Aligning aviation with the Paris Agreement: What’s possible?

Dan Rutherford, Ph.D.
7 July 2022
ICCT webinar
Outline

• Background
• Study design
• Results
• Conclusions and policy implications
• Questions and discussion
Background
Aviation has a fossil fuel problem

Kevin Pluck
@kevpluck

Me flying to New Zealand from the UK with all my luggage.

https://twitter.com/kevpluck/status/1368788614709010432?s=20&t=Tqn8Wm_TSwNIMq3IrjZbA
Postcards from COP 21 (2015)

We are the elephants in the room

No deal without shipping & aviation emissions

IMO leapfrogs ahead in 2018

@guilanpour

@rogeradamson
Aviation attempts a comeback

• Momentum is building for a “Paris moment” for aviation in Montreal this fall.

• A global aviation CO₂ target will unlock new investments and national policies for clean aircraft/fuels.

• Risks:
  ▪ Questions about the achievability of net-zero pathways from some ICAO member states
  ▪ Risk of overshoot, missing Paris targets even if 2050 net-zero is achieved
  ▪ Aspirational targets not followed up by concrete measures

• ICCT’s Vision 2050 aviation roadmap aims to mitigate these risks.

<table>
<thead>
<tr>
<th>Date</th>
<th>Progress</th>
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<tbody>
<tr>
<td>Feb 2021</td>
<td>Europe’s Destination 2050 net-zero roadmap</td>
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<tr>
<td>Mar 2021</td>
<td>Airlines for America commits to net-zero</td>
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<td>Oct 2021</td>
<td>IATA adopts a global aviation industry net-zero goal</td>
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<tr>
<td>Nov 2021</td>
<td>COP 26 International Aviation Climate Ambition Coalition launched</td>
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<tr>
<td>Mar 2022</td>
<td>ICAO concludes that deep GHG cuts are feasible</td>
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<tr>
<td><strong>June 2022</strong></td>
<td><strong>Vision 2050: Aligning Aviation with the Paris Agreement released</strong></td>
</tr>
<tr>
<td>July 2022</td>
<td>ICAO High Level Climate Meeting</td>
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<td>Sept/Oct 2022</td>
<td>ICAO 41st Assembly</td>
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</table>
Study Design
ICCT Vision 2050

- ICCT published Vision 2050 in September 2020
  - Strategy to decarbonize global transport by mid-century
  - Global aviation CO₂ could be cut to 300 Mt in 2050 from aircraft technology improvements, alternative fuels

- What is new in this report?
  - New technologies, notably hydrogen, and aggressive mitigation strategies like modal shift and formation flying
  - Partially integrated model (PACE) estimating fuel and carbon prices plus demand response
  - Comparison to other public decarbonization roadmaps
Research question

To what extent can various measures reduce cumulative CO₂ emissions from global aviation in-line with 1.5°C, 1.75°C, and 2°C targets?
Scenarios

S0: Reference (business-as-usual)

S1: Action

S2: Transformation

S3: Breakthrough

Increasing level of ambition
Key mitigation wedges / technology assumptions

Our three modeling scenarios consider 6 important parameters:

- Aircraft technology
- Operations
- Sustainable aviation fuels (SAFs)
- Zero emission planes (ZEPs)
- Traffic
- Economic incentives

In-depth information on each of the modeling inputs can be found in the study on our website.
Projection of Aviation Carbon Emissions (PACE) model

1. Traffic
   - Base/previous year RPK, traffic CAGR
   - % RPK shifted to rail

2. Fleet Turnover
   - Stock, fleet CAGR, survival curves, ZEP sales share
   - Revised traffic (RPK)

3. Activity Segmentation
   - Fleet (incl. propulsion)

4. Energy Efficiency
   - RPK (by segment)

5. Fuels
   - SAF supply (EJ), feedstock share (%), fuel emissions intensity (CO2/MJ)

6. Emissions
   - MJ, CO2/MJ

7. Demand Response
   - CO2
   - % RPK reduction

Loop into next analysis year

SAF supply, SAF cost -> implied fuel price increase, fare and price elasticities

Base efficiency (MJ/RPK), efficiency improvement factors (new aircraft & operational)
Better characterizing aviation fuel efficiency

Decomposed fuel efficiency into three components

- Aircraft fuel burn
- Payload efficiency
- Traffic efficiency

Key drivers of US airline annual fuel efficiency improvements, 2005 to 2019

Operational Efficiency

Aircraft fuel burn 0.4%
Payload efficiency 1.0%
Traffic efficiency 0.1%

https://theicct.org/aviation-fuel-efficiency-jan22/
Modeling of future fuel costs

To ~2040

Jet A to SAF cross-subsidy via LCFS, SAF mandate, or ETS with revenue recycling

2040+

Fuel, carbon tax, or ETS set at marginal abatement costs.
Results
Jet A fuel share

**Action:** Jet A share of aviation energy almost halves by 2050

**Transformation:** share drops more than 75% as synthetic fuels come to dominate after 2040

**Breakthrough:** Jet A demand peaks in 2025, zeros out before mid-century

Energy demand – Breakthrough scenario

2019: nearly 12.5 EJ of energy was consumed, nearly all Jet A

2025: peak Jet A demand

2030: 14.25 EJ demand, 85% Jet A

2038: Alt fuels overtake Jet A

2050: 16.3 EJ demand, 78% SAFs, 22% H₂

Estimated fuel prices

Action and Transformation: average fuel cost is 60-65% higher than Jet A in 2050

Breakthrough: average fuel cost is 70% higher than Jet A in 2050

Larger SAF volumes and greater use of direct air capture lead to higher fuel costs in Breakthrough

https://theicct.org/publication/global Aviation vision 2050 align aviation paris jun22
Estimated fuel prices

Action and Transformation: average fuel cost is 60-65% higher than Jet A in 2050

Breakthrough: average fuel cost is 70% higher than Jet A in 2050

Larger SAF volumes and greater use of direct air capture lead to higher fuel costs in Breakthrough

Estimated carbon prices

**Action**
- 2030: $15 / tonne
- 2050: $300 / tonne (peak)

**Transformation**
- 2030: $40 / tonne
- 2042 (peak)
- 2050: $200 / tonne

**Breakthrough**
- 2030: $80 / tonne
- 2037 (peak)
- 2050: $225 / tonne

Estimated carbon prices

**Action**
- 2030: $15 / tonne
- 2050: $300 / tonne (peak)

**Transformation**
- 2030: $40 / tonne
- 2042 (peak)
- 2050: $200 / tonne

**Breakthrough**
- 2030: $80 / tonne
- 2037 (peak)
- 2050: $225 / tonne

Impact of fuel prices on passenger traffic

2050 passenger traffic ▼ 7%

2019-2050 cumulative passenger traffic ▼ 2.5%

Energy and carbon intensities – passengers

Energy intensity (MJ/RPK)

Carbon intensity (g CO₂e/MJ)

Notes on cumulative emissions

- CO₂ emissions in this analysis are well-to-wake (WTW)
- Non-CO₂ climate impacts are not included
- IPCC global climate budget with temperature targets at 67% probability used
- Aviation’s share of global carbon budget maintained at 2.9% fuel use (2.4%) and upstream fuel production (0.5%)
Global cumulative CO$_2$ emissions and mitigation

Aviation’s share of global carbon budget maintained at 2.9%
Global CO$_2$ emissions by scenario and traffic assumptions

Global aviation CO$_2$ emissions by scenario and traffic forecast, 2020-2050

(a) Annual

(b) Cumulative

The solid line depicts the central traffic forecast; the shaded area depicts the range between the low and high forecasts.
Here’s what it would take to create synthetic fuels…

Estimated electricity used to generate aviation fuels:
2020: 0 EJ
2050: 25 EJ

Additional 12.5 EJ energy needed to generate hydrogen and carbon for synthetic aviation fuels
... and don’t forget about traffic growth.

Cumulative global aviation CO$_2$ emissions by scenario and traffic forecast, 2019-2050

https://theicct.org/global-aviation-race-jun22/
Conclusions and Policy Implications
Conclusions and policy implications

• Aligning aviation with the Paris Agreement’s Below 2ºC aspiration is possible but requires significant ambition and investment.

• Most ambitious scenarios are consistent with 1.75ºC future where aviation doesn’t increase its share of global carbon budget.

• To get to 1.5ºC, direct atmospheric removals and/or significant direct curbs to traffic growth would be needed.

• CO₂ emissions from aircraft need to peak by 2030 at latest, and as soon as 2025, to align aviation with the Paris Agreement.

• Cumulative targets, rather than an absolute emissions goal for a given year, are recommended.
Thanks to the Brandon Graver, Sola Zheng, Jayant Mukhopadhaya, Erik Prong, Gary Gardner, and Zoë Bowen Smith!

Questions?
Enter into the chat or email dan@theicct.org
Traffic forecasts – passenger

Revenue passenger kilometers (billions)

Historical Data
Low Forecast
Central Forecast
High Forecast
## Traffic forecasts

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Central</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passenger:</strong></td>
<td>+2.4%</td>
<td>+3.0%</td>
<td>+3.7%</td>
</tr>
<tr>
<td><strong>Freight:</strong></td>
<td>+2.6%</td>
<td>+3.5%</td>
<td>+4.2%</td>
</tr>
</tbody>
</table>

per annum growth rates, RPK and RTK, 2019-2050
## Aircraft technical efficiency

<table>
<thead>
<tr>
<th>Scenario 1: Action</th>
<th>Scenario 2: Transformation</th>
<th>Scenario 3: Breakthrough</th>
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</thead>
<tbody>
<tr>
<td><strong>Passenger:</strong></td>
<td></td>
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</tr>
<tr>
<td>-1.08% 2019-2034</td>
<td>-1.08% 2019-2034</td>
<td>-1.08% 2019-2034</td>
</tr>
<tr>
<td>-1.15% 2035-2050</td>
<td>-1.83% 2035-2050</td>
<td>-2.16% 2035-2050</td>
</tr>
<tr>
<td><strong>Freighter:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1.00% 2019-2050</td>
<td>-1.25% 2019-2050</td>
<td>-1.50% 2019-2050</td>
</tr>
</tbody>
</table>

per annum energy reduction rates
MJ/RPK for passenger aircraft
MJ/RTK for freighter aircraft
Payload efficiency reflects how much of the maximum payload is being carried on each flight. The closer a passenger flight is to full capacity, the better its payload efficiency.

<table>
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<th>Scenario 1: Action</th>
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<th>Scenario 3: Breakthrough</th>
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<tbody>
<tr>
<td>-0.20%</td>
<td>-0.35%</td>
<td>-0.50%</td>
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</table>

per annum energy reduction rates, MJ/RPK, 2019-2050
## Aircraft traffic efficiency

<table>
<thead>
<tr>
<th>Scenario 1: Action</th>
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<th>Scenario 3: Breakthrough</th>
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</thead>
<tbody>
<tr>
<td>No formation flying</td>
<td>Formation flying:</td>
<td></td>
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<tr>
<td></td>
<td>-0.1% MJ/RPK per annum, 2019-2050</td>
<td></td>
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<tr>
<td></td>
<td>-0.2% in 2030</td>
<td>-0.7% in 2040</td>
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<td>-1.9% in 2050</td>
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</table>

per annum energy reduction rates
### Zero emission planes

<table>
<thead>
<tr>
<th>Scenario 1: Action</th>
<th>Scenario 2: Transformation</th>
<th>Scenario 3: Breakthrough</th>
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</thead>
<tbody>
<tr>
<td>Electric: None</td>
<td>Electric:</td>
<td>Hydrogen:</td>
</tr>
<tr>
<td></td>
<td>2030 EIS for commuter aircraft</td>
<td>2035 EIS for regional &amp; narrowbody</td>
</tr>
<tr>
<td></td>
<td>50% of new aircraft, 2030</td>
<td>12.5% of new aircraft, 2030</td>
</tr>
<tr>
<td></td>
<td>100% of new aircraft, 2050</td>
<td>25% of new aircraft, 2050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.5% of new aircraft, 2030</td>
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<tr>
<td></td>
<td></td>
<td>50% of new aircraft, 2050</td>
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</tbody>
</table>
## Fuels

### Scenario 1: Action
- 12 Mt biofuels, 2030 (3% of fuel use)
- 100 Mt biofuels, 2050
- 120 Mt e-fuels, 2050 (50% of fuel use)

### Scenario 2: Transformation
- 23 Mt biofuels, 2030
- 2 Mt e-fuels, 2050 (8% of fuel use)
- 100 Mt biofuels, 2050
- 150 Mt e-fuels, 2050 (80% of fuel use)

### Scenario 3: Breakthrough
- 46 Mt biofuels, 2030
- 5 Mt e-fuels, 2030 (17% of fuel use)
- 100 Mt biofuels, 2050
- 215 Mt e-fuels, 2050 (100% of fuel use)
## Fuels (2/3)

<table>
<thead>
<tr>
<th>Scenario 1: Action</th>
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<th>Scenario 3: Breakthrough</th>
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</thead>
<tbody>
<tr>
<td>e-fuel carbon (point / DAC)</td>
<td>e-fuel carbon (point / DAC)</td>
<td>e-fuel carbon (point / DAC)</td>
</tr>
<tr>
<td>2030: 100% / 0%</td>
<td>2030: 67% / 33%</td>
<td>2030: 67% / 33%</td>
</tr>
<tr>
<td>2040: 67% / 33%</td>
<td>2040: 58% / 42%</td>
<td>2040: 46% / 54%</td>
</tr>
<tr>
<td>2050: 67% / 33%</td>
<td>2050: 50% / 50%</td>
<td>2050: 25% / 75%</td>
</tr>
<tr>
<td>No hydrogen aircraft</td>
<td>Hydrogen (blue/green)</td>
<td>Hydrogen (blue/green)</td>
</tr>
<tr>
<td>2030: 75% / 25%</td>
<td>2030: 50% / 50%</td>
<td>2030: 50% / 50%</td>
</tr>
<tr>
<td>2040: 50% / 50%</td>
<td>2040: 33% / 67%</td>
<td>2040: 33% / 67%</td>
</tr>
<tr>
<td>2050: 0% / 100%</td>
<td>2050: 0% / 100%</td>
<td>2050: 0% / 100%</td>
</tr>
</tbody>
</table>

No hydrogen aircraft

Hydrogen (blue/green)

2030: 75% / 25%
2040: 50% / 50%
2050: 0% / 100%
### Fuels (3/3)

<table>
<thead>
<tr>
<th>Scenario 1: Action</th>
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<th>Scenario 3: Breakthrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average costs (biofuel / e-fuels, $/L)</td>
<td>Average costs (biofuel / e-fuels, $/L)</td>
<td>Average costs (biofuel / e-fuels, $/L)</td>
</tr>
<tr>
<td>2030: 1.81 / 1.79</td>
<td>2030: 1.81 / 2.00</td>
<td>2030: 1.81 / 2.00</td>
</tr>
<tr>
<td>2040: 1.98 / 1.59</td>
<td>2040: 1.98 / 1.65</td>
<td>2040: 1.36 / 1.72</td>
</tr>
<tr>
<td>2050: 2.03 / 1.26</td>
<td>2050: 1.40 / 1.36</td>
<td>2050: 1.40 / 1.52</td>
</tr>
</tbody>
</table>
## Modal shift

<table>
<thead>
<tr>
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<th>Scenario 3: Breakthrough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic and intra-European routes of less than 750 km</td>
<td>Number of passengers greater than 100,000 annually</td>
<td>20% traffic shift from air to rail, starting in 2030</td>
</tr>
</tbody>
</table>

20% traffic shift from air to rail, starting in 2030.
As part of this work, we established a panel of experts to review our assumptions and inputs related to carbon reductions.

- Boeing: Bryan Yutko
- CE Delft: Stefan Grebe
- EasyJet plc: Lahiru Ranasinghe
- International Energy Agency: Praveen Bains
- NATS: Jarlath Malloy
- SkyNRG: David Dweck and Amy Malaki
- SVD Consulting: Susan van Dyk
- United Airlines: Aaron Robinson
## Modeling Comparison: ICCT vs ATAG

<table>
<thead>
<tr>
<th></th>
<th>This analysis: Breakthrough(^a)</th>
<th>Waypoint 2050: Scenario 1(^b)</th>
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<tbody>
<tr>
<td><strong>2050 annual emissions</strong></td>
<td>70 Mt</td>
<td>With offsets: 0 Mt</td>
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<tr>
<td></td>
<td></td>
<td>Without offsets: 140 Mt</td>
</tr>
<tr>
<td><strong>2050 energy use</strong></td>
<td>16 EJ</td>
<td>25 EJ</td>
</tr>
<tr>
<td><strong>Total reduction from Baseline, 2050 annual emissions</strong></td>
<td>97%</td>
<td>With offsets: 100%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without offsets: 93%</td>
</tr>
<tr>
<td><strong>2020-2050 cumulative emissions</strong></td>
<td>22.7 Gt</td>
<td>With offsets: 19.6 Gt</td>
</tr>
<tr>
<td><strong>Cumulative emissions temperature pathway</strong></td>
<td>1.75°C</td>
<td>With offsets: 1.78°C (ICCT estimate)</td>
</tr>
<tr>
<td><strong>Share of emission reductions, 2050</strong></td>
<td>Technology: 18% Operations: 17% Fuels: 62% Demand change: 4%</td>
<td>Technology: 22% Operations: 10% Fuels: 61% Offsets: 7%</td>
</tr>
<tr>
<td><strong>Zero-emission plane energy share, 2050</strong></td>
<td>Hydrogen: 22% Electricity: 0.01%</td>
<td>Hydrogen: 20% Electricity: 2%</td>
</tr>
</tbody>
</table>

\(^a\) WTW basis. \(^b\) Modified TTW basis.