 8-9 (Commercial)	TRL 4-6 (Mid stage development)
Economical	Current Cost (Production)	USD $2000-$3500/tonne	USD $2280-7390/ tonne
	Cost per energy unit	USD $0.14-$0.22/MJ	USD $0.10-$0.13/MJ
Environmental	Lifecycle CO_2 Reduction vs conventional jet fuel	50%-89% (Depending on feedstock)	Up to 100% (If produced Via renewable electrolysis)
	Absolute Lifecycle Emissions	10-15 gCO_2e/MJ	0 g CO_2e/MJ
	Production Energy Input (per Kg fuel)	1 kg SAF; requires ~ 40-50 kWh electricity	50-55 kWh electricity per kg H_2; liquefaction adds ~10-12 kWh/kg

Note. Technical, Economical and Environmental data are from (ICAO, 2024), (Braun, M., Grimme, W., & Oesingmann, K, 2024), (Wang, M., & Yu, X. ,2024) and (US Department of Energy, n.d)

3.3 Hong Kong Fuel Supply Chain

An analysis of the fuel supply chain in Hong Kong is crucial given its heavy weighting in the comparative short term feasibility index. The feasibility of a decarbonization pathway for Hong Kong not only depends on the fuel's technical aspects, but also on the practicality of its end-to-end supply chain with Table 7 summarising the SAF vs. Hydrogen Supply Chain comparison for Hong Kong.

The SAF Supply Chain begins with production in regional hubs;Shipment via standard marine tankers; Storage at Hong Kong's existing fuel terminals; Blending with conventional jet fuel at the airport and finally fueling of aircraft using the existing hydrant system (US Department of Energy, n.d). The primary strength of the SAF pathway is its flexibility with existing systems. The existing Airport Fuel Receiving Facility and the underground hydrant pipeline to HKIA can handle blended SAF, meaning existing capital investment and decades of operational expertise can be easily utilised and therefore minimizing cost. However, Hong Kong has an external supply dependency as the city has no space for large-scale local SAF production. Security of supply thus relies entirely on long-term offtake contracts with producers in foreign countries.

Table 14: End-to-End SAF vs. Hydrogen Supply Chain Comparison for Hong Kong

Category	SAF Pathway	Hydrogen Pathway
Production	Regional (Greater Bay Area) or foreign Biorefinery or e-fuel plant.	Green hydrogen plant (location outside of Hong Kong)
Primary Transport	Maritime shipment via chemical/product tanker	Specialized cryogenic tanker ship (liquid H_2) or high-pressure ISO containers (compressed H_2)
Receipt & Storage	At existing surrounding fuel Terminals or directly into HKIA's existing fuel network.	Requires a new, segregated cryogenic (-253°C) or high-pressure storage facility at/near HKIA. Significant land and safety buffer zones needed.
Blending	Blended with conventional Jet A-1 to specified ratio using existing infrastructure	Requires complex cryogenic pumping and vapor management systems.
Distribution & Uplift	Pumped via the existing underground hydrant system to aircraft using standard refueling trucks.	Dedicated, insulated refueling trucks or fixed refueling points at specific gates/stands.

The Hydrogen Supply Chain begins with production of green hydrogen; Transportation via specialized cryogenic tankers or high-pressure containers; Storage in new, high-security, cryogenic tanks at the airport and finally fueling of aircraft using completely separate, dedicated refueling trucks and systems (US Department of Energy, n.d). However, there are some main barriers of the hydrogen supply chain. First, a reliable import supply of hydrogen requires the existence of a global green hydrogen trade that still hasn't been fully developed, requiring specialized cryogenic tanker ships that are rare and expensive. Additionally, liquid hydrogen must be stored at -253°C and the infrastructure required for this is massive, expensive, and requires significant safety exclusion zones due to hydrogen's wide flammability range and potential for embrittlement (Bauen, A., Bitossi, N., German, L., Harris, A., & Leow, K, 2020). Furthermore, integrating hydrogen requires the construction of a completely new system which includes dedicated storage, a separate distribution network and specialized refueling positions. The CapEx would be enormous, and the construction and integration phase would significantly impact the 24/7 operation of the hub, which is crucial to Hong Kong. Unlike SAF, which can be stored for longer periods, liquid hydrogen experiences evaporation, requiring intensive re-liquefaction (Prussi, M., O'Connell, A., & Lonza, L., 2019).

3.4 Discussion

SAF's advantage is its immediate technical and operational compatibility, delivering measurable emissions reductions within the current fleet and infrastructure lifecycle. However, high costs of SAF impact airline competitiveness and ticket prices, while dependency on sustainable feedstocks like used cooking oil or agricultural waste limits scalability due to limited supply. Hydrogen, particularly green hydrogen, offers near-zero Well-to-Wake emissions in the long run. However, there is the need for a full scale system and infrastructure transformation which not only includes the aircraft itself, but the entire aviation ecosystem from global green hydrogen production, cryogenic shipping, new airport infrastructure, and new safety protocols.

Based on the Data and case study analysis, SAF procurement in the short run can be advanced by considering the following protocols. This involves negotiating long-term offtake agreements to secure SAF supply volume and hedge against future price volatility, while diversifying the supplier base geographically and across production pathways. This is a key insight gained from Cathay's case study. Given the experience and expertise, Cathay Pacific must be a lead advocate and partner in shaping the Hong Kong and regional SAF ecosystem. This can be achieved by actively lobbying the HKSAR government for a clear SAF mandate and support policies, working alongside the Airport Authority on the technical specifications and investment plans for airport blending and storage infrastructure (IATA, 2025). Cathay Pacific should lead and influence the Sustainable Aviation Fuel Alliance for Asia and similar consortia to drive standardization, sustainability certification, and collective purchasing power. Cathay Pacific should also engage manufacturers to understand the roadmap for hydrogen or hybrid-hydrogen aircraft and assess the long-term implications for its network and hub operations (Ng, K. S., Farooq, D., & Yang, A., 2021).

While the technical parameters of SAF and hydrogen are well-documented, several critical issues remain actively contested. Industry proponents usually project commercial hydrogen aircraft entry-into-service by 2035, with airport infrastructure following shortly thereafter. However, there is conflict on how these timelines are unrealistic. There are currently no commercial airports that handle liquid hydrogen at scale, with some sources estimating that a full hydrogen aviation system requires 20-30 years to develop, pushing commercial viability to 2045-2055. (Braun, M., Grimme, W., & Oesingmann, K , 2024)

In general, SAF reduces lifecycle emissions by 70-80% (HEFA pathways) compared to conventional jet fuel. However, experts often argue that indirect land-use change (ILUC), where biofuel feedstock cultivation displaces food crops, leading to forest clearing elsewhere, can erode or reverse claimed emissions benefits. Furthermore, different life cycle assessments may produce different lifecycle emission results, though such data remains in a range largely accepted by the industry. In addition, Green hydrogen costs are often projected to fall 40-60% by 2030, driven by falling electrolyzer prices and renewable electricity costs. However, previous energy technology cost forecasts have consistently been too optimistic (Schmidt, P. R., Habersetzer, A., & Raksha, T, 2022).

These debates and ongoing tensions provide more evidence to the weight or relative importance of each of the dimensions and its subcomponents in the feasibility index.

3.5 Subcomponent Weighting (Hong Kong Context)

Based on the discussion surrounding the Cathay Pacific Case Study and Hong Kong’s specific contextual priorities, the following weights are assigned to each subcomponent as illustrated by table 15.

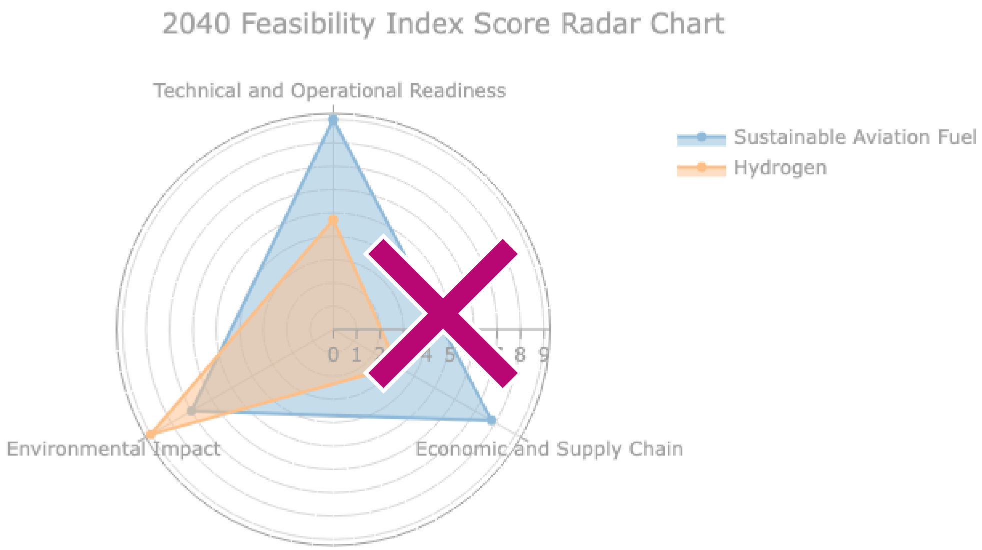
Table 15 : Justification of weighting to the subcomponents of the dimensions of the Feasibility Index

Dimension	Subcomponent	Weight	Justification
Technical and Operational Readiness	A: Energy Density	35%	Hong Kong's long-haul dependent hub cannot accept the range penalties of low-density fuels.
	B: Compatibility with Exiting Fleet	40%	Drop-in compatibility avoids loss of assets and high costs from premature fleet retirement, which is critical for Cathay Pacific's future fleet horizon.
	C: TRL	25%	For pre-2040 deployment, fuels must be commercial (TRL 8-9), not demonstration-stage, to avoid operational risk to Hong Kong's global hub status.
Economic and Supply Chain Feasibility	A: Fuel Cost	40%	As a 100% fuel importer, Hong Kong's aviation competitiveness depends directly on fuel cost.
	B: CapEx	35%	Land scarcity at HKIA makes hydrogen's expensive cryogenic storage near impossible, while SAF's blending fits existing infrastructure, which is economically very advantageous.
	C: Import and Storage Logistics	25%	SAF leverages Hong Kong's existing liquid fuel shipping network, whereas hydrogen requires a non-existent global H_2 supply chain.
Environmental Impact	A: Lifecycle CO_2 Reduction vs. Jet A	60%	Percentage reduction is the primary policy metric used by ICAO CORSIA, IATA, and Cathay Pacific's net-zero targets.
	B: Absolute Lifecycle Emissions	40%	Absolute emissions provide a clear comparison, accounting for the entire life cycle from well to wake.

4. Results

4.1 Indicator Comparison Summary

The following section synthesizes the comparative analysis of SAF and Hydrogen across the three key dimensions established in the methodology.



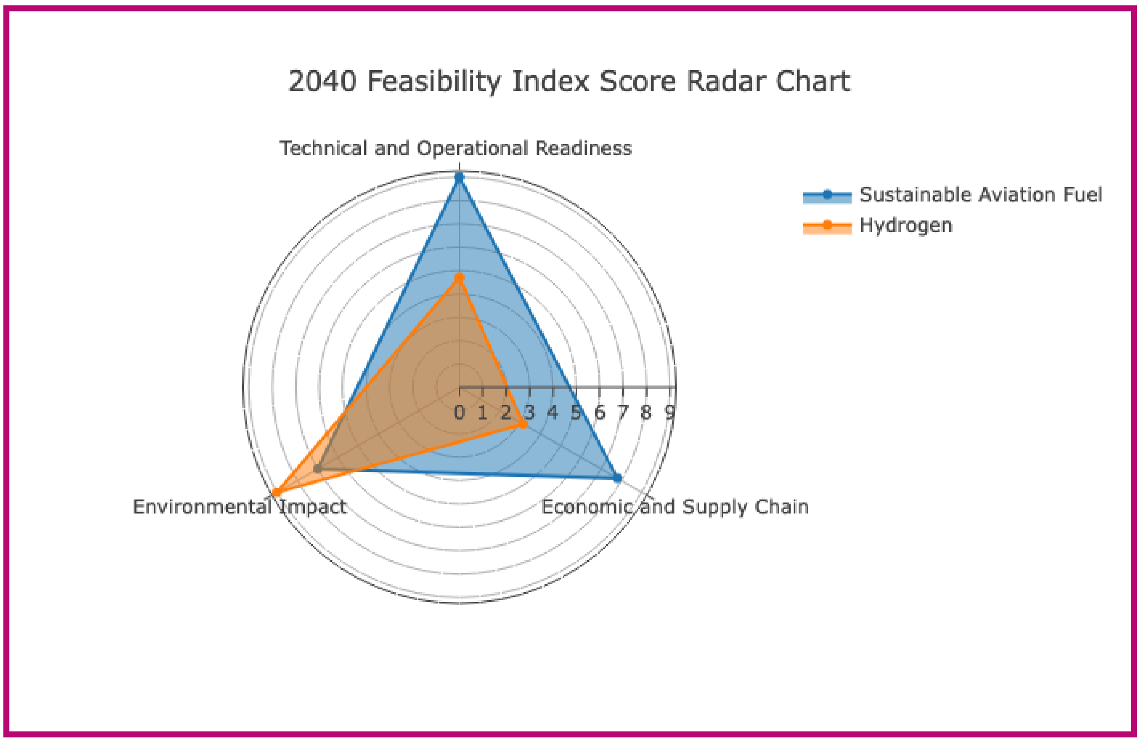


Figure 1: 2040 Feasibility Index Radar Chart

The results are visualized in figure 1 clearly illustrating SAF's dominant overall feasibility profile for the specified timeframe, especially for the technical and economic dimensions. The Master Scoring Table with the assigned scores based on the feasibility index scoring methodology is illustrated by table 16.

Table 16: Master Scoring Table based on methodology, comparing SAF vs Hydrogen for Hong Kong

Dimension and Weight	Subcomponent and Weight	Supporting Evidence (SAF)	SAF Scoring	Supporting Evidence (Hydrogen)	Hydrogen Scoring
Technical and Operational Readiness (40%)	A: Energy density (35%)	Mass: 43 MJ/kg; Vol: 35 MJ/L (near identical to Jet A)	9	Mass: 120 MJ/kg; Vol: 9 MJ/L (74% decrease in volumetric)	6
	B: Compatibility (45%)	Full drop-in; 100% compatible with existing pipelines, fuel trucks, and storage tanks	9	Requires specialized cryogenic storage and new refueling equipment; supply infrastructure costs \$3.83-5.03/kg H_2 handled	3
	C: TRL (25%)	TRL 8-9 (Commercial)	9	TRL 4-6 (Mid-stage development)	5
	Sub Total (Weighed)		9.00		4.70
Economic and Supply Chain (40%)	A: Fuel Cost (40%)	\$2,000-3,500/tonne = 2-3.5 x Jet A	6	\$2,280-7,390 /tonne = 2.3-7.4x Jet A	4
	B: Infrastructure CapEx (35%)	Uses existing Jet A infrastructure with minor or no modifications. Certification already exists	9	Requires completely new cryogenic storage tanks, piping, vaporizers, safety systems, and refueling vehicles. Estimated extra cost: \$1–3B for a major hub.	3
	C: Import and Storage Feasibility (25%)	Uses existing shipping, pipelines, and airport storage; zero new infrastructure required	9	Requires new facility type ; significant land needed and global LH_2 shipping network does not yet exist	2

	Sub Total (Weighed)		7.80		3.15
Environmental Impact (20%)	A: Reduction vs Jet A (60%)	50-89% depending on feedstock.	7	Up to 100% if produced via renewable electrolysis	9
	B: Absolute Emissions (40%)	As low as 8 g CO_2e/MJ	7	0g CO_2e/MJ at combustion; Only emissions from construction/maintenance; can approach zero with fully renewable grid	9
	Sub Total (Weighed)		7.00		9.00

4.2 2040 Feasibility Index Scoring

A summarised table of results is represented by table 17, underscoring the weighting of each dimension and the weighted scores for each dimension and total score for each fuel.

Table 17: 2040 Feasibility Index (FI) Scoring

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)
Technical and Operational Readiness	40%	9.00	4.70
Economic and Supply Chain	40%	7.80	3.15
Environmental Impact	20%	7.00	9.00
Total	100%	8.12	4.94

Note: Hydrogen's environmental score assumes green hydrogen; grey/blue hydrogen would score significantly lower.

Table 17 shows that SAF benefits from high technical readiness (9.00) and economic compatibility (7.80), enabling near-term deployment. Hydrogen, while environmentally superior (9.00), is held back by low technical (4.70) and economic (3.15) scores due to poor volumetric energy density, fleet incompatibility, and high infrastructure costs. However, hydrogen's strong environmental performance suggests that if technical and economic barriers are overcome post-2040 (through advanced aircraft design, cost reductions, and global supply chain development) it could very well become the dominant long-term solution.

4.3 Sensitivity Analysis and Uncertainty

To test the robustness of the 2040 Feasibility Index, a sensitivity analysis was conducted by adjusting key parameters and weighting , as presented by table 18 and 19 :

Table 18: Weight Sensitivity Analysis

Scenario	Technical weight (%)	Economic weight (%)	Environmental Weight (%)	SAF Score	Hydrogen Score	Winner
Baseline	40	40	20	8.12	4.94	SAF
Heavy Technical	50	25	25	8.20	5.39	SAF
Heavy Economic	25	50	23	7.90	5.00	SAF
Heavy Environmental	25	25	50	7.70	6.47	SAF
Equal Weights	33	33	33	7.92	5.64	SAF
Extreme Environmental (long-term)	10	10	80	7.28	7.99	Hydrogen

From the weighting sensitivity analysis, SAF has a narrow score range (7.70-8.20), highlighting its robustness under various circumstances. On the other hand, hydrogen has a wide score range (5.94-7.99), heavily influenced by environmental weighting. Under a long-term, extreme environmental weighting, hydrogen marginally outperforms SAF (7.99 vs. 7.28). This is also the only scenario where hydrogen outperforms SAF. However, for a pre-2040 feasibility assessment where technical and economic barriers remain binding, such a weighting is unrealistic.

Table 19: Parameter Sensitivity Analysis

Parameter Varied	SAF Score Change	Hydrogen Score Change	New SAF Score	New Hydrogen Score	Winner
Baseline	-	-	8.12	4.94	SAF
H_2 cost drops 50% (to $1,140-3,700/tonne)	0	+0.32	8.12	5.26	SAF
SAF production CapEx increases 50%	-0.48	0	7.64	4.94	SAF
H_2 TRL advances to 7	0	+0.20	8.12	5.14	SAF

SAF feedstock constrained (emission reduction falls to 40-60%)	-0.38	0	7.74	4.94	SAF
Green Hydrogen absolute emissions become net zero 0 CO_2e/MJ	0	+0.20	8.12	5.14	SAF
SAF supply chain disruption	-0.64	0	7.48	4.94	SAF
Combined: H_2 optimistic + SAF pessimistic	-1.50	+0.72	6.62	5.66	SAF

SAF remains the winner under every single scenario tested. Even when combining the most optimistic hydrogen assumptions with the most pessimistic SAF assumptions, the gap narrows to 0.96 points but never closes, validating the conclusion that SAF is more feasible for pre 2040 operations in Hong Kong. The robustness of SAF's advantage across parameter and weight variations suggests that detailed point-uncertainty quantification for individual subcomponents would not alter the study's primary conclusion.

5. Conclusion

This study evaluated SAF and hydrogen for Hong Kong's aviation sector before 2040. The Feasibility Index (Section 4.2) shows SAF scoring 8.12/10 versus hydrogen's 4.94/10. From this investigation, three valuable insights can be concluded:

Firstly, for hydrogen to compete with SAF in Hong Kong before 2040, it must cross four independent thresholds. First, green hydrogen production costs must fall below USD $3,000 per tonne. Second, a commercial hydrogen aircraft must be certified and operating from HKIA by 2038 at the earliest. Third, cryogenic storage requires approximately 5-10 acres of land with 100-200m safety exclusion zones and this does not currently exist at Hong Kong International Airport. Fourth, a liquid hydrogen shipping network to Hong Kong must be established from scratch. Crossing all four thresholds are required simultaneously which is extremely unlikely before 2040. Therefore, Hong Kong should not delay SAF deployment and depend on a potential breakthrough of hydrogen.

Secondly, no single mechanism alone can influence SAF's clear advantage over hydrogen in the short run. The only winning scenario for hydrogen requires four simultaneous advancements which includes cost reduction, early certification, SAF feedstock collapse, and strong hydrogen policy. This combined scenario has very low probability before 2040. Therefore, Policymakers and local stakeholders should collaborate and focus on SAF specific policies instead such as mandates, offtake incentives, regional partnerships.

Thirdly, Hong Kong's constraints and this study cannot be used to deem generic global conclusions. Land scarcity, import dependency, long-haul network requirements, and the absence of mandates make hydrogen significantly less feasible in Hong Kong than in regions like Europe or the

United States. A study conducted in a country such as the Netherlands might conclude hydrogen is viable by 2040 where the same conclusion does not hold for Hong Kong. This study's contribution is not to declare a global conclusion for SAF and Hydrogen, but to provide a context-sensitive methodology that other hubs can adapt to their own constraints.

For Hong Kong, this study recommends a phased approach as illustrated by figure 2:

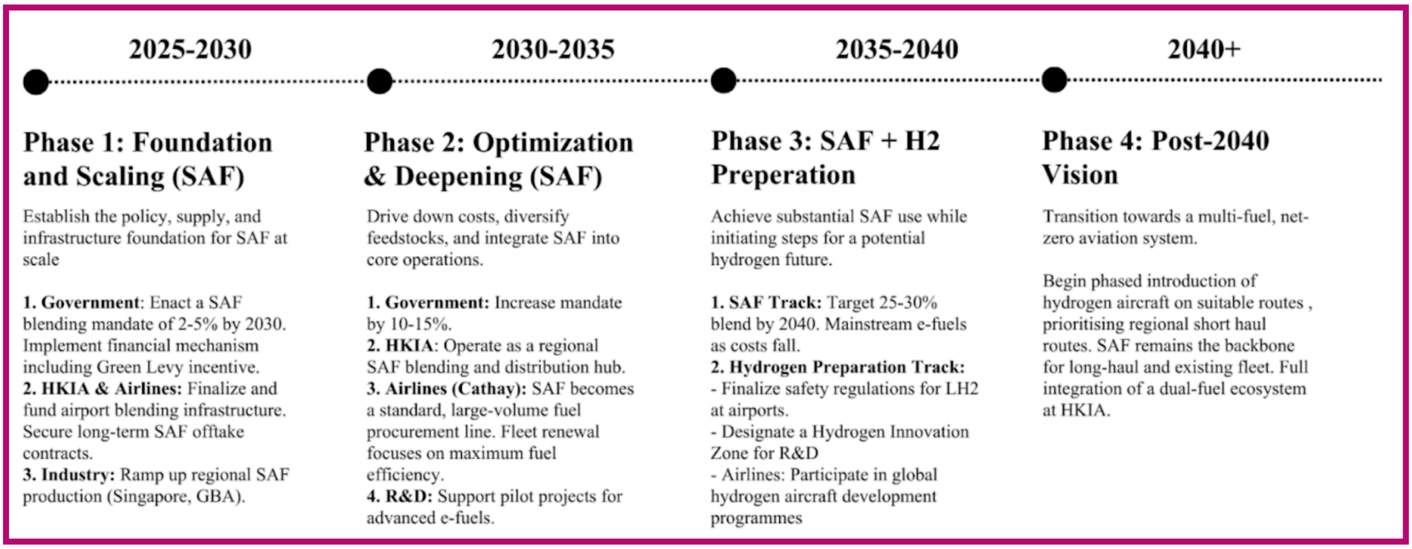


figure 2: Proposed 2040 Adoption Roadmap

For researchers, this study contributes a replicable, context-sensitive methodology. Future work should apply this framework to other Aviation hubs to identify region-specific thresholds and to refine hydrogen cost and TRL projections as new data emerge.

5.1 Limitations and Uncertainty

The Feasibility Index presented in this study is subject to several limitations that readers should consider when interpreting the results. Fuel cost projections for both SAF and hydrogen vary widely across sources depending on electricity prices, electrolyzer efficiency, and scale. The assigned scores use median estimates which may give rise to statistical uncertainty, but the sensitivity analysis shows that even under optimistic hydrogen cost assumptions, SAF has a competitive feasibility advantage given the weighting and dimensions of this index. In addition, the weights and scoring criteria were developed specifically for Hong Kong's unique constraints which may not generalize to aviation hubs with different characteristics. Researchers applying this framework to other contexts should recalibrate weights accordingly.

While the scoring rubrics (Tables 3-10) and master justification table (Table 16) provide transparency, the synthesis of evidence into numerical scores ultimately involves researcher judgment where different experts might assign slightly different scores. The sensitivity analysis addresses this by showing that moderate score variations (±1-2 points) do not change the overall conclusion that SAF is more feasible before 2040. Hydrogen's feasibility score would increase substantially for a post-2050 horizon as infrastructure matures and costs decline. This study does not conclude that hydrogen is infeasible indefinitely, instead that it is not the optimal pathway for Hong Kong's near-term decarbonization efforts.

6. Acknowledgement

The author would like to thank and acknowledge the guidance and encouragement of ~~their mentor, Dr. Minnie Yu,~~[mentor name redacted] in the development of this manuscript. The mentor’s contributions were advisory and supervisory, which included the reviewing of the manuscript for logical consistency, formatting standards and alignment with the stated research objective. The use of large language model tools (LLM) were only for minor editing tasks which include grammar correction, punctuation, and formatting consistency.

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RESPONSE TO REVIEWER 1

Summary: In response to Reviewer 1, a total of sixteen revisions were made across seven categories. Structurally, the manuscript was reorganized so that the Results section (section 4) precedes the Contextual Analysis (section 3), Table 15 was moved to the Methodology as table 3, the sensitivity analysis framework was moved to Methodology (section 2.4) while its findings remain in Results (section 4.3), and the former "Analysis and Discussion" section was renamed "Contextual Analysis" with no separate Discussion section remaining. Conceptually, a justification was added for the sensitivity analysis weighting percentages and a paragraph was added to the Conclusion comparing policy recommendations to existing Hong Kong strategies. The abstract was revised to give hydrogen the same level of quantitative detail as SAF, including specific numerical values for technical readiness, environmental superiority, and economic feasibility, and two concluding sentences on broader implications were added. In the Introduction, missing citations were added and unnecessary subsections were removed. In the Literature Review, missing citations were added along with a new paragraph on Hong Kong's aviation context. In the Methodology, the entire section was rewritten in the past tense, citations were added to Tables 4–11, and Table 4 was reformatted for clearer score-to-description mapping. Finally, the Conclusion was verified to contain no results tables, with Figure 2 remaining as a policy recommendation.

General Review

Comment 1: *Correct the structure and organization of the manuscript. The discussion of initial analysis appears before results.*

Response: Corrected the structure and organization of the manuscript. Moved the discussion of the "initial analysis" to the end of the results section (section 4.4). Renamed the "Analysis and Discussion" section to "Contextual Analysis."

Comment 2: *Move the sensitivity analysis framework to Methodology; keep findings in Results.*

Response: Corrected. A new subsection 2.4 (Sensitivity Analysis Methodology) has been added to the Methodology, describing how weights and parameters were varied and justifying the selected ranges. The findings remain in Results 4.3.

Comment 3: *Only one Discussion section to avoid confusion.*

Response:** Corrected. The former "Analysis and Discussion" section has been renamed "Contextual Analysis" (section 3). No separate Discussion section remains; the Conclusion serves the synthesizing function.

Comment 4: *Subcomponent weightings (table 15 old, table 3 New) belong in Methodology, not before Results.*

Response: Corrected. Table 15 and its accompanying justification have been moved from their original location in the “initial analysis” to the Methodology section as table 3, immediately following Table 2 (dimension weightings). Initially I was skeptical of this change as the subcomponent weightings were heavily based on the contextual analysis; however, since there are signposts to the tables, I thought it worked out.

Comment 5: S*pecify software used to generate graphs in figure captions.*

Response: The caption for Figure 1 now includes: "Generated from GeographyFieldwork.com." The caption for Figure 2 now includes: "Graphic created through Canva.com."

Comment 6: *Add citations to tables that were missing them (Tables 3–10).*

Response: Source citations have been added to the captions of Tables 4–11 (formerly Tables 3–10). Each table now includes a note referencing the source literature.

Comment 7: *Line numbering is inconsistent, either fix or remove.*

Response: Line numbers have been removed from the manuscript to avoid confusion, as continuous numbering could not be maintained across all sections.

Conceptual Comments

Comment 8: *Justify why specific weighting percentages were chosen for sensitivity analysis scenarios.*

Response: A new subsection 2.3 has been added to the Methodology with the following justification for Heavy Technical (50/25/25), Heavy Economic (25/50/25), Heavy Environmental (25/25/50) and Extreme Long-term (10/10/80) now provided.

Comment 9: *Compare policy recommendations with Hong Kong's current aviation decarbonization strategies.*

Response: A new paragraph has been added to the Conclusion directly after figure 2 explicitly comparing my recommendations to existing Hong Kong policy. The paragraph notes that Hong Kong currently lacks a binding SAF mandate, relying on voluntary corporate initiatives, and contrasts this with Singapore's Changi Airport SAF target and the EU's Aviation regulation.

Abstract

Comment 10: *Revise the abstract to give hydrogen the same level of quantitative detail as SAF.*

Response: The abstract has been revised. Hydrogen now includes specific numerical values: technical readiness (4.70), superior environmental potential (9.00), and low economic feasibility (3.15).

Comment 11: *Add 1–2 concluding sentences on broader implications.*

Response: The abstract now concludes with: "These findings suggest that Hong Kong should prioritize SAF mandates and offtake incentives for the pre-2040 period while funding targeted hydrogen R&D. The context-sensitive methodology developed here can be adapted by other aviation hubs with similar land and import constraints."

Introduction

Comment 12: *Add citations to factual claims ('decarbonization of aviation is challenging').*

Response: Corrected. Citations have been added throughout the Introduction. Specific additions include: ICAO (n.d.) for decarbonization challenges; Braun et al. (2024) for operational constraints; and IATA (2025) for SAF production volume statistics.

Comment 13: Remove unnecessary subsections ('Contribution' and 'Structure of the Study') and incorporate research questions into the introduction without separate subheadings.*

Response: *Corrected. Section 1.3 and 1.4 has been removed. Its content has been integrated into section 1.2. The research questions are now presented as part of section 1.2*

Literature Review / Background

Comment 14: *Add citations to missing statements.*

Response: Missing citations have been added throughout the Literature Review, including for the claim that global SAF production remains below 0.1% of jet fuel demand (IATA, 2025).

Comment 15: *More discussion specifically on Hong Kong's aviation context.*

Response: A new paragraph has been added to the Literature Review section 1.2 discussing: (1) HKIA's passenger and cargo volume (60 million passengers, 5 million tonnes of cargo in 2025); (2) HKIA's operation as a near-100% fuel importer with no local refining capacity; (3) Hong Kong's long-haul network requiring aircraft range exceeding 12,000 km; and (4) land scarcity and urban proximity constraints on new fuel storage infrastructure. Citations include Airport Authority Hong Kong (2025) and Bauen et al. (2020).

Methodology

Comment 16: *Rewrite Methodology in past tense.*

Response: All verbs in section 2 have been converted to past tense.

Comment 17: *Add citations supporting Tables 4–11.*

Response: Corrected. Source citations have been added to the captions of all scoring rubric tables. Each table now includes a note referencing the source literature.

Comment 18: *Reformat Table 4 descriptions for clearer score-to-description mapping.*

Response: Table 4 has been reformatted with improved alignment and readability by providing a distinct qualitative scale.

Conclusion

Comment 19: *Do not introduce results tables in the Conclusion.*

Response: Upon review, no results tables were found in the Conclusion section of the original manuscript. However, to be consistent with reviewer guidance, the author has verified that all results tables (Tables 16–19) remain in the Results section (section 4). Figure 2 (Adoption Roadmap) remains in the Conclusion as a policy recommendation, which is appropriate.

RESPONSE TO REVIEWER 2

Summary: In response to Reviewer 2, revisions were made across five major categories. First, major technical terminologies including "decarbonization," "drop-in capability," and "cryogenic storage" were defined at first use to improve accessibility for interdisciplinary readers. Second, all in-text citations were corrected to follow standard academic format, with multi-author citations such as Gutiérrez-Antonio et al., 2017 revised to use "et al." and last names only throughout the manuscript. Third, citations were added for all technical claims, particularly fuel energy densities (MJ/L) in Table 16 and Rubric 1 Fourth, the justification for the 20% environmental weighting was strengthened by expanding Table 2 to reference the HKSAR Climate Action Plan 2050 and explicitly stating that this weighting reflects binding near-term constraints rather than the long-term importance of emissions reduction. Fifth, regarding the request for a comparative diagram, Table 15 (End-to-End SAF vs. Hydrogen Supply Chain Summary Comparison for Hong Kong) was referenced as providing a clear side-by-side textual comparison of infrastructure requirements at each stage.

Engagement with Literature

Comment 1: *Define technical terminologies when first introduced ('drop-in capability,' 'cryogenic storage,' 'decarbonization').*

Response: The following terms are now defined at first use: Decarbonization: "...reducing carbon dioxide emissions from aviation operations to net zero"; Drop-in capability: "...meaning the fuel can be blended with or directly replace conventional jet fuel without modifying existing aircraft engines or fuel infrastructure"; Cryogenic storage: ("...storage at extremely low temperatures below -253°C to maintain it as a liquid." Additional technical terms (Well-to-Wake, TRL, volumetric vs. gravimetric energy density, CapEx) are also defined at first use throughout the manuscript.

Comment 2: *Fix in-text citation formatting, especially multi-author citations (Gutiérrez-Antonio et al., 2017 was incorrectly written with full names).*

Response: Corrected. All in-text citations have been revised to follow standard academic format (last names only, "et al." for three or more authors after first citation). Specific corrections include: (Gutiérrez-Antonio et al., 2017); (Wang & Yu, 2024); (Bauen et al., 2020); (Schmidt et al., 2022); (Ng et al., 2021); (Prussi et al., 2019). The bibliography has also been checked for consistency.

Comment 3: *Add citations for technical claims, particularly fuel energy densities (MJ/L).*

Response: Corrected. Citations have been added for all numerical claims.

Comment 4: *Strengthen justification for 20% environmental weighting. Reference HKSAR Climate Action Plan 2050 or other policy frameworks.*

Response: Table 2 justification has been expanded. Explaining that emissions reduction is the fundamental objective of decarbonization, but for the pre-2040 horizon, a pathway that delivers deep lifecycle CO_2 reductions while remaining technically or economically infeasible cannot be deployed at scale in Hong Kong. Given that SAF already achieves 50–89% emissions reductions with existing infrastructure, the environmental dimension receives lower relative weight than technical and economic dimensions for this near-term feasibility assessment. The author notes that the weighting does not reflect the long-term importance of emissions reduction, but rather the binding constraints of the 2040 timeframe."

Other Issues

Comment 5: *Include a simple comparative diagram illustrating the drop-in infrastructure compatibility of SAF versus the specialized cryogenic storage required for Hydrogen.*

Response: The Author believes that the End-to-End SAF vs. Hydrogen Supply Chain Summary Comparison for Hong Kong (Table 15) addresses the request for a comparative diagram. The table provides a clear side-by-side textual comparison of the end-to-end supply chain, which includes the infrastructure requirements at each stage (production, primary transport, receipt and storage, blending, distribution and uplift).

Thank you for sharing the revised materials for Submission 100173, "Aviation Net-Zero Pathways: A Comparative Study of Sustainable Aviation Fuels (SAF) vs. Hydrogen in Hong Kong". After reviewing the updated manuscript and response to my feedback, I am pleased to see the author has addressed most of my methodological and formatting concerns. These improvements have significantly improved the clarity and justification behind this work, and I believe this manuscript is in good condition for publication in Convergence Journal.

I did notice a couple of minor errors that can be corrected during the copyediting process, such as some citations missing years (e.g., n.d.) and some inconsistent spacing across paragraphs.

Final Review Submission

The author has done an outstanding job and has adhered to all previous review feedback. It shows that the writer took the feedback seriously, successfully resolving every technical and academic concern raised during the review.

The manuscript's academic accuracy is significantly enhanced by the clarified terminologies and standardized academic citation formats. Also, the addition of the detailed textual matrix provided in Table 15 serves as an acceptable alternative to a supply chain diagram and solidifies the foundation of the study's framework.

Overall, this is a high-quality, original, and context-specific study that contributes meaningfully to ongoing discussions on aviation sustainability, and I recommend that it be accepted without further changes.