INTEGRATING CLIMATE POLICIES INTO AIR TRANSPORT OPERATIONS: CHALLENGES, RISKS, AND IMPACTS

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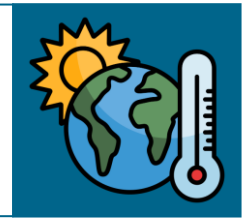
M. Niklaß[1], Z. Zengerling[1], K. Kölker[1], M. Mendiguchia Meuser[1], T. Ehlers[1], A. Lau[1],
R. Eichinger[2], K. Dahlmann[2], S. Matthes[2], V. Grewe[2,3], F. Yin[3], A. Stefanidi[3], T. Roetger[4], F. Crova[4]

[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Luftverkehr, Hamburg, Germany
[2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Weßling, Germany
[3]Delft University of Technology (TU Delft), Section Aircraft Noise and Climate Effects, HS Delft, Netherlands
[4]ENV-ISA, Paris, France

Policy driven flight planning in BeCoM
Motivation & Overview

Non-CO_2 Climate Effects of Flights

- Non-CO_2 effects are **more uncertain** than CO_2 and **vary with location, timing, and weather conditions**.
- **Climate optimized routing** offers high mitigation potentials, but increases costs and affects airline operations



Market-based / policy measures as an option to incentivize climate mitigation

- **EU non-CO_2 MRV started in Jan 2025:** Aircraft operators must monitor and report non-CO_2 effects on all intra-EU flights.
- **By Dec 2027,** the Commission **may** adopt **non-CO_2 mitigation rules and extend EU ETS** scope to include non-CO_2.

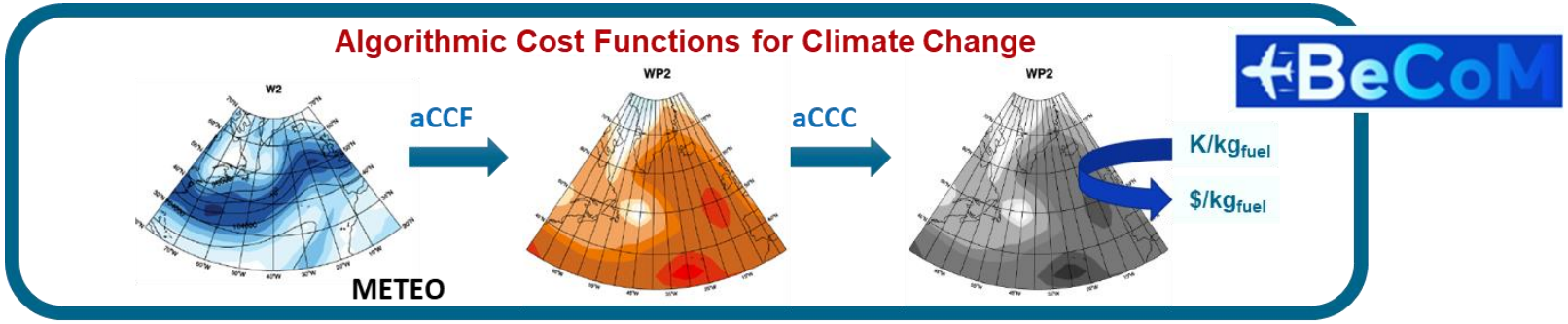
BeCoM: Non-CO_2 Policy Effects on Individual Flights

- **Analyses key non-CO_2 policy parameters** and their impact on operations, ticket prices, and climate impact.
- Explores **approaches for integrating non-CO_2 uncertainties into policy design** to avoid perverse incentives.

BeCoM: Network Analyses and Stakeholder Consultations

- Impacts on **demand**, **airline networks** and potential **regional leakage**
- CO_2e accounting as a **driver for implementing operational & technological mitigation?**
- Gather expertise and **identify stakeholder expectations** on non-CO_2 policies.

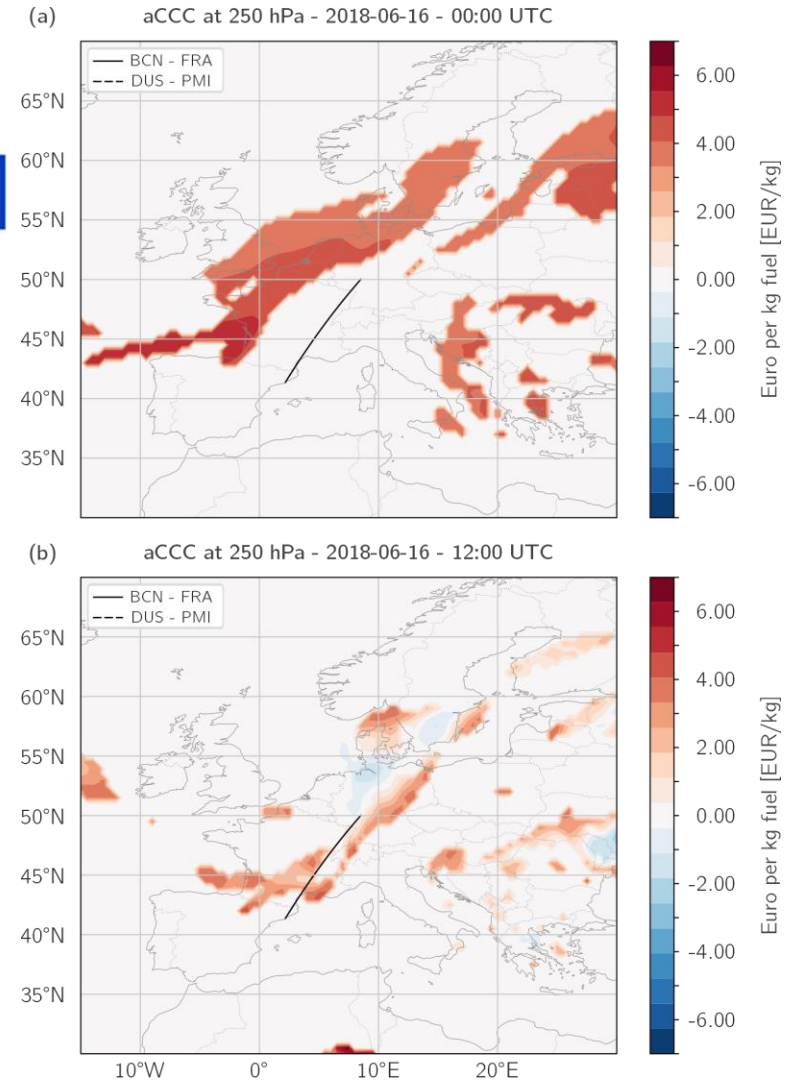
Modeling policy driven flight planning
Method



- Calculation of optimized routes with DLR's trajectory optimizer **pyTOM**
- Extension of aCCFs to algorithmic cost functions for climate change (aCCC) providing climate cost response surface in EUR/kg$_{fuel}$
- Non-CO_2 pricing simplifies this to purely economic costs:

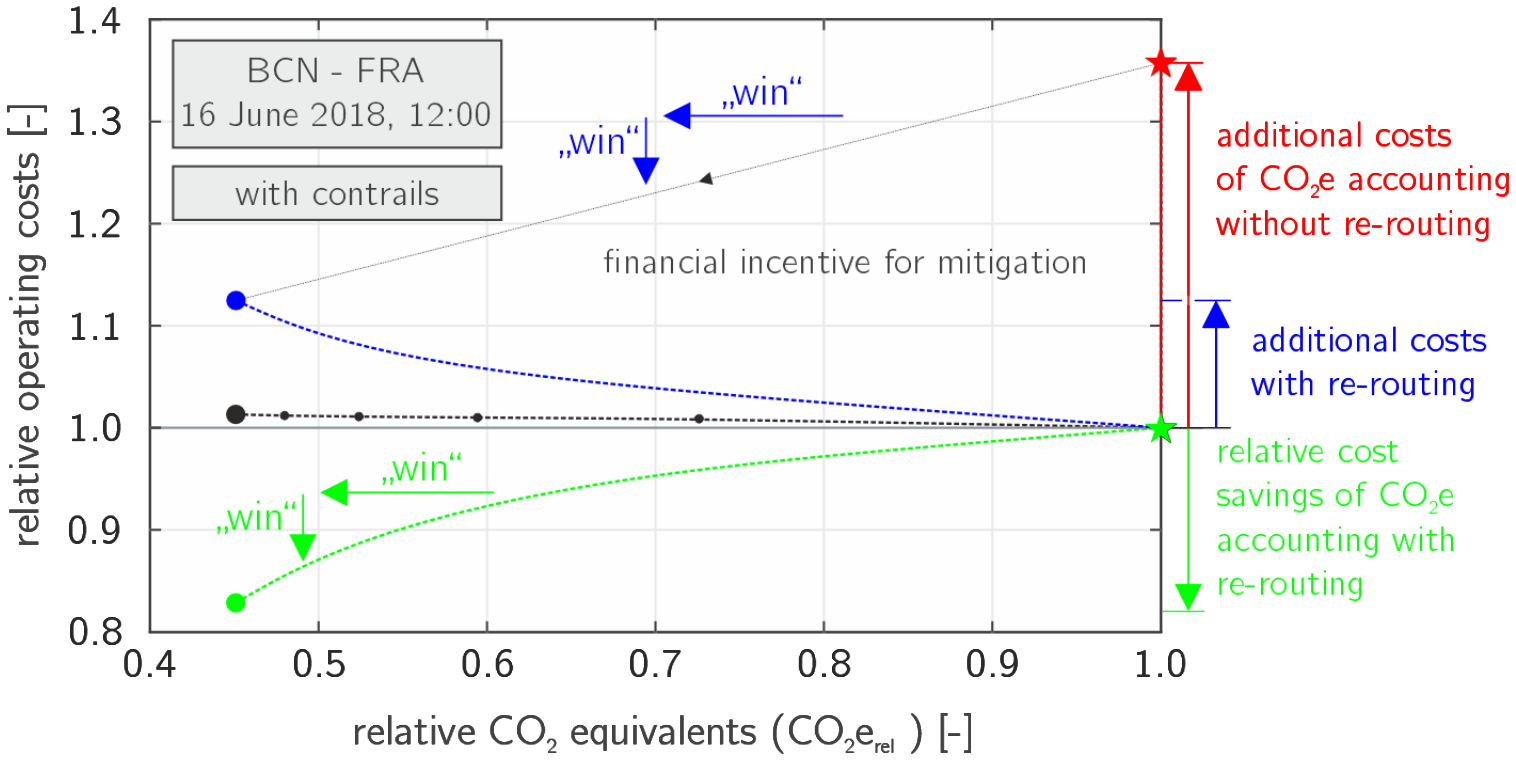
$$\mathbf{TOC}(\boldsymbol{x}, \boldsymbol{t}) = \boldsymbol{f}_{\mathbf{DOC}}(\boldsymbol{m}_{\mathbf{fuel}}, \boldsymbol{t}, \boldsymbol{d}) + \mathbf{CO_2e}(\boldsymbol{x}, \boldsymbol{t}) \cdot \mathbf{EUAA}_{\mathbf{price}}$$

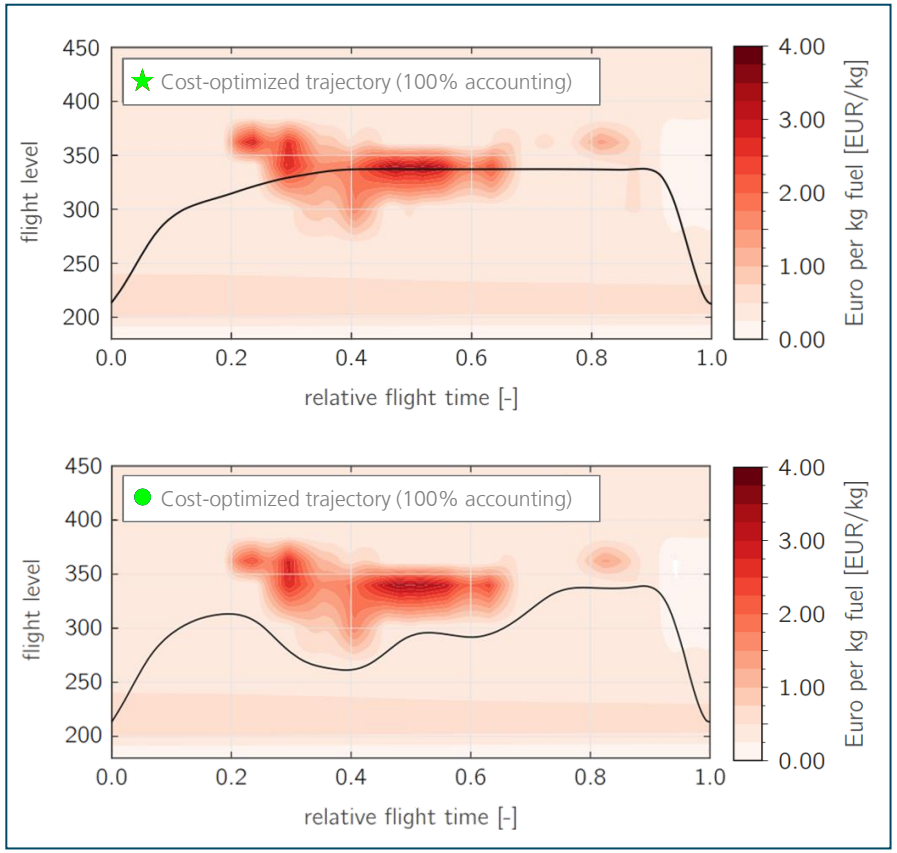
- Assumption of additional cost to be transferred to passengers



Can Non-CO_2 Policies Drive Climate-Optimized Flying?
Exploring their incentive and suitability

options	re-routing	CO_2e accounting	reference costs
★	no	no	BAU
●–	yes	no	BAU
●–	no	yes	BAU
●–	yes	yes	BAU
●–	yes	yes	incl. CO_2e accounting





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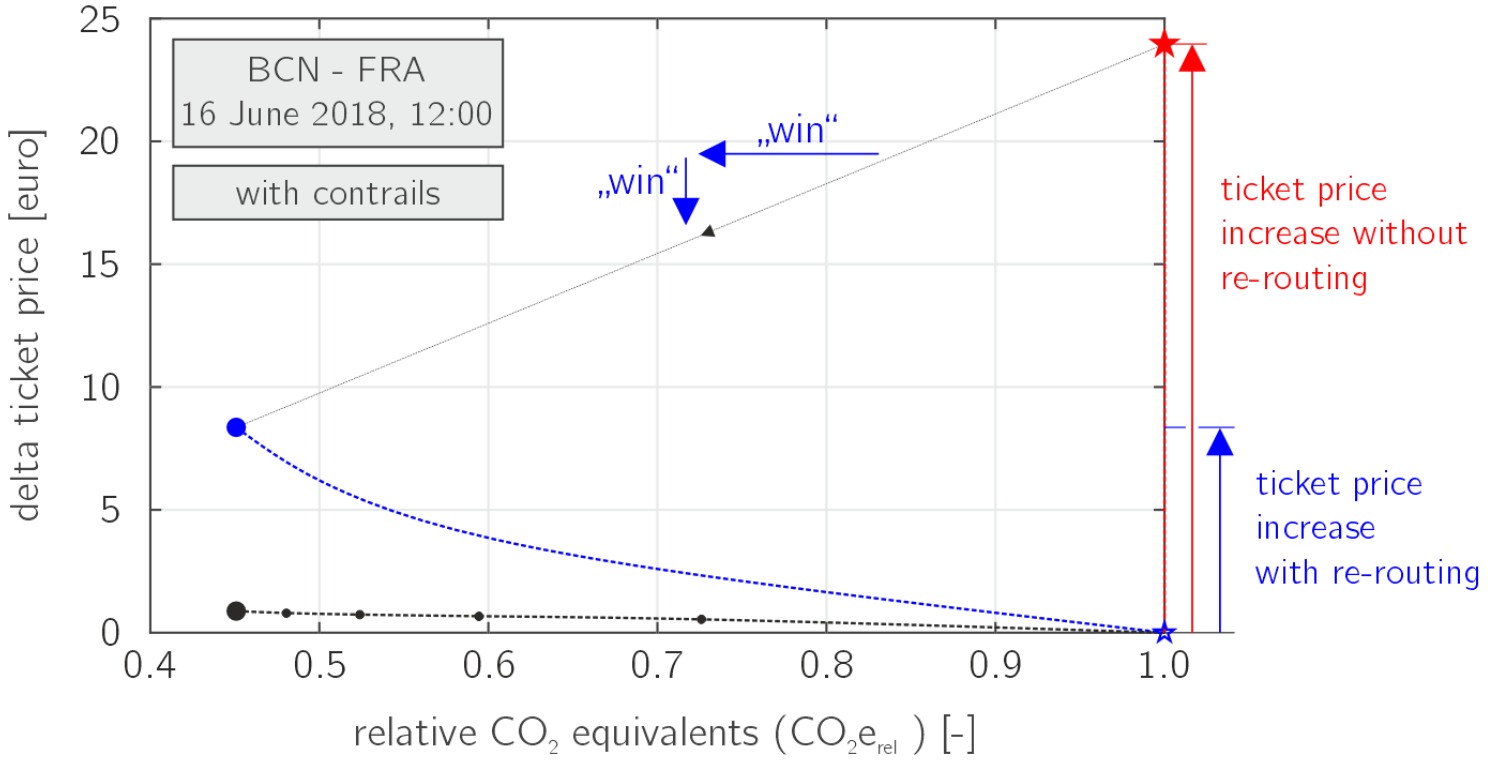
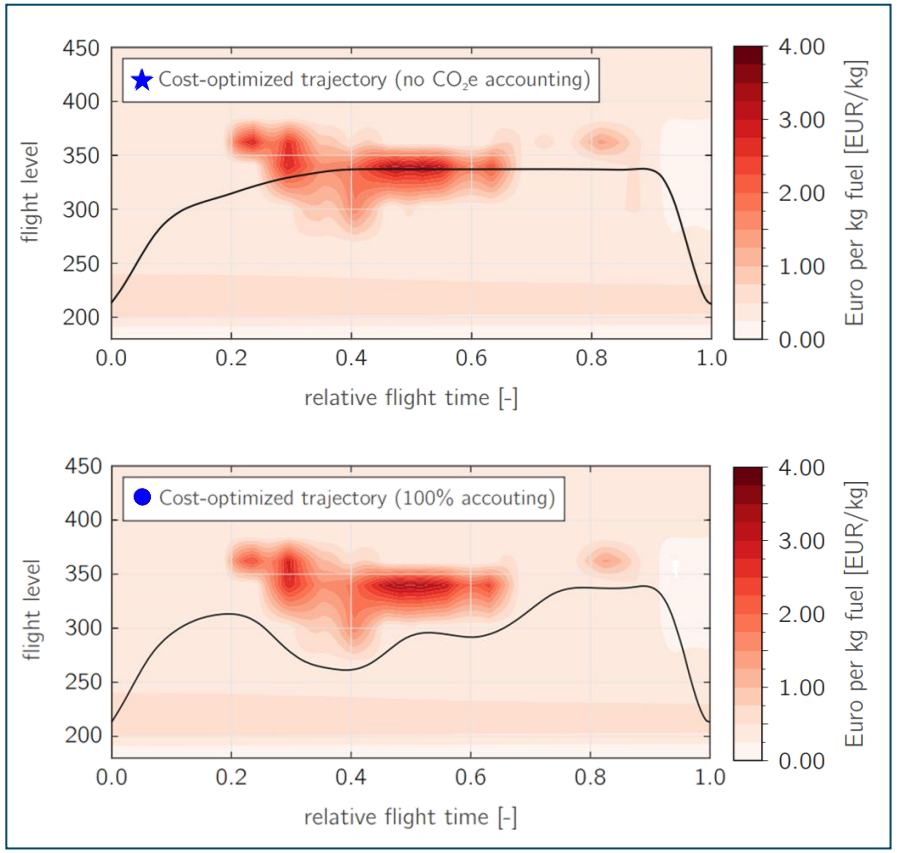




Assuming 100% CO_2e accounting and a CO2e price of 80€

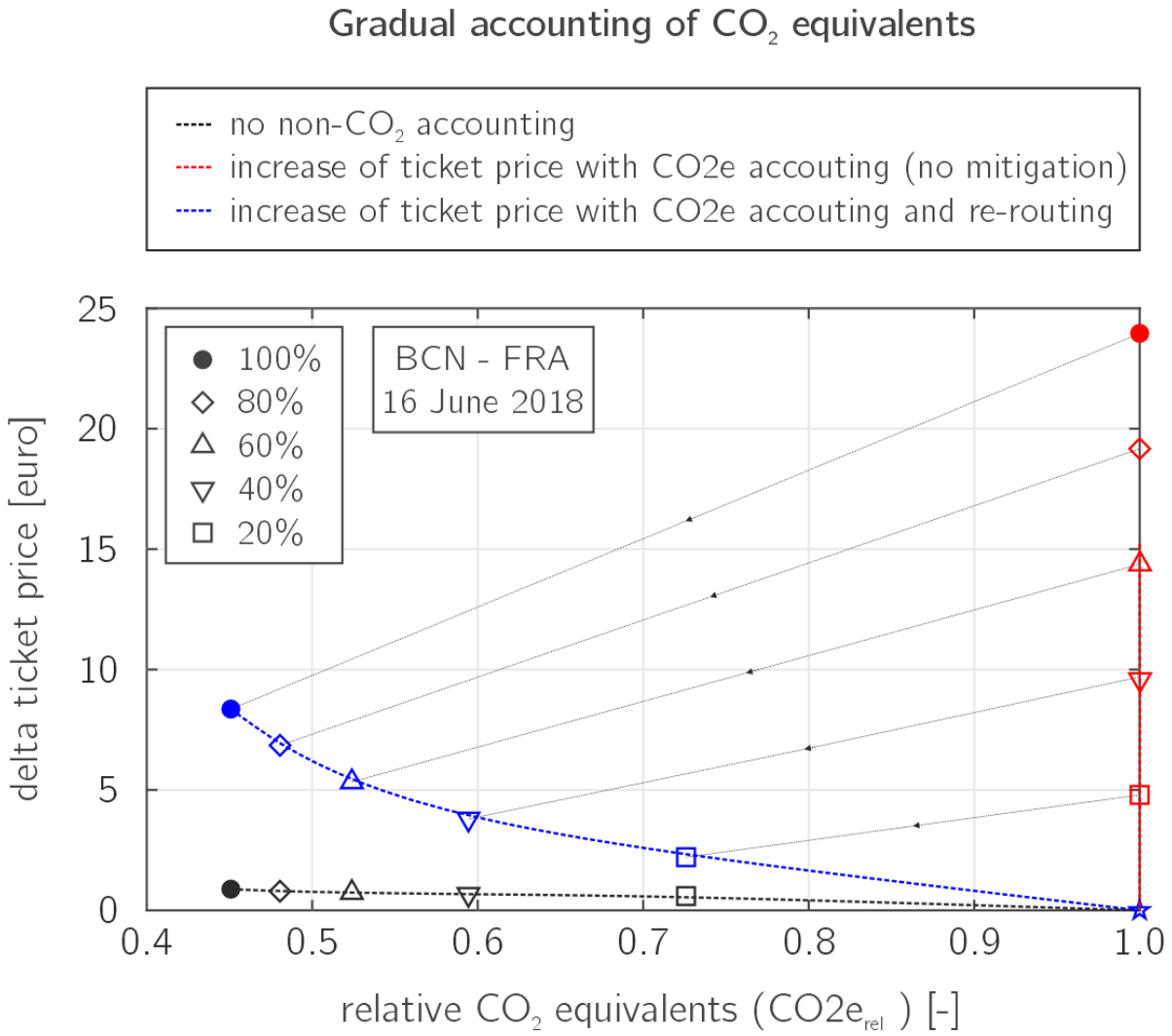
Can Non-CO_2 Policies Drive Climate-Optimized Flying?
Sensitivity analyses of key design parameters

(1) Accounting scheme: Calculation of CO_2e to be considered in EU ETS

- **Gradual accouting:** Emitters must hold permits for, e.g., 20% of calculated CO_2e in the first year, with increasing share over the time
- **Uncertainty-based accounting:** Emitters must hold permits for all calculated CO_2e values of a climate agent with a certain confidence level

(2) Price for CO_2e

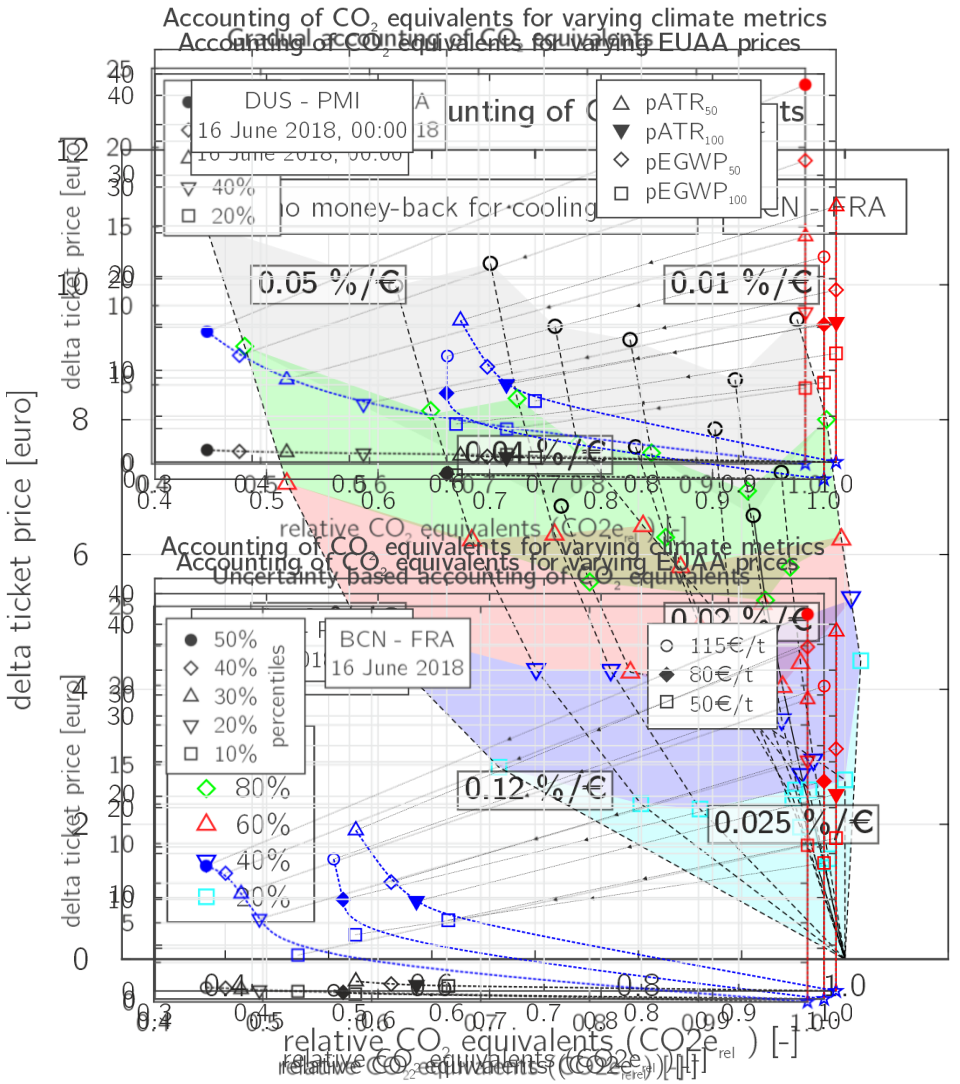
(3) Metric for calculation of CO_2e



Can Non-CO_2 Policies Drive Climate-Optimized Flying?

Sensitivity analyses of key design parameters

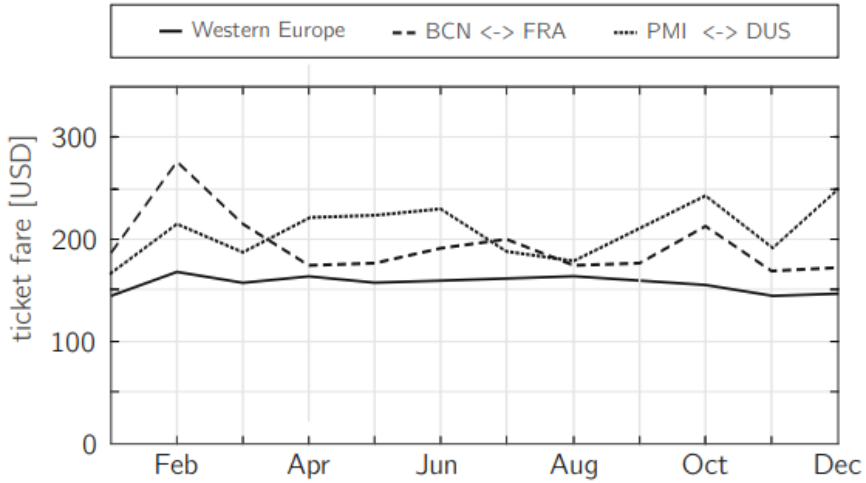
- **Gradual accounting** is more conservative than **uncertainty based accounting**
- **CO_2e price** drives the resulting cost increase, but only has minor effects on mitigation in contrail-intensive situations
- **Climate metrics** with a higher weight on non-CO_2 effects lead to higher mitigation results
- **Climate mitigation potentials** mainly depend on weather situation, while ticket price increase is influenced by the accounting share



Can Non-CO_2 Policies Drive Climate-Optimized Flying?
Impact on ticket prices and passenger demand

Demand & Passenger Impact

- **Price elasticities of air travel** quantify how demand responds to ticket price changes.
- **Price changes affect demand differently** across routes and market segments.
- **Network-wide effects** arise from passenger choices and airline responses.



Ticket fare		Additional CO2e charge per ticket				
		2.00 €	4.00 €	6.00 €	8.00 €	10.00 €
25th Percentile	182.82 €	1.7%	3.4%	5.0%	6.7%	8.4%
Mean	206.71 €	1.0%	1.9%	2.9%	3.9%	4.8%
75th Percentile	312.05 €	0.7%	1.4%	2.1%	2.8%	3.5%

Impact of CO2e pricing on passenger demand		Additional CO2e charge per ticket				
		2.00 €	4.00 €	6.00 €	8.00 €	10.00 €
Mean	206.71 €	-0.8%	-1.7%	-2.5%	-3.4%	-4.2%

Assuming an aggregated elasticity value of -0.87 (Oesingmann and Kölker, 2025)

Network Impact of Non-CO_2 Pricing in EU-ETS

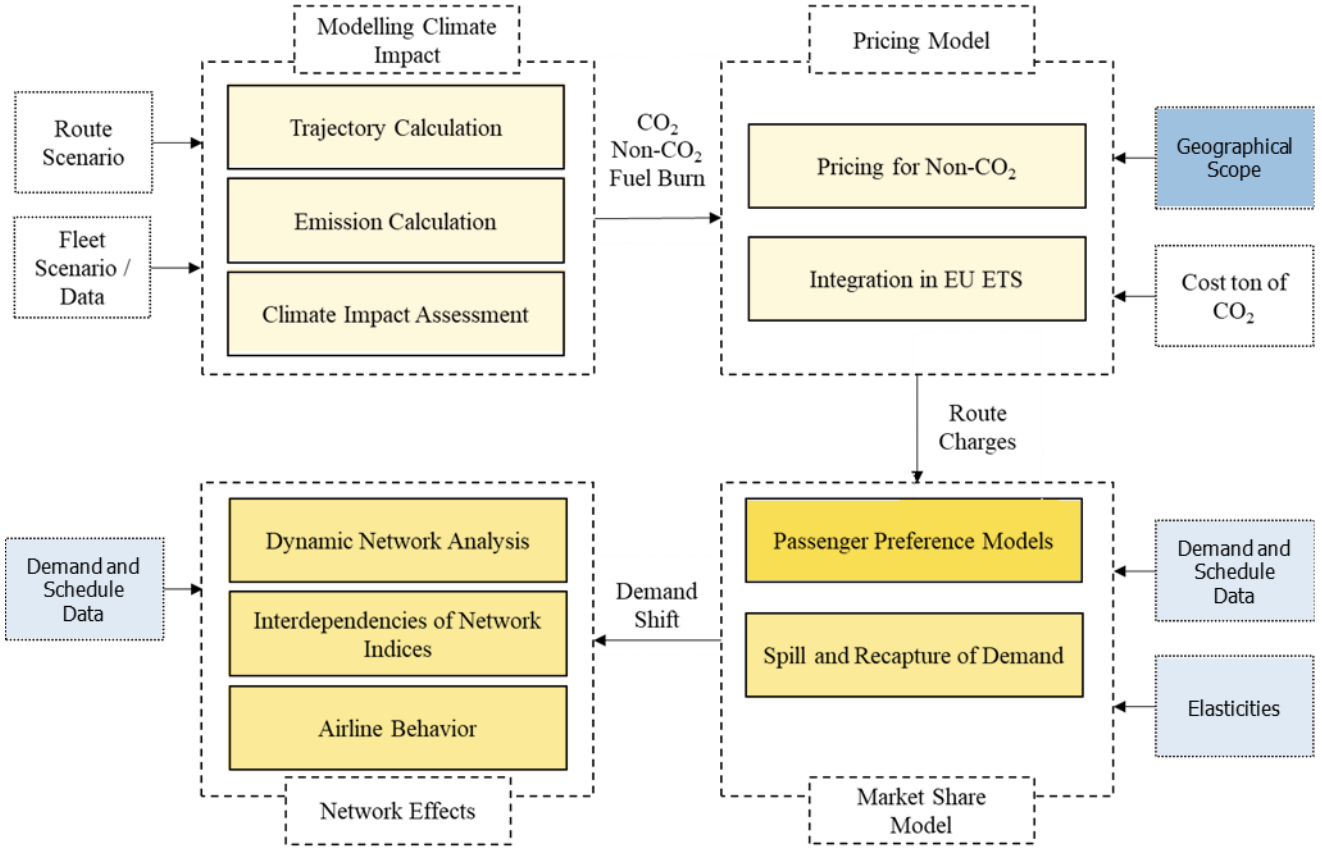
Demand and ticket price dynamics across geographical scopes

Demand & Passenger Impact

- **Price elasticities of air travel** quantify how demand responds to ticket price changes.
- **Price changes affect demand differently** across routes and market segments.
- **Network-wide effects** arise from passenger choices and airline responses.

→ **Integration of Passenger Preference Models into simulation framework** (Kölker et al., 2025).

Simulation Framework



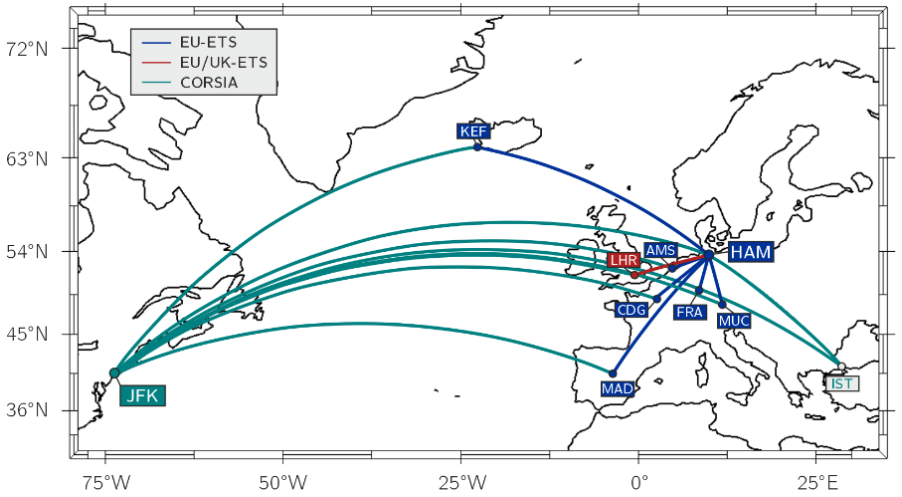
Kölker et al., 2025

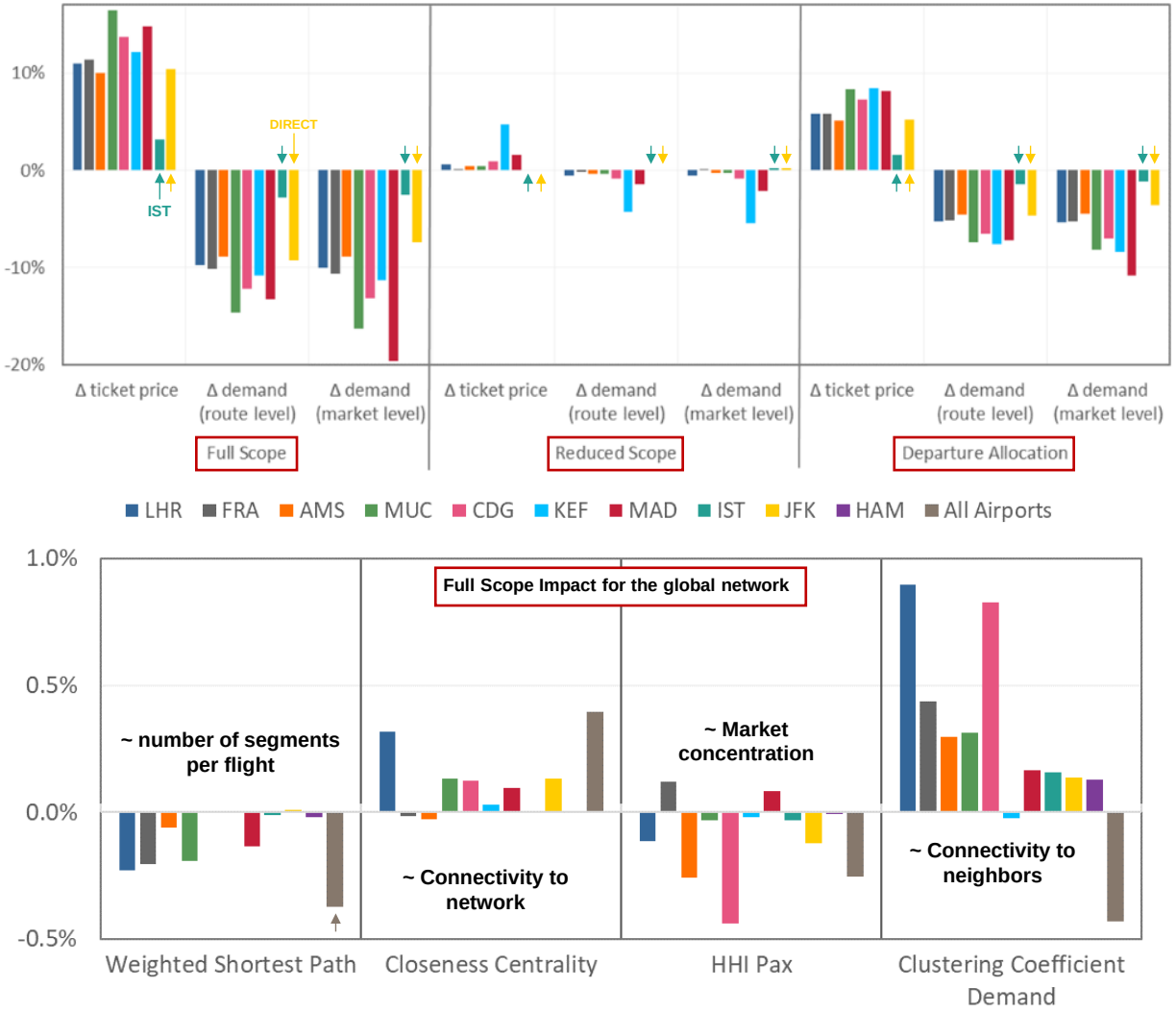
Network Impact of Non-CO_2 Pricing in EU-ETS

Demand and ticket price dynamics across geographical scopes

Use case & assumptions:

- OD-market from Hamburg to New York (9 potential passenger routes)
- subject to different CO2 pricing schemes (EU ETS, UK ETS, CORSIA)
- real operated fleet types (2023) for different airlines
- ticket prices averaged based on real 2023 per route
- pricing of routes is subject to different geographical scopes
- **Geographical scope scenarios:**
  (1) Full scope (all flights from/to Europe)
  (2) Reduced Scope (intra-European flight only)
  (3) Departure-based allocation.
- **Price assumptions**: EU ETS (€80/t), UK ETS (€50/t), CORSIA (€15/t) for 30% of CO_2 above 2019 levels; €800/ton extra fuel; 50% allocation of CO2e

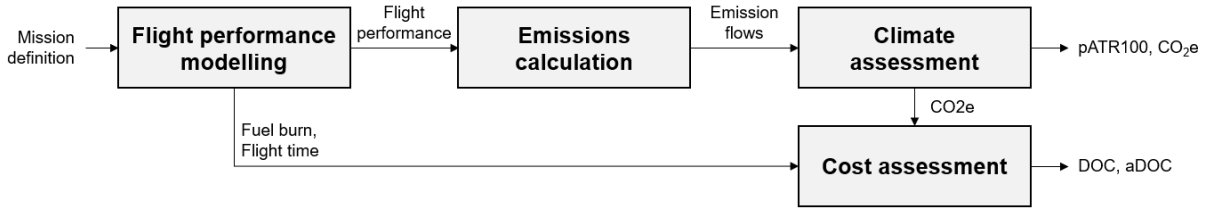


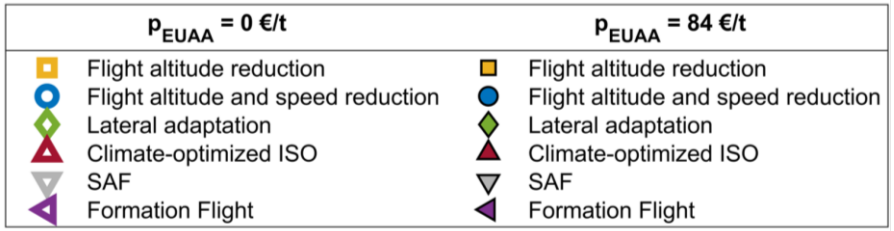


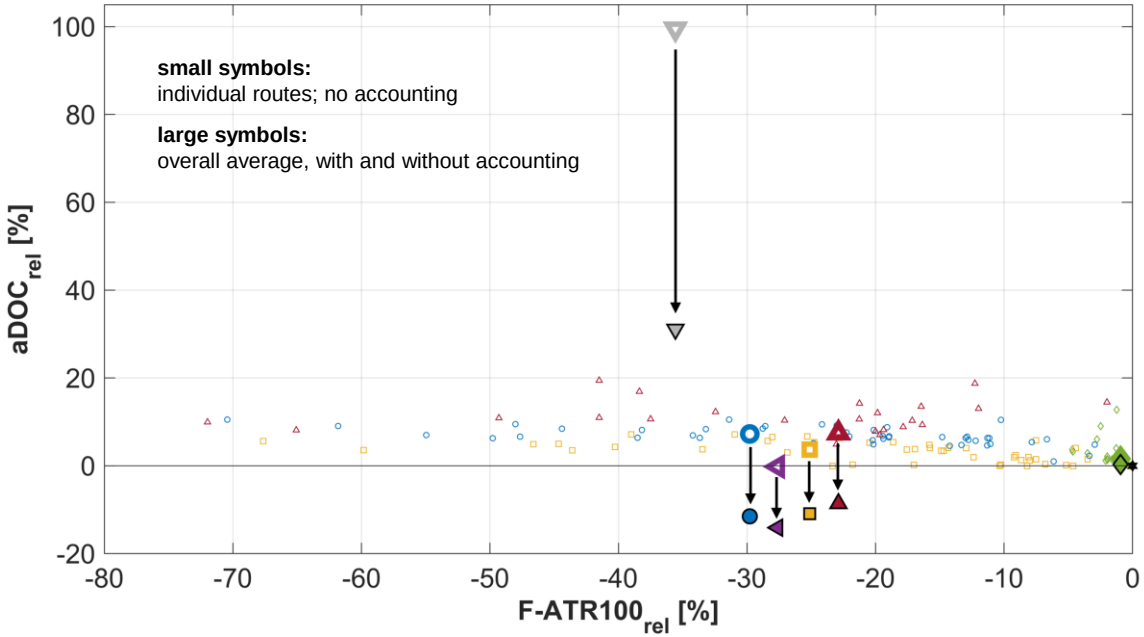
Zengerling et al., 2025

CO_2e accounting as a driver for implementing **operational & technological mitigation measures?**

- **Purpose**: Evaluate CO_2e accounting to support climate mitigation measures:
  - **Operational**: flight altitude & speed adjustments, climate-optimized intermediate stops, formation flight
  - **Fuel & Tech:** Sustainable Aviation Fuels (SAF), technical efficiency improvements
- **Method**: Analysis based on representative long-haul ECAC flights selected by traffic volume, OD pairs, and aircraft type
- **Key Findings:**
  - **CO_2e pricing lowers economic barriers** for operational mitigation
  - **High SAF costs not fully offset** by CO_2e accounting
  - **Technological improvements** (fuel burn & NOx reduction) significantly **increase mitigation potential**
  - **Cost/ticket impact** can be **reduced by** flexible **accounting schemes** (e.g., gradual accounting)

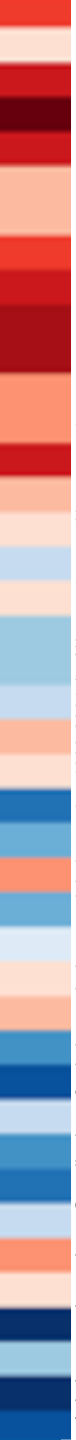






Conclusion
Policy driven flight-planning considering non-CO_2 effects

- **EU non-CO_2 MRV started** in January 2025
- **EU-COM may propose non-CO_2 inclusion into EU ETS** by Dec 2027
- **Designing robust, fair, and effective accounting** of aviation's non-CO_2 climate effects **is challenging**
  - **Incorporation of uncertainties** of weather forecast, climate metrics, and models **into the policy**
  - **Balancing** proven **CO_2 strategies with** promising but uncertain **non-CO_2 options**
  - **Mitigation potential and costs vary** by route and weather situation, **creating uneven network impacts**
  - Potential **competitive disadvantages** of regional implementation **have to be avoided**
- **Implementation depends on** scientific **models**
  - **Risk of false** incentives from imperfect models & data
  - **premature rollout may reduce trust** and frustrate stakeholders
- Unique **chance for reducing aviation's climate impact** and help to **comply with Paris agreement**
  - Non-CO_2 mitigation offers **substantial climate benefits**
  - Non-CO_2 accounting **can drive** operational & technological **mitigation** measures
  - **Lower abatement costs** than other sectors (such as wind or solar energy and direct air capture)
- Proactive development and stakeholder cooperation needed



Dr. Malte Niklaß

Institute of Air Transport
German Aerospace Center (DLR)
Hamburg, Germany

malte.niklass@dlr.de
+49 40 2489641 214
www.dlr.de/lv

LinkedIn

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