Do airlines adopt sustainable aviation fuels under modal competition?

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35 researchers based in Saclay and Grenoble, France

Our Research Themes

Low-carbon production and storage technologies	Key resources of the energy transition	Future energy demand and consumption patterns	Regulation and market design

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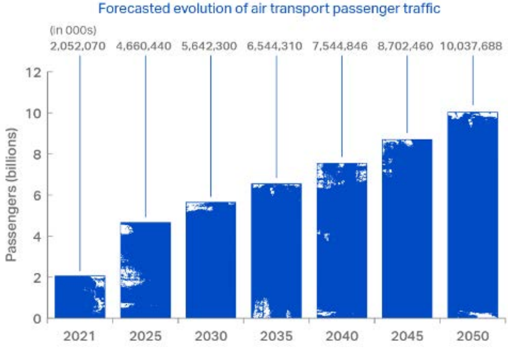
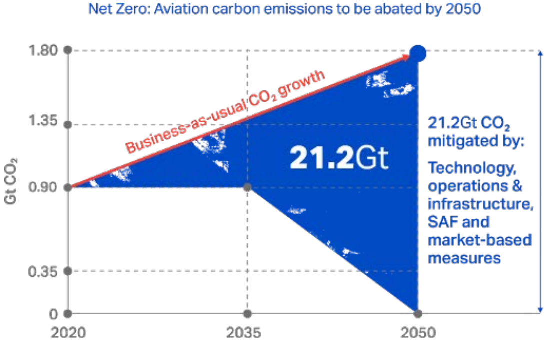
- Today, air transportation accounts only for 3% of global energy-related CO_2 emissions.



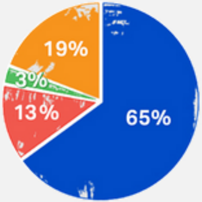


- However, its contribution to global CO_2 emissions will grow.

A four-pillar strategy to reach Net Zero Emissions by 2050

Our strategy towards net zero

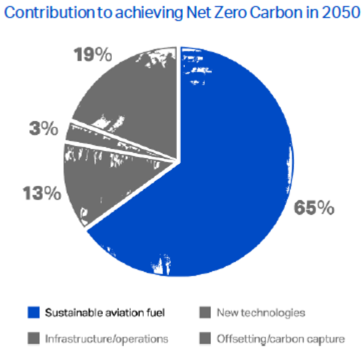
Achieving net zero by 2050 will require a combination of maximum elimination of emissions at the source, offsetting and carbon capture technologies.



- **65%** Sustainable Aviation Fuel (SAF)
- **13%** New technology, electric and hydrogen
- **3%** Infrastructure and operational efficiencies
- **19%** Offsets and carbon capture

Sustainable Aviation Fuels (SAFs)

Main solution to decarbonize air transportation.



- “Drop-in”: same physical and chemical properties as fossil kerosene thus can be safely used (blended) with the current aircraft/fuel infrastructure.
- Different production pathways and feedstocks.
- Liquid fuels with up to 99% less CO_2 emissions than fossil kerosene.
- 2024 production capacity represents 0.53% of global aviation’s fuel demand.

Table: Comparison of production pathways for SAFs.

Kerosene type	Bio-kerosene	E-kerosene
Feedstock	Biowaste*[1] (oils, municipal, crops)	Hydrogen and CO_2
Availability	Very constrained to constrained	Least constrained
Strong demand from	Other transportation modes, construction, and heating	Steel and fertilizer production
Emissions savings	74–94%	89–99%
Readiness (IEA scale)	Up to 6/11 – commercially available to proven to be deployed	Up to 5/11 – prototype
Extra Cost	1181 – 2921 €/ton	6086 – 8671€/ton

Source: Authors' elaboration using information from ICCT (2022) and EASA (2025).

- Bio-kerosene less costly than e-kerosene but
  - Limited feed-stock.
  - More carbon intensive.

[1] *List of advanced biofuels in Annex IX part A RED.

Replacing 2019 French aviation demand (91TWh) with SAFs: 110 TWh low-carbon H2 and 142 TWh biomass (Merceron et al., 2024).

- Total electricity demand higher than what RTE considers possible in 2050.
- 30% of biomass is used for air transport.

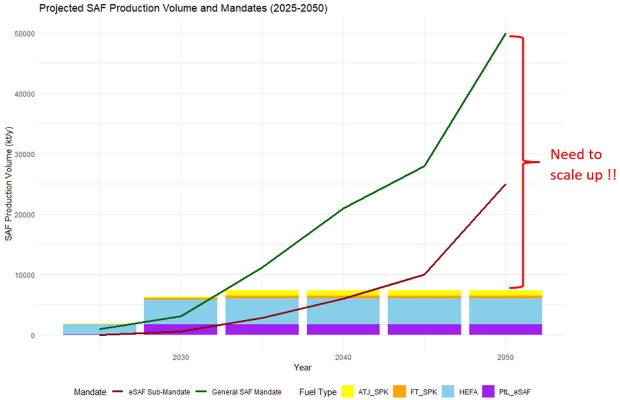
Domestic supply will not be enough to cover demand: imports.

- Sustainability concerns: fuel deforestation in third countries difficult to monitor (Grinsven et al., 2020).

What about other non CO_2 emissions such as NOx, PM and contrails?

RefuelEU Aviation

% of SAFs that fuel producers must supply to EU airports flights.



Source: Transport & Environment (2024), ICCT (2024) and EC (2024).

- Starting 2025: monitoring and penalties for no complying producers and airlines.
- Until 2035: book and claim across airports.

Other Policies

EU-ETS

- Polluter-pays quantity based instrument, aviation included since 2012 (85% allowances were free of charge).
- Changes following the “Fit for 55” legislative package:
  - Progressively reduce the number of freely allocated carbon allowances to 0 by 2026.
  - Progressively increase the annual target for emissions decline in the cap from 2.2% to 4.2% (intra EEA+UK+Swiz flights).
  - 20 millions allowances (1.7 billion EU) set aside to finance the price premium paid by SAF using airlines.

Different domestic taxes possible but so far none has directly targeted the carbon content of kerosene (Art 24 Chicago Convention).

Decentralized measures

Vinci (French airporst and Gatwick) as well as Swedavia airports have introduced since 2021 a CO2 impact-based modulation of landing fees.

Article 15 of the Chicago Convention: Non-discrimination.

- Art 3 of EU's Airport Charges Directive: National regulators.
- Costlier SAFs have the lowest CO2 content + limited production capacity: asymmetric useof SAFs.

Why would a regulator authorized such a modulation?

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Economic Model

What could be the impact of SAFs?

- SAFs are more expensive than kerosene: Higher fares for consumers.
- May attract “environmentally conscious passengers”.

In some markets passengers have outside options.

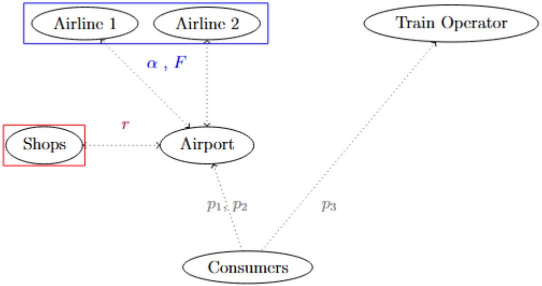
- Short to medium-haul markets: rail competition (Dobruszkes et al., 2014; Friederiszick et al., 2009; Givoni et al., 2012; Wang et al., 2021).

Effect on other transportation modes: Global picture of passengers’ choices.

The market

Airports are 2-sided platforms: aeronautical and commercial revenues (Flores-Fillol et al., 2018; Gillen, 2011; Malavolti, 2016; Malavolti and Marty, 2019).

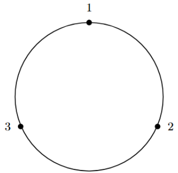
Figure: Organization of the market



E.g. Brussels-London (British Airways, Brussels Airlines, and Eurostar), and Toulouse-Paris (Air France, Easyjet, and SNCF.)

Supply-side

- $k \in \{1, 2, 3\}$ firms symmetrically located along a circle of unit length at $\frac{k-1}{3}$ (Salop, 1979).



- Two-part aeronautical charge: per unit α & fixed lump-sum price F.

Aircraft landing fees excluding noise level coefficient	
Price per landing (€ excluding VAT)	304.38 + 4.251 x t where t equals MTOW in tons

Source: Paris Airports (2022)

- Shop fixed rent r to the airport and revenues depend on PAX.

$$\gamma(D_1 + D_2) \quad \text{with} \quad 0 \leq \gamma \leq 1$$

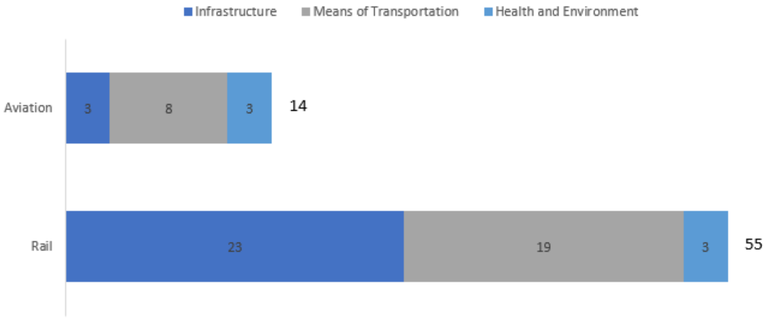
- The airport has unit cost f per PAX.
- Train operator has unit cost c_T per PAX.

Supply-Side

Assumption

$c_T - \alpha - f > 0$ *rail costs per PAX/km are larger than air transport.*

- Rail sustainable but costly: PAX/km costs 3 times larger.

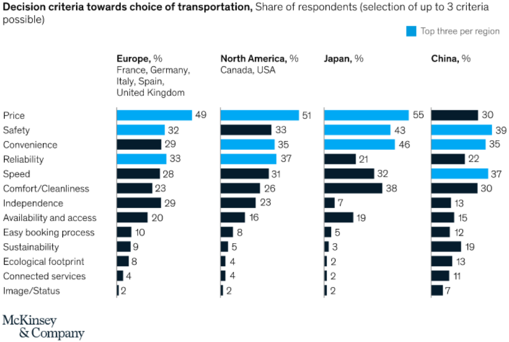


Source: OFS (2022)

Demand-Side

Net utility of passenger travelling with firm k:

$$U_k = \beta_k - p_k - t\left|\frac{k-1}{3} - x\right|$$



Source: McKinsey & Company (2022)

Timing

The timing of the game is as follows:

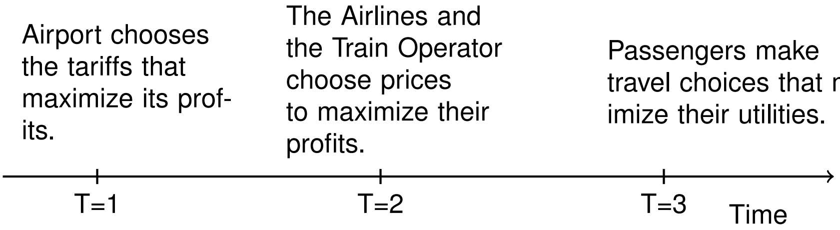
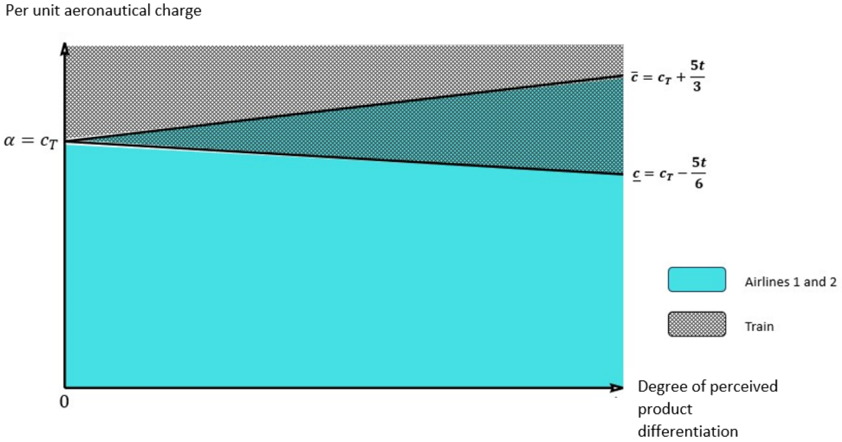


Figure: Decision Timeline

Benchmark: Firms active in the market



Benchmark: Airport program

$$\underset{\alpha,r,F}{Max} \quad \pi_A = D_A(\alpha)(\alpha - f) + 2F + rS(D_A(\alpha), r)$$

$$\text{s.t.} \quad D_1(\alpha) + D_2(\alpha) = D_A(\alpha)$$

$$D_1(\alpha)(p_1 - \alpha) \geq F \qquad \text{(Airline 1 PC)}$$

$$D_2(\alpha)(p_2 - \alpha) \geq F \qquad \text{(Airline 2 PC)}$$

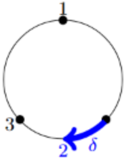
Regarding modal competition, we find that airport tariffs increase with the cost of rail.

$$\frac{\partial F}{\partial c_T} > 0 \quad \text{and} \quad \frac{\partial r}{\partial c_T} > 0$$

$$\frac{\partial \alpha}{\partial c_T} > 0 \quad \text{if} \quad t > \frac{\gamma^2}{3} > \hat{t}$$

A transition phase

Airline 2 can use a cleaner SAF at a higher cost δc_{SAF} (e.g. bio to e-fuel).



- This reduces its carbon emissions level: product closer to the one of rail.
- Differentiates its product further from airline 1.

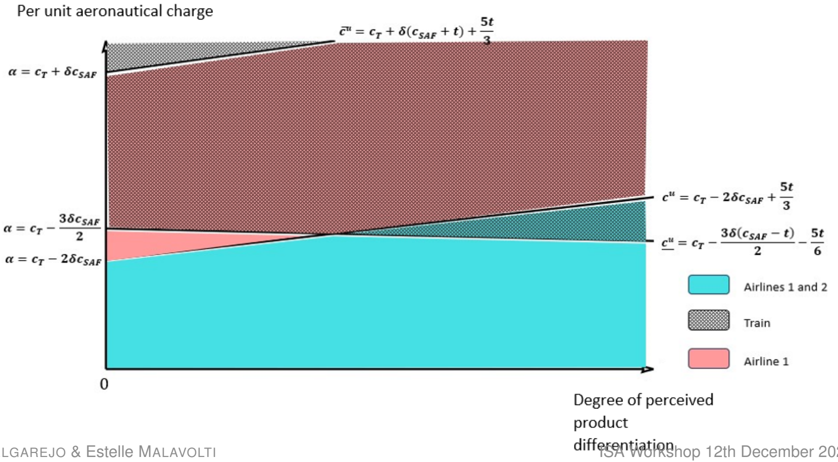
The other firms' locations remain unchanged in the short term.[2]

This adds $T = 0$ where airline 2 decides whether to use e-fuels or not.

[2] E.g. changing departure times could conflict with other train lines or flights, e-fuel availability limited.

Current regulation: non-discriminatory aeronautical charges

- Airline 1 is active in the market for larger values of α.
- Airline 2 may only be active when α is such that there is no modal competition.



The airport cannot discriminate: set the same F for both airlines.

Table: Airlines' payoffs under uniform tariffs

Case	1 (F high)	2 (F low)
Airline 1	$\pi_1 = 0$	$\pi_1 > 0$
Airline 2	$\pi_2 < 0$	$\pi_2 = 0$

In Case 1, the passengers who addressed their demand to airline 2 can:

- Stop traveling (Case 1.a.): the market is uncovered.
- Buy from another firm (Case 1.b.): the market remains covered.

Here β high passengers' reservation price is such that they always travel.
The airport is better-off if F high such that only airline 1 operates rather than both airlines.

Differentiated aeronautical charges

$$\underset{\alpha_1,\alpha_2,r,F_1,F_2}{Max}\pi_A = D_1(\alpha_1,\alpha_2)(p_1(\alpha_1,\alpha_2) - f) + D_2(\alpha_1,\alpha_2)(p_2(\alpha_1,\alpha_2) - f)$$

$$+F_1 + F_2 + rS(D_A(\alpha_1,\alpha_2), r) \qquad (2)$$

$$\text{s.t.} \quad D_1(\alpha_1,\alpha_2)(p_1(\alpha_1,\alpha_2) - \alpha_1 - c) \geq F_1 \qquad \text{(PC1)}$$

$$D_2(\alpha_1,\alpha_))(p_2(\alpha_1,\alpha_2) - \alpha_2 - (1-\delta)c - \delta c_{SAF}) \geq F_2 \qquad \text{(PC2)}$$

Proposition

There exists a tariff structure such that airline 2 is indifferent between using e-fuels or not.

If $t > c_{SAF}$, the market share of air transportation is larger than in the benchmark case.

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Concluding Remarks

Transition phase economic analysis: asymmetric use of SAFs as need to scale up production capacity.

- We studied an airline's incentives to use cleaner SAFs in the context of modal competition
- With non-discriminatory aeronautical charges, no incentive to use cleaner SAFs if a rival airline does not do the same.
- If a regulator does authorize discriminatory aeronautical charges, asymmetric use of SAFs is possible (multiple equilibrium).
- However this can reduce rail transport's market share $\rightarrow$ What is the optimal transport-mix?

SAFs are part of the solution to decrease aviation's GHG emissions:

- Lower carbon footprint than current jet fossil fuel.
- Some production pathways have a high TRL (unlike disruptive technologies).
- Increasing support across the globe: policies supporting SAFs.

... but face a certain number of limitations:

- Feedstock availability: arbitrage between end-sectors.
  - Different SAFs will co-exist.
  - Rail cooperation or competition air travel.

SAFs deployment requires cooperation among the players within the supply chain but also outside.

⟶ The aviation sector needs to take into account the challenges of other end-sectors.

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