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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 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 technical readiness (4.70) and low economic feasibility (3.15). 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. 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.

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 and 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 (which refers to the reduction of carbon dioxide emissions from aviation operations to net zero) is challenging due to both underlying technical and operational constraints (ICAO, n.d.). 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 like 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 (H2) (Bauen et al., 2020).

1.1. 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 (Wang & Yu, 2024). 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 (IATA, 2025).

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. Hydrogen boasts a superior gravimetric energy density (critical for aircraft weight and range) but a very low volumetric density (critical for aircraft fuel tank space), requiring either cryogenic storage (storage at -253°C to maintain it as a liquid) or high-pressure storage as a gas (Bauen et al., 2020). This requires a complete change of current aircraft designs, airport fueling infrastructure, and ground handling procedures. (Gutiérrez-Antonio et al., 2017)

Hong Kong International Airport (HKIA) handled approximately 60 million passengers and 5 million tonnes of cargo throughout the 2025 calendar year, ranking among the top global cargo hubs that operate as near-100% fuel importers, with no local refining capacity (Airport Authority Hong Kong, 2025). Hong Kong's long-haul network requires aircraft with range exceeding 12,000 km, a constraint that eliminates battery-electric options with low-volumetric-energy-density fuels. Additionally, Hong Kong's land scarcity and dense urban proximity to HKIA impose strict limits on new fuel storage infrastructure, particularly for cryogenic or high-pressure systems that require safety exclusion zones (Bauen et al., 2020).

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) (A 1–9 scale used to assess the maturity of a technology); the Economic Dimension, which considers the fuel production (cost per gallon), total cost of ownership, and the capital expenditure (CapEx, upfront investment costs for physical infrastructure) 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 (Ng et al., 2021).

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 of decarbonization pathways in Hong Kong's unique realities, using a major local case study as a point of analysis (Ng et al., 2021).

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 focuses 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?

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 constructed and utilized 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 was based on three carefully constructed dimensions (Table 1) that are each assigned a weighting (Table 2) based on their perceived criticality for Hong Kong's specific context. Each dimension includes subcomponents that were also given a weight based on their perceived criticality as analysed in the contextual analysis (Table 3). The scoring for each dimension and its subcomponents was derived from a detailed assessment of literature data, case study evidence, and logical inference that ensures replicability. All subcomponent scoring and its dimension were scored from 1-10 based on specific scoring rubrics and a robust scoring protocol as illustrated in Tables 4-11.

2.1.1. Dimensional Weighting (Hong Kong Context)

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 meaning the extent to which the fuel can be blended with or directly replace conventional jet fuel without modifying existing aircraft engines or fuel infrastructure) 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 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 dependence.

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 (most common fuel used in aviation) as a percentage B. Absolute Lifecycle Emissions (g CO_2e/MJ)

Note: Descriptions adapted from Ng et al. (2021), according to Zamani et al. (2020).

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 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. This weighting does not reflect the long-term importance of emissions reduction, but rather the binding constraints of the 2040 timeframe.

Note: Justification based on (Cathay Pacific Airways Limited, 2025).

2.1.2. Subcomponent Weighting (Hong Kong Context)

Based on the contextual analysis surrounding the Cathay Pacific Case Study and Hong Kong's specific contextual priorities (section 3), the following weights were assigned to each subcomponent as illustrated in Table 3.

Table 3: Justification of dimensional subcomponent weightings.

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 Existing 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.

Note: Justification based on Cathay Pacific Airways Limited (2025).

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 from the contextual analysis were reviewed to identify the range of reported values and/or descriptions in its respective scoring rubric found in Tables 4-11.

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 4-11. 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 contextual analysis section will have mapped out the evidence to formulate and justify each score.

4. Where a dimension contains multiple sub-components, sub-component scores of range 1-10 were weighted across a 100% to give an overall dimension score of also 1-10. Weights were assigned based on the dimension's definition and criticality in Hong Kong's specific context (refer to Table 3).

5. The final scores of each fuel were calculated by multiplying each dimension-specific score by its given weight (Table 2) and summing 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 mitigate 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 Operational Readiness Scoring Criteria

Table 4: 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 the percentage reduction between volumetric and gravimetric energy density lies in a different score range, the mean score between the two is taken. Energy Density reference data from the US Department of Energy (n.d).

Table 5: Sub Component B: Compatibility With Existing Fleet

Score Range	Description
9-10	Full drop-in capability; with no modifications and certified for 100% blends

7-8	High Drop-in capability; with minor modifications for higher blends
5-6	Medium drop in Capability; Requires new fuel system components (tanks, seals, pumps)
3-4	Low drop in capability; Requires new engine or airframe design
0-2	No drop in capability; Incompatible; requires entirely new fleet

Note: Drop in capability ranges adapted from Braun et al. (2024).

Table 6: 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)

Note: TRL general level descriptions from ICAO (2024).

Rubric 2: Economic and Supply Chain Feasibility

Table 7: Subcomponent 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

Note: Fuel Cost References adapted from Wang et al. (2024).

Table 8: Subcomponent 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

Note: CapEx Cost Reference adapted from Cathay Pacific Airways Limited (2025).

Table 9: Subcomponent C: Import Logistics and Storage Feasibility

Score Range	Description
9-10	No new land required; Uses existing shipping and storage infrastructure
7-8	Small land footprint; Minor modifications to existing terminals
5-6	Moderate land use; New equipment at existing facilities
3-4	Significant land needed; Requires new facility type
0-2	Massive land and safety exclusion zones required; Requires infrastructure that does not yet exist globally

Note: Import logistical descriptions adapted from Braun et al. (2024).

Rubric 3: Environmental Impact

Table 10: Subcomponent 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%

Note: Lifecycle reduction referenced from US Department of Energy (n.d).

Table 11: Subcomponent 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. Absolute Life Cycle emissions referenced from the US Department of Energy (n.d).

2.3. Sensitivity Analysis Methodology

To test the robustness of the 2040 Feasibility Index, a sensitivity analysis was conducted by adjusting key parameters and weighting. The five weighting scenarios were selected according to various policy priorities, represented by the brackets in the form (Technical/Economic/Environmental), and which also represents the dimensional weights in % respectively: Heavy Technical (50/25/25) reflects a policymaker prioritizing operational continuity above all else; Heavy Economic (25/50/25) reflects a cost-minimization mandate; Heavy Environmental (25/25/50) reflects a decarbonization prioritized agenda despite near-term feasibility trade-offs. Individual weights not exceeding 50% ensure no weight is greater than double that of the other remaining weights and that every component is considered and not neglected. Equal Weights (33/33/33) serves as a neutral benchmark, and Extreme Long-term (10/10/80) tests the theoretical threshold at which hydrogen could outperform SAF, where technical and infrastructural factors become near negligible due to advancement, though it is not realistic for pre-2040 decisions. For the sensitivity analysis by parameter variation, several situations were determined based on situations/events that are likely to occur and make an impact on the score.

2.4. 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 give rise to more accurate qualitative-based scores (Table 12):

Table 12: 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. Contextual Analysis

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 13 outlines Cathay Pacific's recent SAF action timeline.

Table 13: 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 et al., 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	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.

	Pacific Airways Limited, 2025)		

Note: In-text citation embedded within the table.

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, Economic and Environmental Fuel Data

Table 14 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 4-11.

Table 14: Quantitative technical, economic, 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, economic, and environmental data taken from ICAO (2024), Braun et al. (2024), Wang et al. (2024), and the 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 15 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 utilized and therefore minimize 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 (Hong Kong Airport Authority, 2025).

The Hydrogen Supply Chain begins with the 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 to 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 et al., 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 et al., 2019).

Table 15: End-to-End SAF vs. Hydrogen Supply Chain Summary 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.

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.

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 in Table 16.

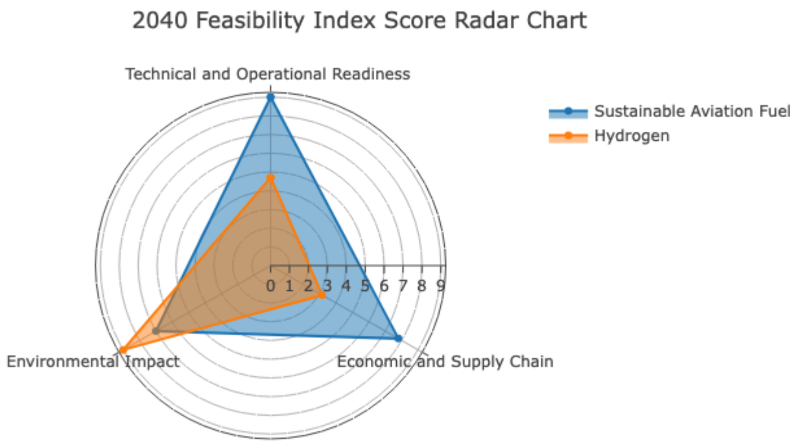

Figure 1: 2040 Feasibility Index radar chart.

Note: Generated from GeographyFieldwork.com.

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	9	Requires specialized cryogenic storage and new refueling equipment; supply infrastructure costs	3

		storage tanks		\$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 (Weighted)		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

Note: Supporting evidence can be traced back in Section 3, from the general contextual analysis to the quantitative literature data where the general citations are included as well.

4.2. 2040 Feasibility Index Scoring

A summarized 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 Scoring.

Dimension	Weight	SAF Score (0-10)	Hydrogen Score (0-10)
Technical and Operational Readiness	40%	9.00	4.70
Economic and	40%	7.80	3.15

Supply Chain			
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

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.

4.4. 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 a need for a full-scale system and infrastructure transformation that 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 results and contextual 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 et al., 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 over whether 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 et al., 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 life cycle 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 et al., 2022). These debates and ongoing tensions provide more evidence on the weight or relative importance of each of the dimensions and their subcomponents in the feasibility index.

5. Conclusion

This study evaluated SAF and hydrogen for Hong Kong's aviation sector before 2040. The Feasibility Index Scoring table (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 is 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 include 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, and regional partnerships.

Thirdly, Hong Kong's constraints and this study cannot be used to draw 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:

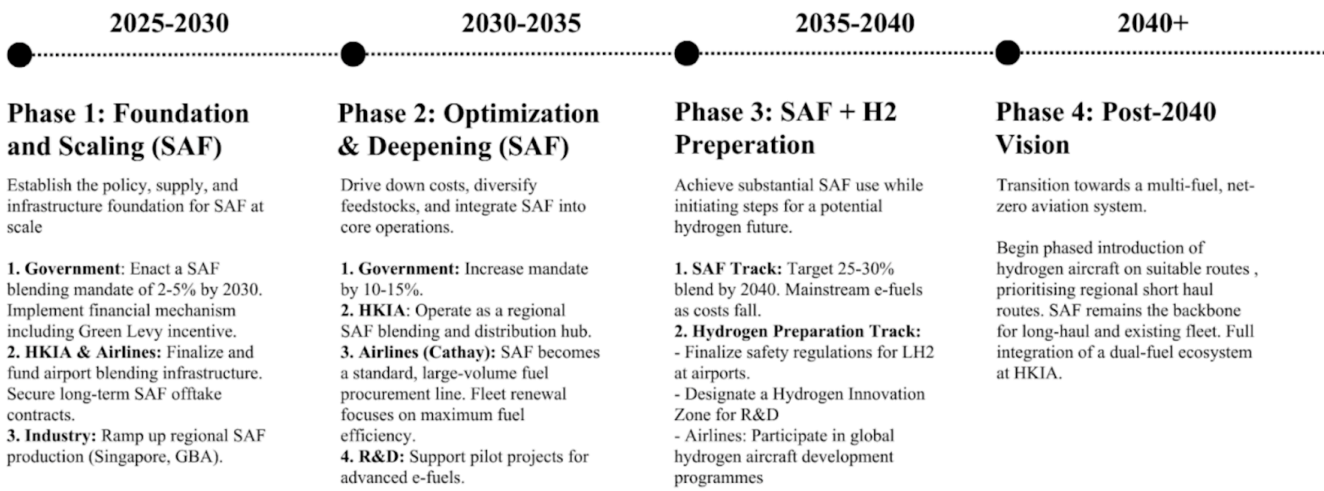

Figure 2: Proposed 2040 Adoption Roadmap.

Note: Graphic created through Canva.com.

Currently, Hong Kong lacks a binding SAF mandate or price support mechanism, relying primarily on voluntary corporate initiatives such as Cathay Pacific's SAF programme. The HKSAR government's Climate Action Plan 2050 mentions sustainable aviation only briefly, with no specific SAF targets or funding (Cathay Pacific, 2024). This study's recommendation of a mandated SAF blend and a contracted offtake guarantee creates demand certainty that can unlock regional SAF production investment. Unlike the existing strategy, which places decarbonization responsibility largely on individual airlines, the proposed approach treats SAF as a collective goal among all parties responsible, requiring government coordination, which is similar to policies in Singapore and the European Union.

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 4-11) 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.

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AI Tools Statement

The use of large language model tools (LLMs) was only for minor editing tasks, which included grammar correction, punctuation, and formatting consistency.

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Mentor Contribution Statement

Dr. Minnie Yu's contributions were advisory and supervisory, which included reviewing the manuscript for logical consistency, formatting standards, and alignment with the stated research objective.