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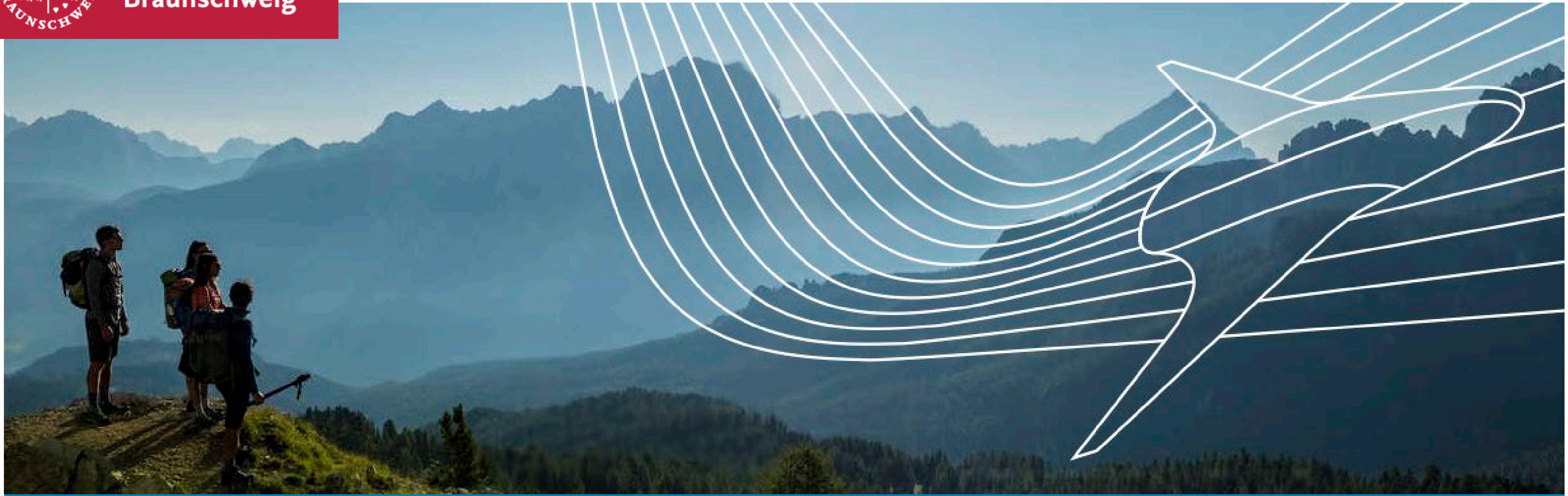

How much can electric aircraft contribute to reaching the Flightpath 2050 CO_2 emissions goal? A system dynamics approach for European short haul flights

Chetan Talwar, Imke Joormann, Raphael Ginster, Thomas S. Spengler | ISDC 2022

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1.) Introduction

2.) Model and validation

3.) Results and sensitivity analysis

4.) Implications

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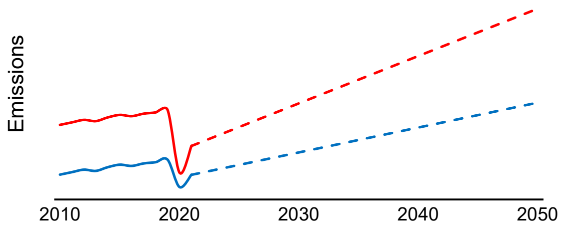
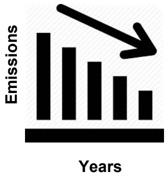
Introduction – future goals for aviation and role of electric aircraft

Development of harmful emissions



Air traffic expected to grow at 4.3 % annually

EU commission Flightpath 2050 goals



- Reduce *CO_2 emissions by 75 %
- Reduce *NO_x emissions by 90 %
- Reduce noise emissions by 65 %

Compared to the base year 2000 emission value

Innovative propulsion concepts

- Novel powertrain technologies
- Sustainable alternative fuels (SAFs)
- Battery electric based concepts

Reduction potential for environmental impact

Battery electric aircraft for short haul flights

- Battery with specific energy of 700 – 800 Wh/kg
- 72 – 180 passengers comparable to the ATR-72 and A320 neo
- Can provide 926 km range

No emissions: considering only in-flight operations

*CO_2: Carbon dioxide ; *No_x: Nitrogen oxides

Source: Airbus 2021; Roland Berger, 2020 ; ; Karpuk and Elham, 2021; Gnadt et al., 2019; ACARE, 2020

Goal of this study

- How much can electric aircraft contribute to reaching Flightpath 2050 CO_2 emission goal for short haul flights segment within the EU?
- Which policies and interventions would be required?
- Behavior/Scenario of these policies?

Clarity to policy makers

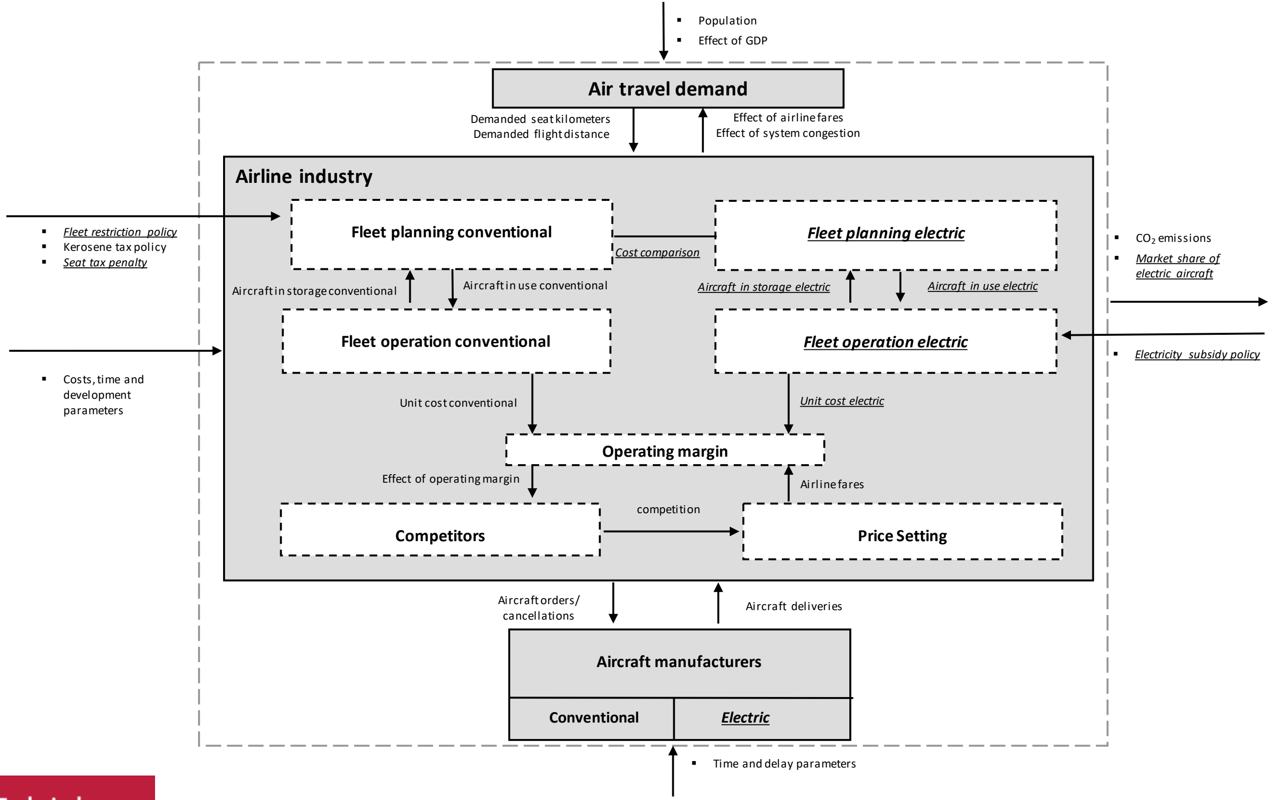
Electric aircraft's contribution

Different policy scenarios

Initial impression of possibilities

Agenda

Air transport system model overview



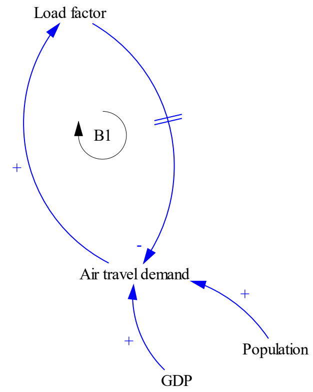
- Time period – 1991-2050
- Electric aircraft available 2035 (fully electric)
- Within the geographical area of the EU

Based on:

- Pierson & Sterman (MIT Sloan) 2013
- Kieckhäfer et al. 2018

Underlined italics variables are the extensions made in the model

ATS model extended – core causal loop diagram



Legend:
'+' sign means variables move in same direction
'-' sign means variables move in opposite direction
'||' delays in transmission of information

Source: Pierson & Sterman (MIT Sloan) 2013 ; Kieckhäfer et al. 2018 ; Lyneis, 2000 ; Leihr et. al., 2001 ; Sterman, 2000

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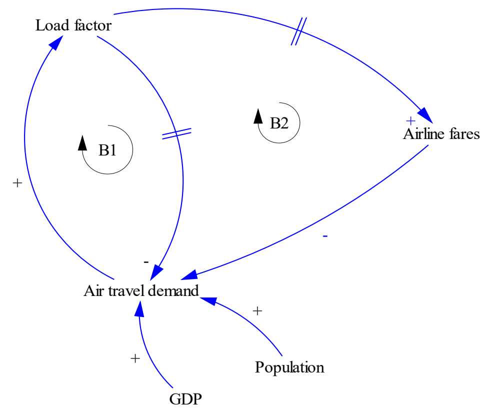

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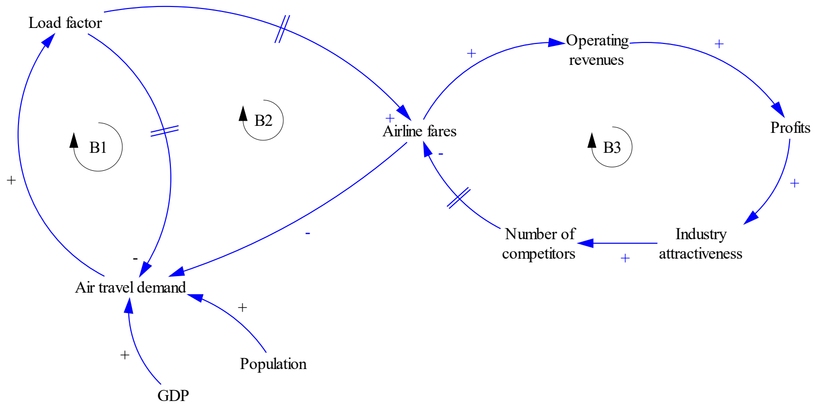

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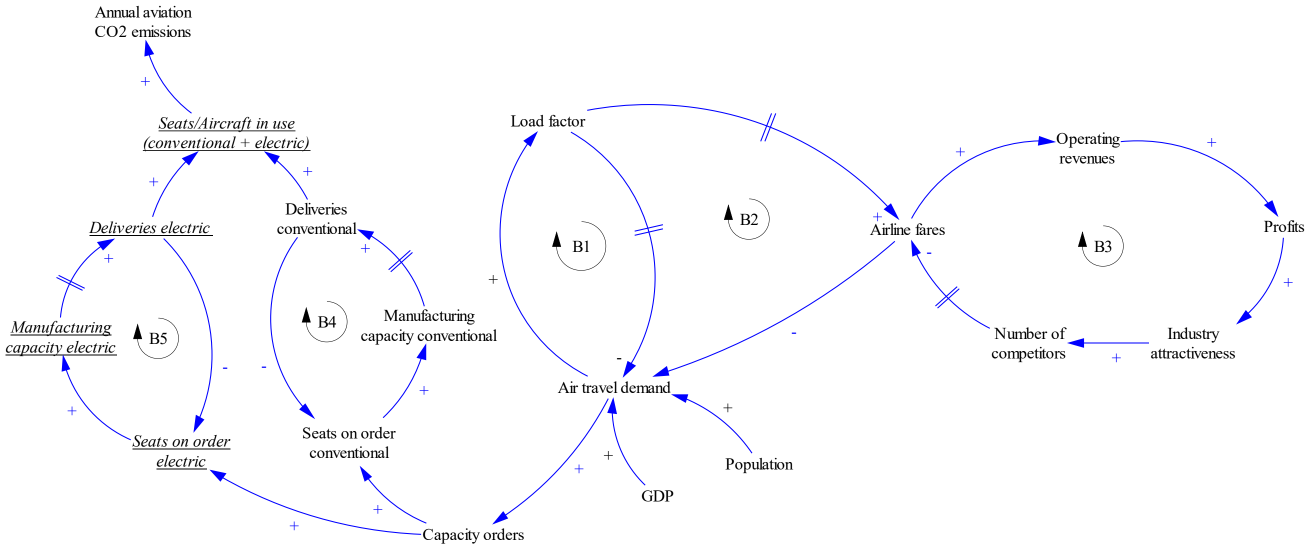

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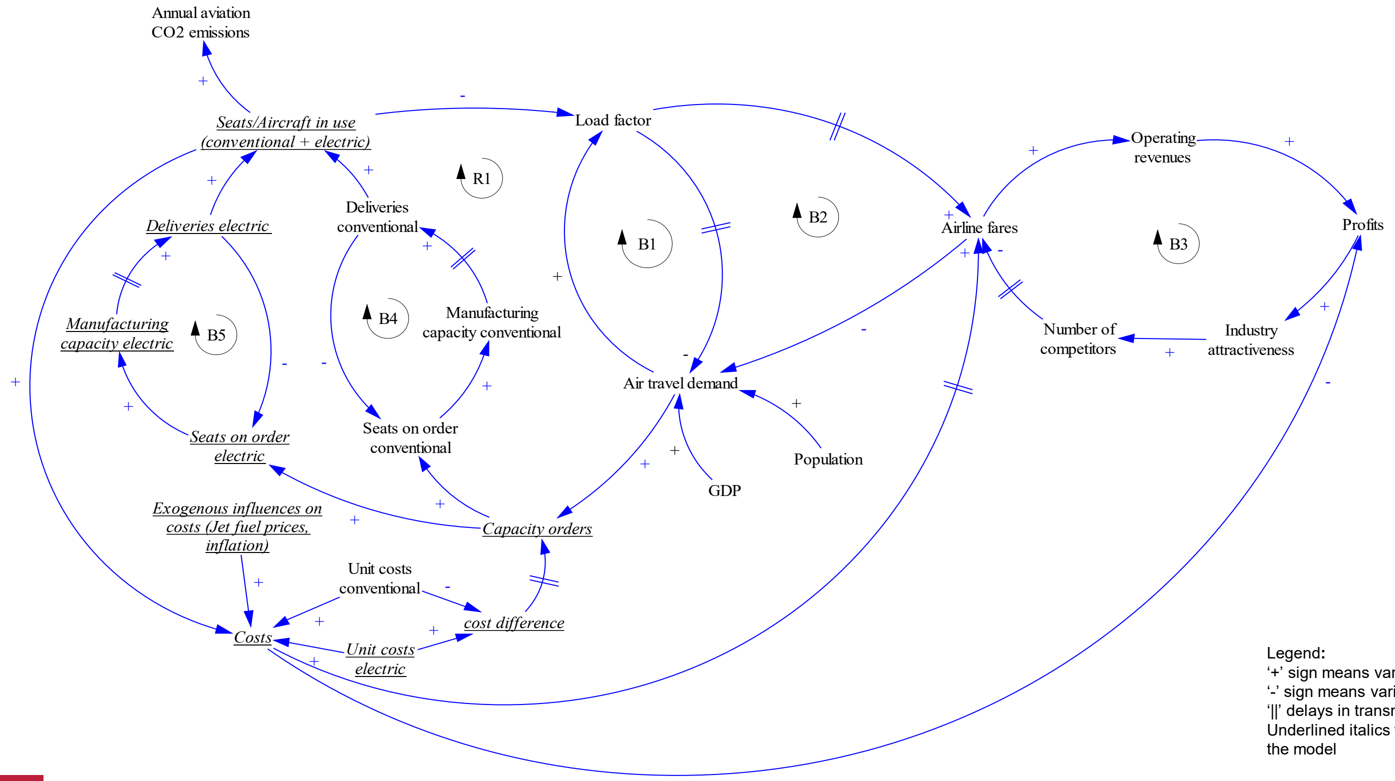

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ATS model extended – policies considered

Kerosene tax:

- Introduction year: 2025
- Policy to tax airline jet fuel
- Reduce cost attractiveness of conventional aircraft
- Generate government revenue

Electricity subsidy:

- Introduction year: 2035
- Policy to make electricity inexpensive
- Increase cost attractiveness of electric aircraft
- Provide government support

Fleet restriction policy:

- Introduction year: 2038
- Mandatory to operate certain percentage of fleet by electric regardless of costs
- Promote airlines to adopt electric fleet

Seat tax penalty:

- A penalty payment imposed per extra conventional seat in use
- Introduced along with fleet restriction policy
- To discourage conventional fleet usage

Source: (Avinor, 2022, 2018; Dagens industri, 2022; Eurocontrol, 2019; Fossilfritt Sverige, 2021; Mckinsey, 2020; Rolls Royce, 2021; yle, 2022)

Model validation

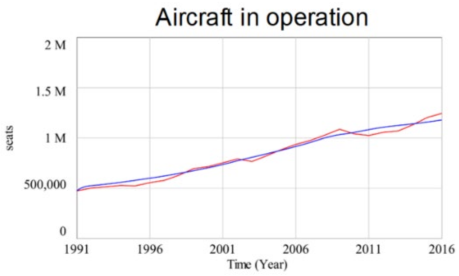
Testing against historical data:

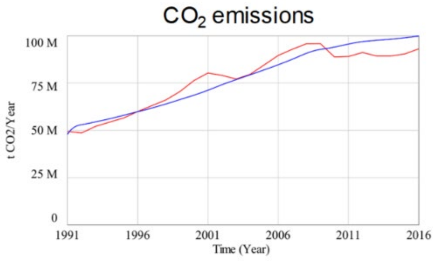
- Helps to account for the distance between the real world and model data
- Confidence in model if unequal bias and variation near 0
- Model is fairly depicting real world historical data

Variable	Splitting of the MSE		
	Bias	Unequal variation	Unequal covariance
Aircraft in use	0.089	0.064	0.847
Airline fares	0.006	0.094	0.901
Air travel demand	0.035	0.341	0.623
Annual aviation CO_2 emissions	0.000	0.035	0.965
Load factor	0.002	0.452	0.546
Operating margin	0.302	0.006	0.692

Other methods:

- Extreme policy test
- Dimensional consistency*
- Integration errors*





Historical time series
Model time series

*Conducted in Vensim DSS x64 Version 8.0.8
Source: United States census Bureau, 2016 ; Theil, 1966

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Results – individual policies

Scenario	Policy measures				Results year 2050	
Runs	Jet fuel tax rate	Electricity subsidy	Government restriction policy	Seat tax penalty	CO_2 compared to 2000 value	ASK electric fleet %
Basis	0	0	0%	0	162%	0%
High jet fuel tax	High	0	0%	0	160%	0%
High electricity subsidy	0	High	0%	0	74%	28%
Low fleet restriction	0	0	10%	0	57%	13%
Medium fleet restriction	0	0	15%	0	39%	23%
High fleet restriction	0	0	20%	0	29%	34%

: Flightpath 2050 CO_2 emission goals reached

: Flightpath 2050 CO_2 emission goals not reached

*Conducted in Vensim DSS x64 Version 8.0.8

Results – combination of policies

Scenario	Policy measures				Results year 2050	
Runs	Jet fuel tax rate	Electricity subsidy	Government restriction policy	Seat tax penalty	CO_2 compared to 2000 value	ASK electric fleet %
Basis	0	0	0%	0	162%	0%
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Low fleet restriction	0	0	10%	0	57%	13%
Medium fleet restriction	0	0	15%	0	39%	23%
High fleet restriction	0	0	20%	0	29%	34%
High jet fuel tax and subsidy	High	High	0%	0	7%	89%
Low fleet restriction and low seat tax	0	0	10%	Low	56%	13%
Low fleet restriction and high seat tax	0	0	10%	High	35%	45%
High fleet restriction and low seat tax	0	0	20%	Low	29%	34%
High fleet restriction and seat tax	0	0	20%	High	27%	51%
High subsidy and low fleet restriction	0	High	10%	0	37%	43%
High subsidy and fleet restriction	0	High	20%	0	25%	56%

: Flightpath 2050 CO_2 emission goals reached
: Flightpath 2050 CO_2 emission goals not reached

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High fleet restriction and seat tax	0	0	20%	High	27%	51%
High subsidy and low fleet restriction	0	High	10%	0	37%	43%
High subsidy and fleet restriction	0	High	20%	0	25%	56%
Pro electric	High	High	20%	0	8%	89%
Best case scenario	High	High	20%	High	11%	82%
Worst case scenario	0	0	0%	0	192%	0%

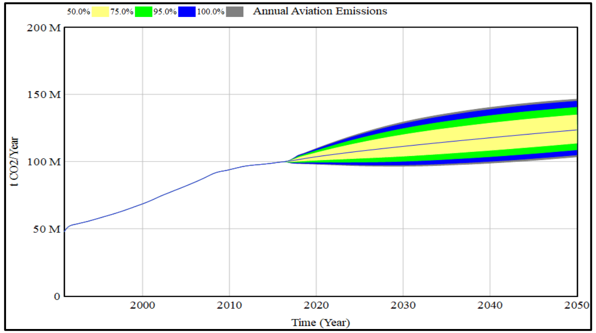
: Flightpath 2050 CO_2 emission goals reached

: Flightpath 2050 CO_2 emission goals not reached

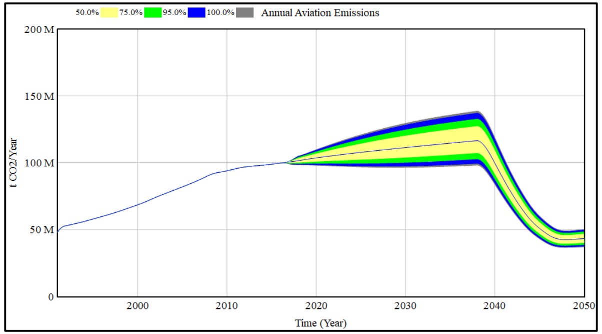
*Conducted in Vensim DSS x64 Version 8.0.8

Results – sensitivity analysis

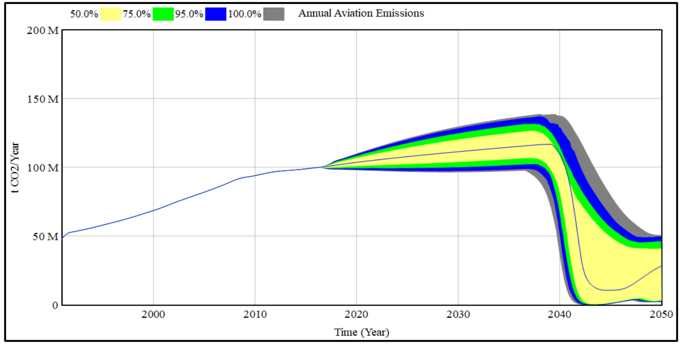
- Base case:
  - Sensitivity to growth factor (EU GDP per capita, Population growth etc.)
- Fleet restriction with seat tax:
  - More sensitive to growth factor
  - Less to other variables
- Fleet restriction with subsidy:
  - Sensitivity to electricity price, ownership costs and growth factor



Base case



Fleet restriction with seat tax



Fleet restriction with subsidy

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Implications

In summary, what can be implied about the potential of electric aircraft in contribution to reaching the Flightpath 2050 CO_2 emissions goal for European short haul flights?

Policies:

- A **kerosene tax** equivalent to **180 € per ton of CO_2** was not enough to reduce air travel demand or encourage electric aircraft adoption
- A **combination of policies** was found to be more effective than implementing **individual policies**
- Due to the **high cost of electric aircraft**, an **electricity subsidy of 75 %** was required to achieve higher adoption rates

Parameter sensitivity:

- Growth factor parameters like **GDP per capita, population growth, and jet fuel price** can affect the emissions (for all simulation runs)
- Electric aircraft related parameters like **energy consumption efficiency, electricity price and ownership costs** cause high uncertainty

Policy makers should monitor the **growth rate factors** and **electricity aircraft development parameters** as they can affect the **air travel demand** and **cost attractiveness** of operating electric aircraft.

Thank you for your attention

Forward. Foresight. For flight.

Chetan Talwar

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