Energy Transition in global Aviation

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Motivation

- The global aviation sector is responsible for approx. 2.5% of global CO$_2$ Emission
- In TIAM the aviation sector is modelled via energy input and output
  - Demand is projected in PJ
  - a-km and p-km not differentiated
  - Generic airplane process

→ different airplane types (kerosene, hydrogen and e-fuels)
→ Demand in Bp-km
→ Interested in hydrogen and e-fuel demand
• 78% passenger and 22% freight transport.

• Fuel demand decreased: 2.8 MJ/p-km in 1990 to 1.1 MJ/p-km in 2021.

• 6 l/100 km gasoline/diesel car has 2.11 MJ/v-km -> 2 person 1.05 MJ/p-km

• 1100 km per person a year on global average

• 2000 – 2019: 5.68% increase p.a.

• 2019 – 2020: 66% drop in demand
Global Fleet

Fleet size of different regions 2023

- North America
- Western Europe
- Asia Pacific
- China
- Latin America
- Middle East
- Africa
- Eastern Europe
- India

Distribution of the global fleet 2023

- Narrowbody 60%
- Widebody 20%
- Regional Jet 12%
- Other 8%

Planes in stock 2023

- A321-200
- 737-700
- 737-300
- A319-100
- 737-800
- A320-200

- Approx. 28000 airplanes in global fleet
- Highly populated countries/regions (e.g. India & Africa) with small fleet
- Airbus and Boeing mostly share the market for passenger aviation
### Emission distribution in the global aviation

**Range in km up to**

<table>
<thead>
<tr>
<th>PAX</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4500</th>
<th>7000</th>
<th>8500</th>
<th>10000</th>
<th>&gt;10000</th>
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<tr>
<td><strong>Commuter &lt;19</strong></td>
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<td><img src="#" alt="Green" /></td>
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<td>&lt;1%</td>
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<tr>
<td><strong>Regional 20-80</strong></td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td>3%</td>
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<tr>
<td><strong>Short-range 81-165</strong></td>
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<td><img src="#" alt="Orange" /></td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
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<td><img src="#" alt="Green" /></td>
<td>24%</td>
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<tr>
<td><strong>Medium-range 166-250</strong></td>
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<td><img src="#" alt="Orange" /></td>
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<td><img src="#" alt="Orange" /></td>
<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Green" /></td>
<td>43%</td>
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<tr>
<td><strong>Long-range &gt;250</strong></td>
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<td><img src="#" alt="Green" /></td>
<td><img src="#" alt="Orange" /></td>
<td><img src="#" alt="Orange" /></td>
<td><img src="#" alt="Orange" /></td>
<td><img src="#" alt="Orange" /></td>
<td>30%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4%</td>
<td>13%</td>
<td>25%</td>
<td>14%</td>
<td>11%</td>
<td>12%</td>
<td>7%</td>
<td>7%</td>
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</tbody>
</table>

**CO₂ emissions** | **Global Fleet** |
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>&lt;1%</td>
<td>4%</td>
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<tr>
<td>3%</td>
<td>13%</td>
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<tr>
<td>24%</td>
<td>53%</td>
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<tr>
<td>43%</td>
<td>18%</td>
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<tr>
<td>30%</td>
<td>12%</td>
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Cost and fuel assumption

- Hydrogen planes are overall more expensive in terms of invest cost
- Starting 25% for small range and up to 45% for large range
- Small range airplanes can be 4% more efficient compared to the kerosene technology
- For large range up to 40% more fuel consumption is possible
Energy carrier in global aviation

Process chain for sustainable aviation fuels

- Electricity: 100%
- Hydrogen: 60% - 70%
- e-fuel: Best case: 44%

Direct air capture or biomass

CO₂

Biomass

CHP: heat and electricity

Optional
Results
Aviation Model

Based on TIAM properties

- 16 regions
- Time horizon: 2019-2100
- 12 Time-slices
- perfect foresight
## Results

### Scenario description

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Demand</th>
<th>Efficiency increase</th>
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</thead>
<tbody>
<tr>
<td>BAU</td>
<td>No climate policy</td>
<td></td>
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</tr>
<tr>
<td>CO2 Tax</td>
<td>Climate policy via CO\textsubscript{2} tax</td>
<td>1% rise in demand p.a.</td>
<td>20% in 2050</td>
</tr>
<tr>
<td></td>
<td>Hydrogen and e-fuels are available starting 2030</td>
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</tr>
<tr>
<td>CO2 Tax 2</td>
<td>Climate policy via CO\textsubscript{2} tax</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen is not considered. E-fuels available starting 2030</td>
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</tbody>
</table>
Results

CO₂ Emissions related to global aviation

- Net Zero 2050 with CO₂ Tax
- In BAU the CO₂ emission rise to over 1.2 Gt
- e-fuels need an adjusted price path
Results

Global cumulative CO$_2$ Emissions

- Cumulative CO$_2$ of BAU 80 Gt in 2100.
- 420 Gt CO$_2$ Emission available according to the IPCC
- 19% of CO$_2$ Budget for BAU 4,2% for CO2 Tax 2 and 3,6% for CO2 Tax
Results

Global fuel demand for aviation

• Fuel demand can rise to roughly 5000 TWh in 2100

• 60% increase in overall fuel demand for CO2 Tax

• 53% increase in overall fuel demand for CO2 Tax 2

• 60/40 hydrogen to e-fuels in 2100 for CO2 Tax
Results

Global electricity demand for aviation

- Over 9000 TWh demand in 2100 for CO2 Tax 2
- Approx. 4000 TWh demand in 2100 for CO2 Tax
- Germany 2100
  - CO2 Tax: 174 TWh
  - CO2 Tax 2: 255 TWh
  - Electricity production 2022: 510 TWh
Results

Cost comparison

- Stuttgart – Hamburg
  - 550 km
  - CO2 Tax + 44%
  - CO2 Tax 2 + 47%

- London – New York
  - 5500 km
  - CO2 Tax + 46%
  - CO2 Tax 2 + 52%
Discussion & Conclusion
Discussion and limitations

- Only direct CO₂ emissions are considered for now
  - Emission factor of 73.5 g CO₂/MJ considered (135 g CO₂/MJ)
  - Cloud building not been considered so far
- Hydrogen airplanes uncertain
  - Data availability is uncertain and infrastructure costs as well
- Standalone model for now
  - No competition with other sectors
- Behavioral change is possible but not considered
- A demand increase of 1 % p.a. is the lowest estimate in recent literature (often 4% or even more)
- No consideration of battery electric or fuel cell airplanes and biofuels
Conclusion

- Net zero possible for both hydrogen and e-fuels
- Hydrogen planes will require a new infrastructure which will cause additional costs
- e-fuels are more flexible
  - No change in technology is necessary
  - Shares with fossil kerosene possible
- Due to climate policy flights increased by 40% in cost at a minimum
- At least 5000 TWh of sustainable aviation fuels are required in 2100
- The decision of e-fuels or hydrogen will increase the energy dependency for certain countries/regions
- Global coordination necessary
- Behavioral change would be beneficial
Sources

- Slide 4
  - IATA: Worldwide Air Transport Statistics 2021, July 2021

- Slide 5

- Slide 6/8

- Slide 7

- Overall
  - https://www.boeing.com/commercial/
Thanks!

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