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Green-GEAR

Final Dissemination Workshop
Green route charging (GRC) Solution

12th February 2026

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EUROPEAN PARTNERSHIP

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Overview

- Introduction
- Initial Solution
- Full Solution
- Discussion

GRC Context

- Green-GEAR project Solution maturity: SESAR ER, TRL 2
- GRC provenance: charge modulation concept (e.g. SES2+)
- Awareness of other options (e.g. ETS)
  - Monitoring, Reporting and Verification (MRV)
  - Very similar data and models used in Full Solution
  - By end of 2027, Commission will deliver report on the results and if appropriate, make a legislative proposal to address non-CO_2 effects of aviation

- Evaluating options for charge modulation
  - assessing potential benefits and disbenefits
  - barriers and enablers
  - stakeholder feedback vital (in addition to already received)
- We are ***reporting*** on the above, ***not advocating*** any particular solution

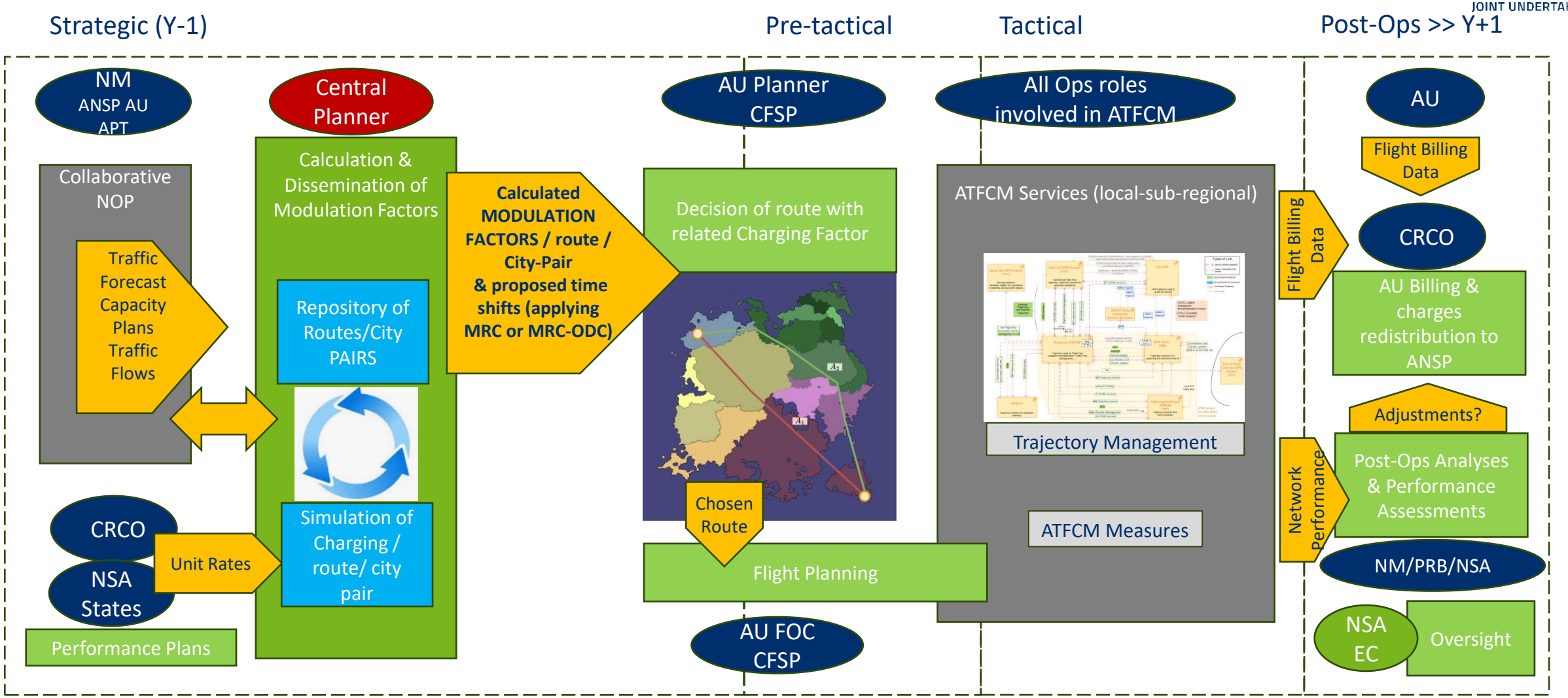
TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on very specific application area(s) to perform the analysis to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

GRC Context

Heads-up on two 'Solutions' that we are assessing

Feature	Initial Solution	Full Solution
Includes CO_2	Yes	Yes
Includes non-CO_2 (e.g. NO_X)	No	Yes
Includes contrails	No	Yes (albeit as part of full impact)
Basic principle	Avoid congestion	Avoid climate 'hotspots'
FP notification period	Once/twice per year	Appx. 3-6 hours in advance
ANSP revenue basis	Appx. neutral	Appx. neutral
AU charge basis	Appx. neutral	Appx. neutral
Full AU equity	TBD	TBD
Simulation Results	**-1.5% distance flown**	**-6% to -20% climate impact**

Initial Solution



Activity/task part of Green-GEAR

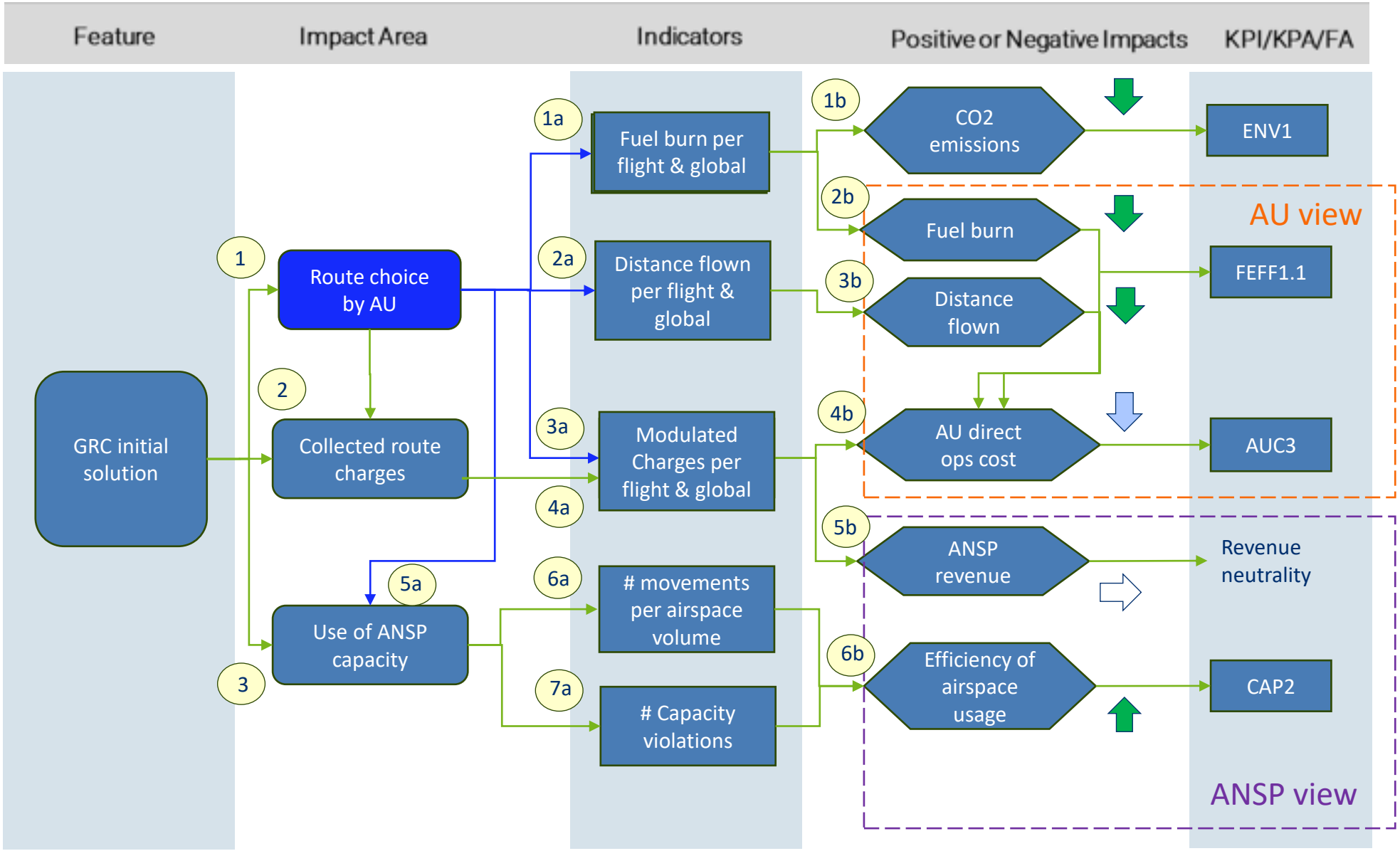
Inputs Outputs

New function

Activity not impacted by Green-GEAR

Activity with some impact from Green-GEAR

Benefit Impact Mechanisms (BIMs) – Initial Solution



Full Solution

Strategic (Y-1) | Pre-tactical | Tactical | Post-Ops >> Y+1

NM
ANSP AU
APT

Collaborative NOP

Traffic Forecast
Capacity Plans
Traffic Flows

Central Planner

Calculation & Dissemination of Env. Impact Rates (EI)

Repository of Routes/City PAIRS

Calculated Environment Impact (EI) / route / City-Pair translated into an EI rate

MET provider

NWP for climate

Forecast Climate Hotspots?

CRCO

NSA States

Unit Rates

Simulation of Charging / route/ city pair

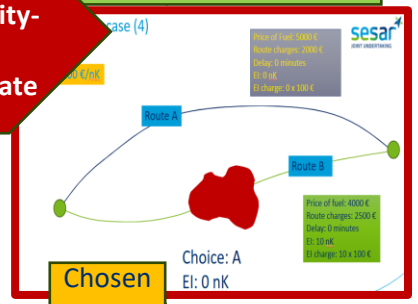
Performance Plans

Reduced Unit Rates

Forecasted additional revenue "Pot" to incentivise AU on EI

AU Planner
CFSP

Decision of route with related Charging Factor (EI)



Chosen Route

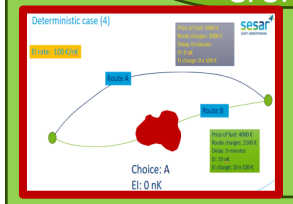
Flight Planning

All Ops roles involved in ATFCM

ATFCM Services (local-sub-regional)

Trajectory Management

AU FOC
CFSP



Decision for Flight Plan Update

ATFCM Measures

Updated Measures & Processes to include Climate Hotspots

Update

NM
ANSP AU
APT

MET

Flight Billing Data

AU

Flight Billing Data

CRCO

AU Billing & charges redistribution to ANSP

Adjustments?

Post-Ops Analyses & Performance Assessments

Network Performance

NM/PRB/NSA

NSA EC

Oversight

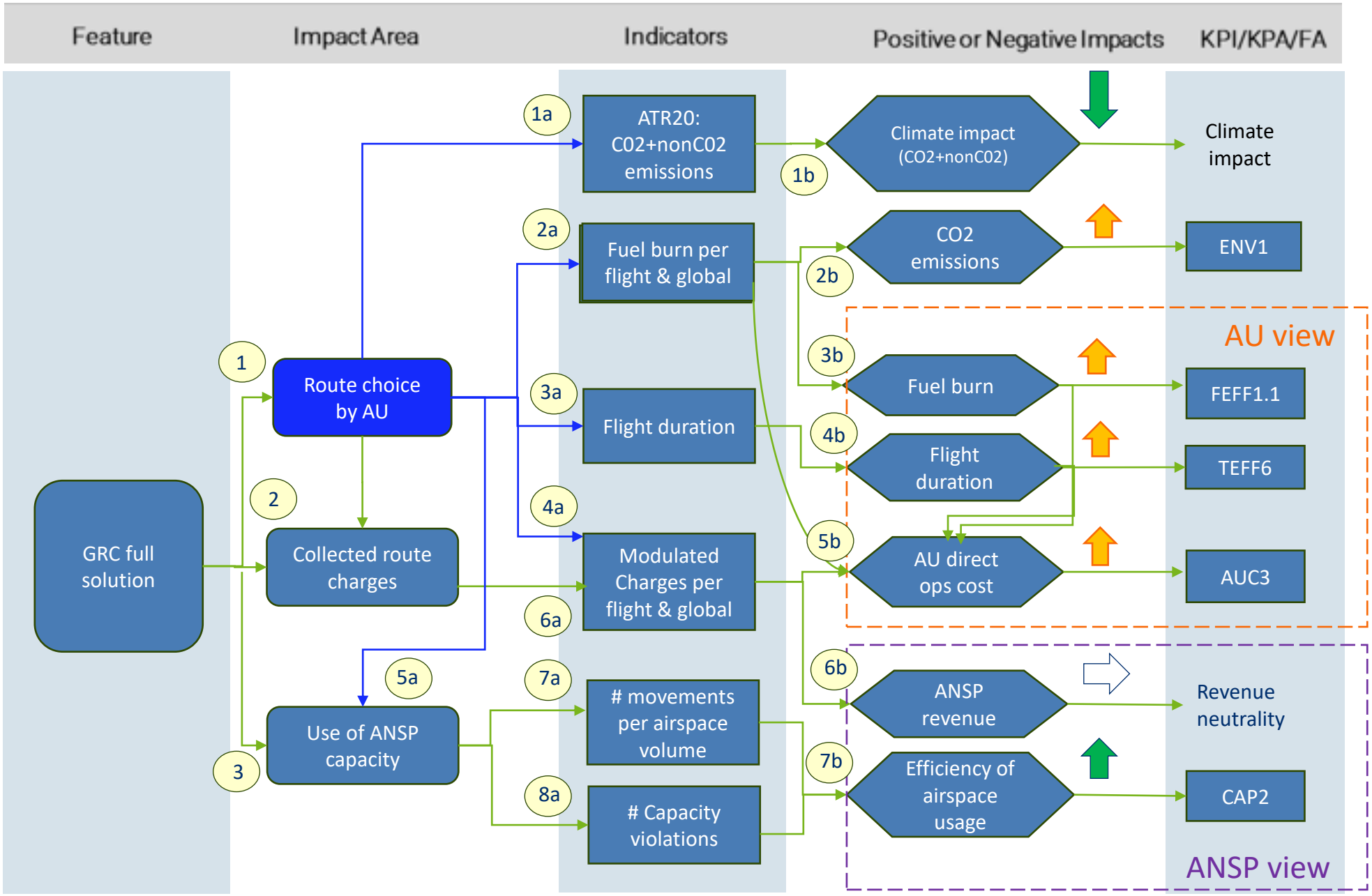
Activity/task part of Green-GEAR

Inputs Outputs

New tasks in Full Solution

New function

Activity with some impact from Green-GEAR



Benefit Impact Mechanisms (BIMs) – Full Solution

Stakeholder feedback

- Route charging system would become more complex
- Strong opposition to any environmental modulation of route charges
  - Perceived bias towards burden on airlines only
  - Immaturity of science behind non-CO_2 emissions
- Other limitations – material for discussions later on

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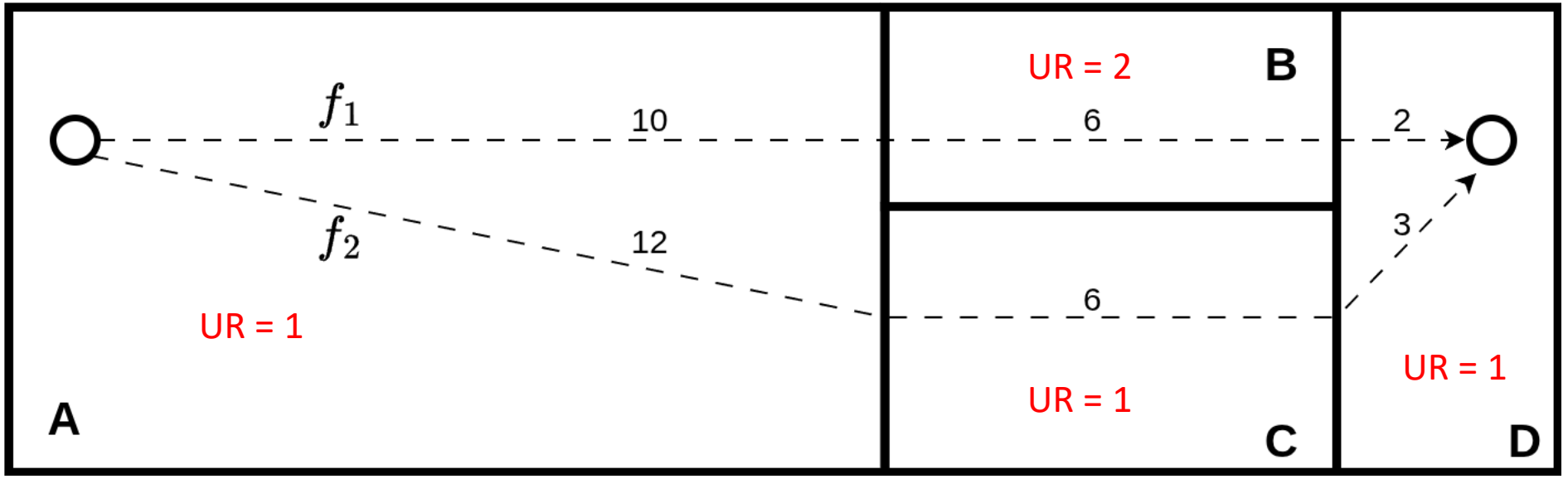
Longer routes may be cheaper in terms of RCs

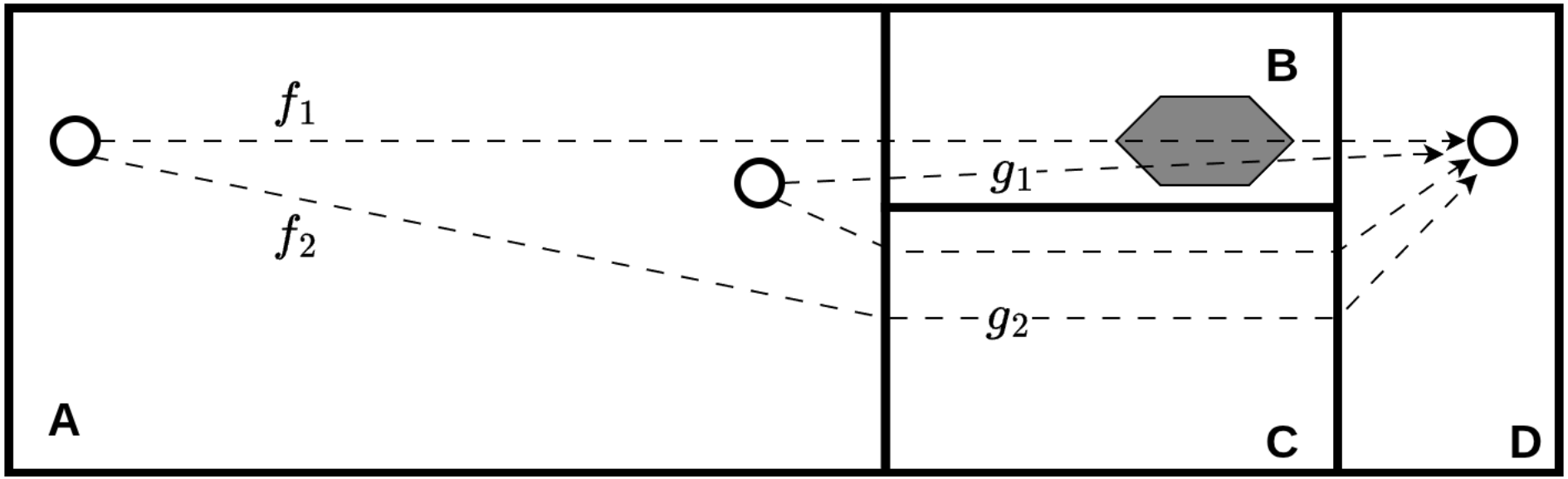


WF = 1, Distance 1 = 18 => RC1 = 10*1 + 6*2 + 2*1 = 24

WF = 1, Distance 2 = 21 => RC2 = 12*1 + 6*1 + 3*1 = 21

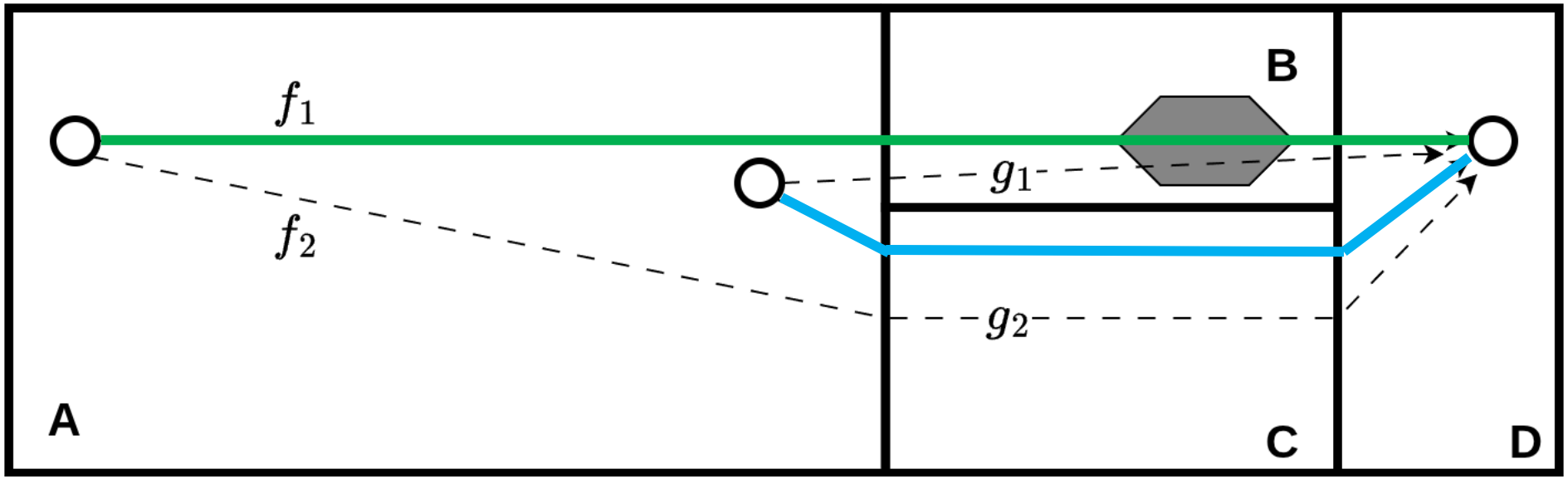
The current system may not incentivise the reduction of CO_2 emissions

Shortest routes are not always possible



To minimise CO_2, ideally f1 and g1, but if nominal capacity of the grey hexagon = 1, not possible

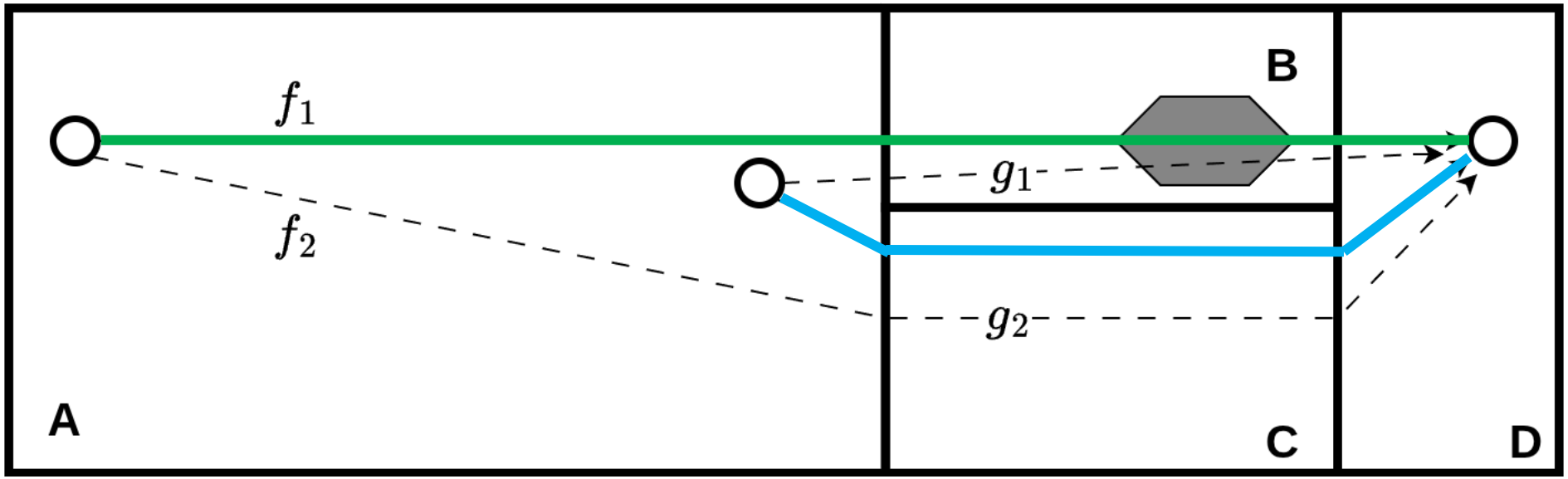
Shortest routes are not always possible



To minimise CO_2, ideally f1 and g1, but if nominal capacity of the grey hexagon = 1, not possible

Hence, the best option (min CO_2) is to fly f1 (green) and g2 (blue) because g2-g1 < f2-f1.

Shortest routes are not always possible

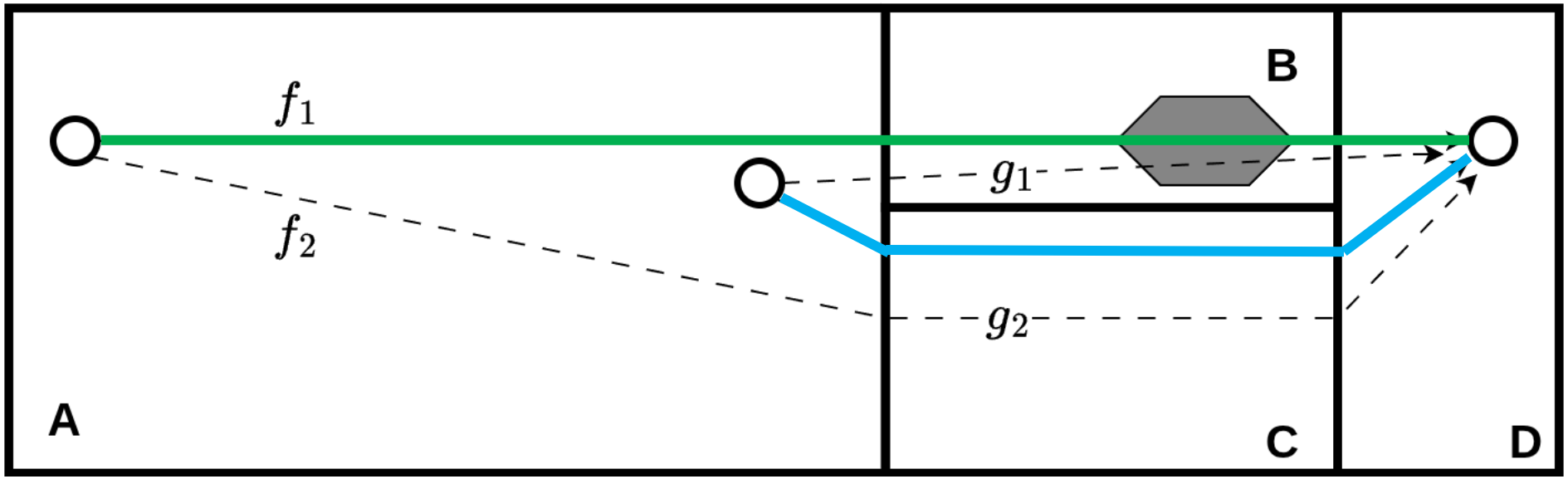


To minimise CO_2, ideally f1 and g1, but if nominal capacity of the grey hexagon = 1, not possible

Hence, the best option (min CO_2) is to fly f1 (green) and g2 (blue) because g2-g1 < f2-f1.

Question: can we tweak/tune/modulate route charges/unit rates to get f1 and g2?

Can we modulate route charges to get f1 and g2?



Yes, if consider route (trajectory) pricing, and not airspace pricing

A <u>modulation factor γ</u> per route is introduced such that

$$\gamma_{f1} \cdot RC_{f1} + AC_{f1} < \gamma_{f2} \cdot RC_{f2} + AC_{f2}$$
$$\gamma_{g2} \cdot RC_{g2} + AC_{g2} < \gamma_{g1} \cdot RC_{g1} + AC_{g1}$$

where AC (airborne strategic costs) is the sum

- **Fuel costs**
- **Fleet and crew utilisation costs**
- **Airborne maintenance costs**

(Cook and Tanner, 2015)

A mathematical framework

Three sequential subproblems

1. Solve a **flow problem** considering the "*statistically typical*" scenario (identify the set C_{OD} of the most common routes for each OD pair & use traffic forecast to predict traffic flow)
   - DECISIONS: compute the flow distribution (per OD, the portion of flights using each route) (green and blue)
   - OBJ: reduce capacity violations while minimising the flown distance
2. Computes and publishes modulation factor γ for each route in C_{OD}
   - DECISIONS: compute the γ
   - OBJ: minimise the deviation of γ from 1 (*i.e., modulate only if needed and as little as possible*)
3. Solve route selection and time shift problem day by day and **flight by flight. Here** γ is given, i.e., RCs are an input.
   - DECISIONS: allocate flights
   - OBJ: reduce capacity violations while minimising the flown distance

GRC Initial Solution – Benefits (Distance and fuel)

AIRAC cycle	Scenario	Origin OR destination in ECAC			Origin AND destination in ECAC		
		No. of flights	Distance flown	Diff	No. of flights	Distance flown	Diff
1910	Reference	929,640	1,726,552	/	739,305	824,530	/
1910	Minimum distance	929,640	1,713,831	-0.74%	739,305	811,809	-1.54%
1910	MRC	929,640	1,715,138	-0.66%	739,305	813,116	-1.39%

Distance flown

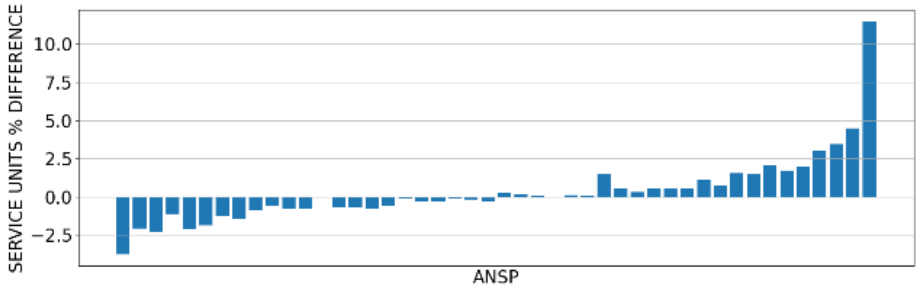
AIRAC cycle	Scenario	Origin OR destination in ECAC			Origin AND destination in ECAC		
		No. of flights	Fuel consumption	Diff	No. of flights	Fuel consumption	Diff
1910	Reference	929,640	8,946,937	/	739,305	2,701,070	/
1910	Minimum distance	929,640	8,905,678	-0.46%	739,305	2,659,811	-1.53%
1910	MRC	929,640	8,910,106	-0.41%	739,305	2,664,238	-1.36%

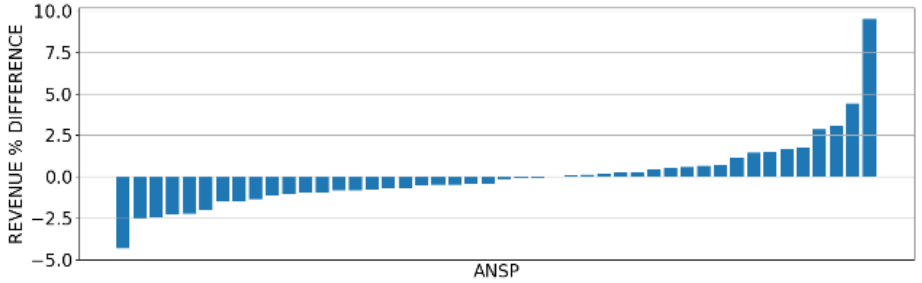
Fuel consumption

GRC Initial Solution – Benefits (ANSPs and AUs)

Top: service unit variation

Bottom: revenue variation





Total % difference	
Revenue	Service Units
-0.72 %	-0.20 %

Share of flights whose costs increased, decreased or remained nearly (±1%) the same compared to the reference

Increased	Decreased	Same cost
8.8%	25.4%	65.8%

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Concept of full solution

- Beginning of year:
  - Central planner (or similar entity) determines the Environmental Impact modulation rate (or **EI rate**) on each OD pair.
- At flight plan submission time, climate hotspots are predicted
- After the flight:
  - Flight pays normal CRCO charges
  - Flight crossing a hotspot pays an extra modulation charge: (EI rate) * (distance inside hotspot)
- Central planner redistributes the extra revenues to ANSPs, who can than lower the unit rates in the next period to keep revenue neutrality.

Concept of full solution

Some notes:

- Hotspots combine CO_2 and non-CO_2 impact: cheapest trajectory might be more fuel intensive sometimes.
- Mechanism is exactly equivalent to flight not crossing a hotspot having a rebate on their charges (because CRCO charges are decreased!).
- Flight pays the modulation charge based on the prediction of the central planner.
- An alternative flavour is to set the modulation charge based on the predicted total EI (no hotspot in this case).

Concept of full solution

How to set the EI rate?

➔ How to forecast the average EI (and financial impact) with the additional modulation of charge given that airlines will react to the modulation?

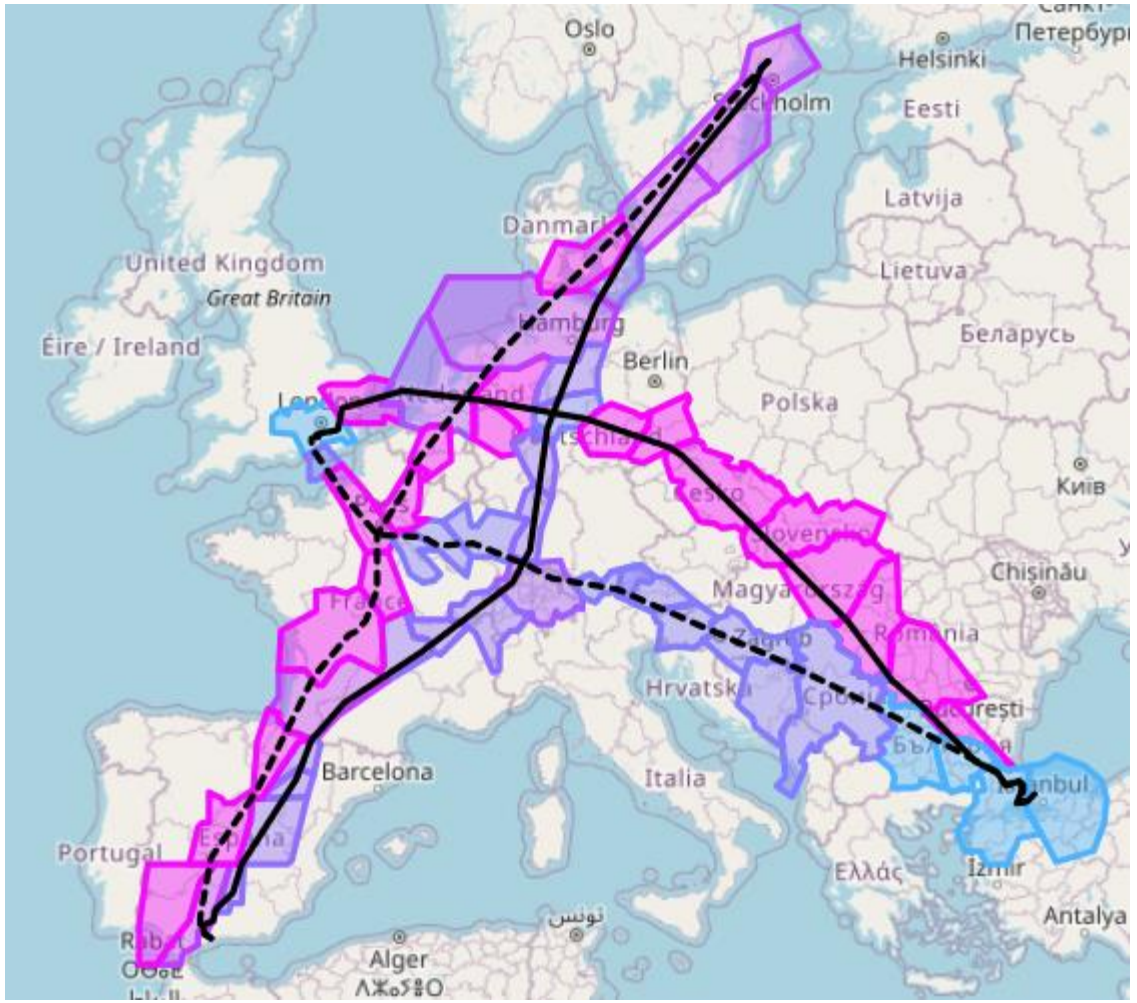
➔ Green-Gear developed a first simple model to do the forecast. More advanced models could be developed to be used by the central planner if the solution is implemented.

Model is semi-analytical, computes expectations of various indicators and adds an optimisation procedure to take congestion into account.

Scenarios

Different scenarios, all traffic data from 19th September 2019:

- Small: 'EGKK’ -> 'LTFM', 'ESSA’-> 'LEMG’
- Medium: all flights from and to 10 biggest airports in Europe
- Big: all flights from and to 100 (?) biggest airports in Europe



Indicators and parameters

Indicators:

- Environmental impact
- Fuel consumed
- ANSP revenues
- Capacity violations
- Airline costs

Parameters:

- Environmental impact (EI) modulation charge
- Route charges
- Delays (for capacity constraints)

'Free' and 'Cap' computation: effect of EI rate

'Free' assumptions:

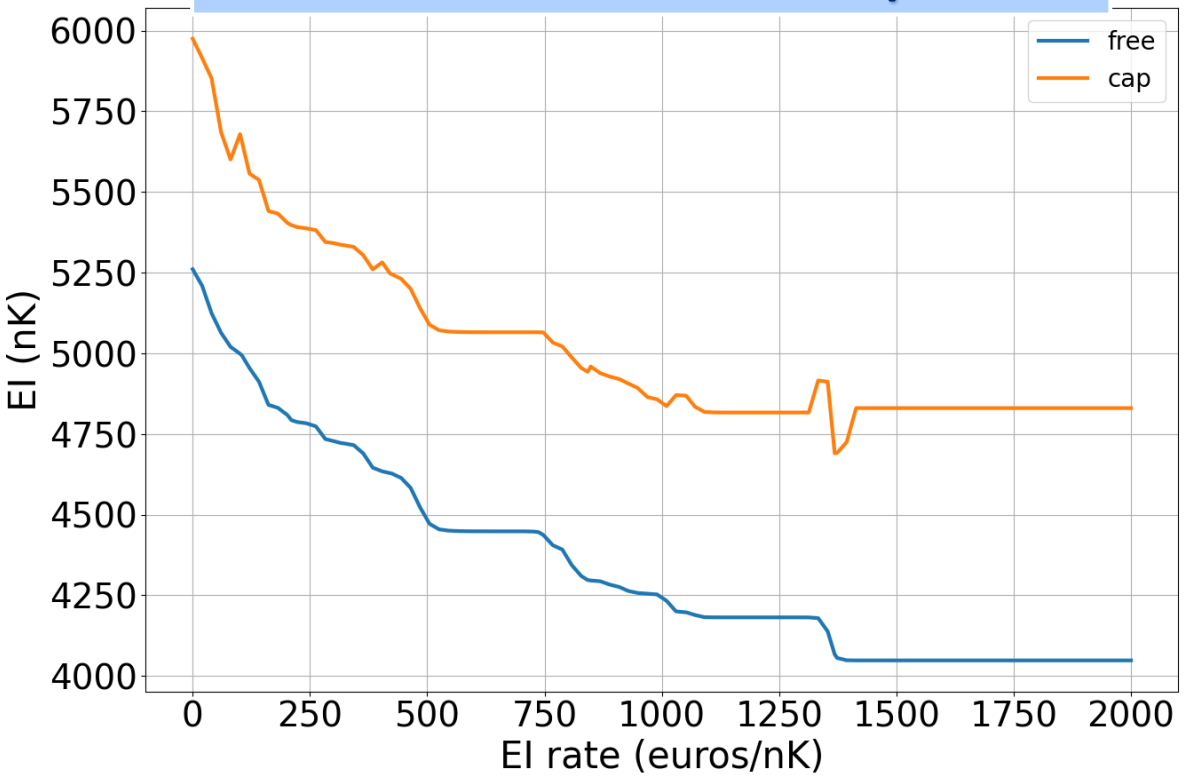
- Airlines choose minimum cost
- No redistribution of money
- Infinite capacity

'Cap' assumptions:

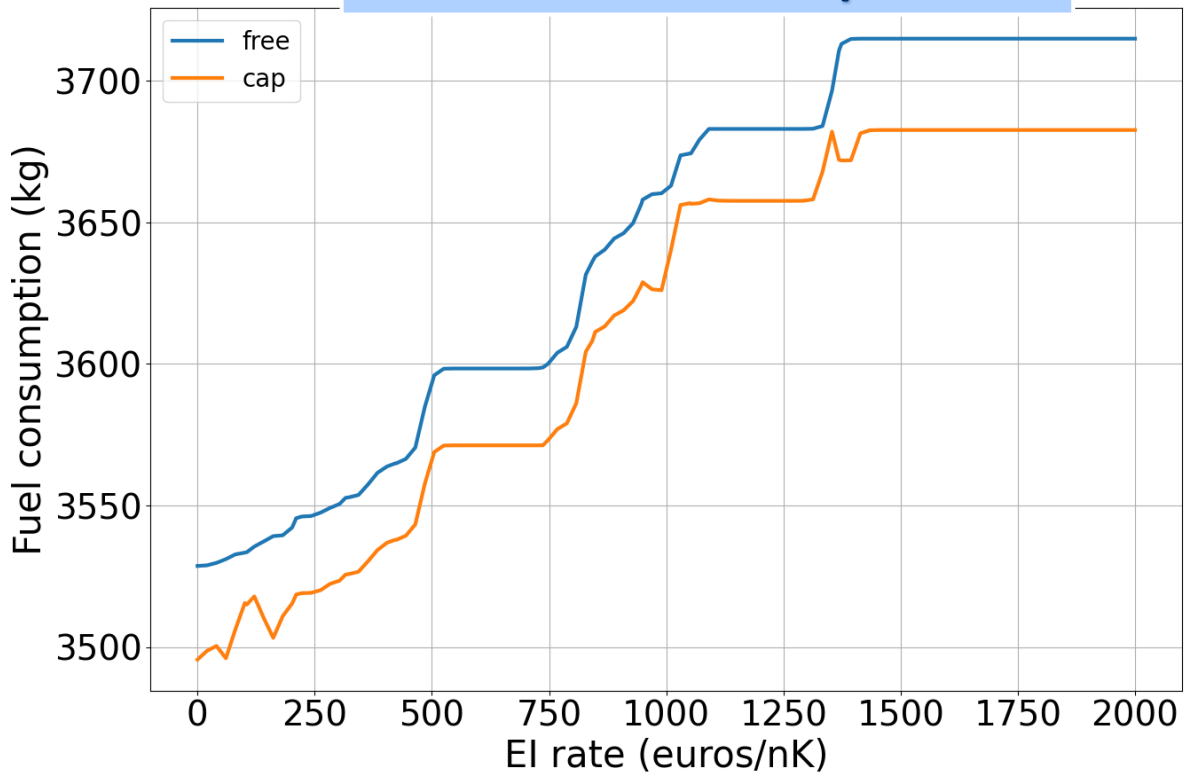
- Airlines choose minimum cost
- No redistribution of money
- Capacity constraints

EI and fuel consumption

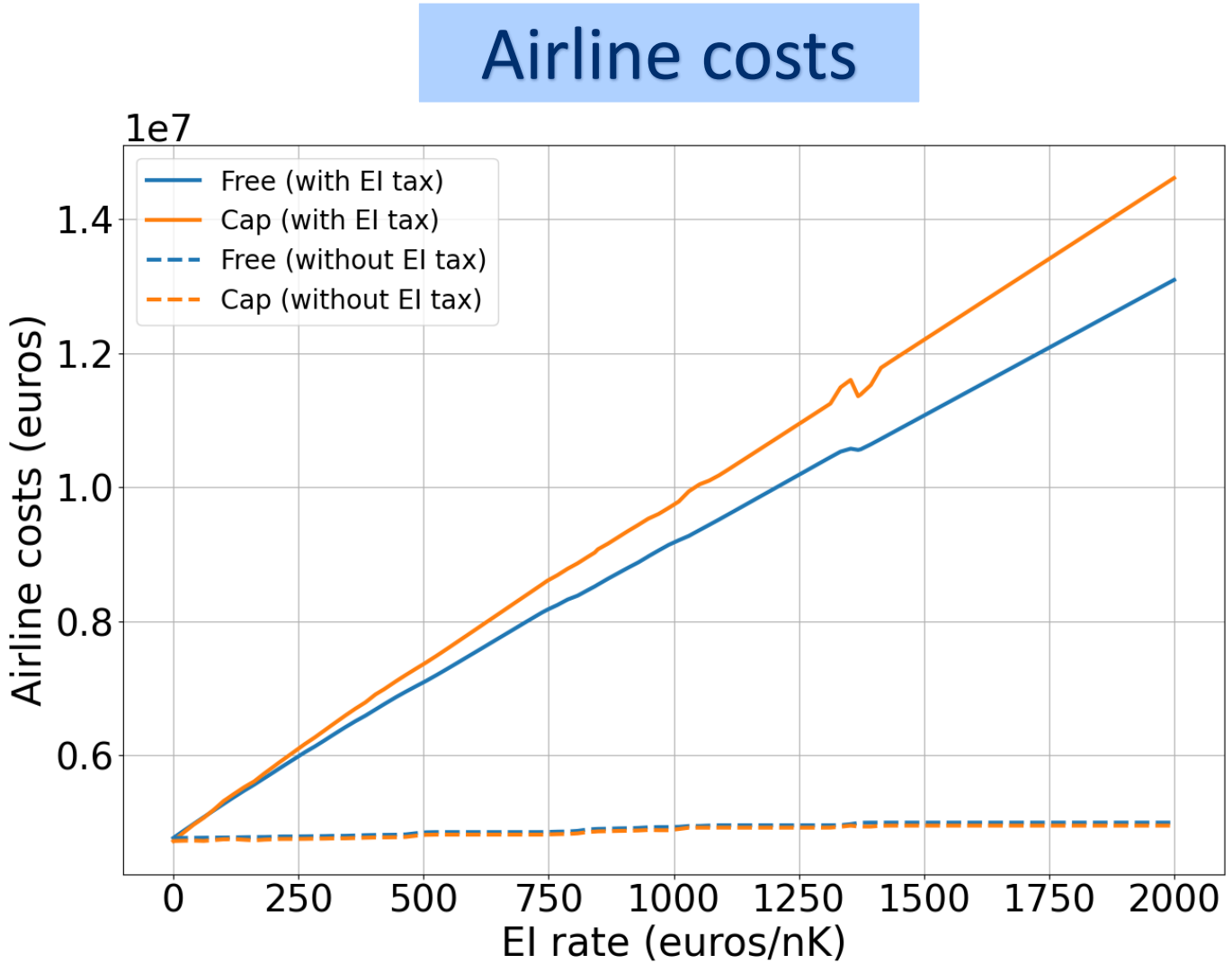
Environmental impact



Fuel consumption



Airline costs

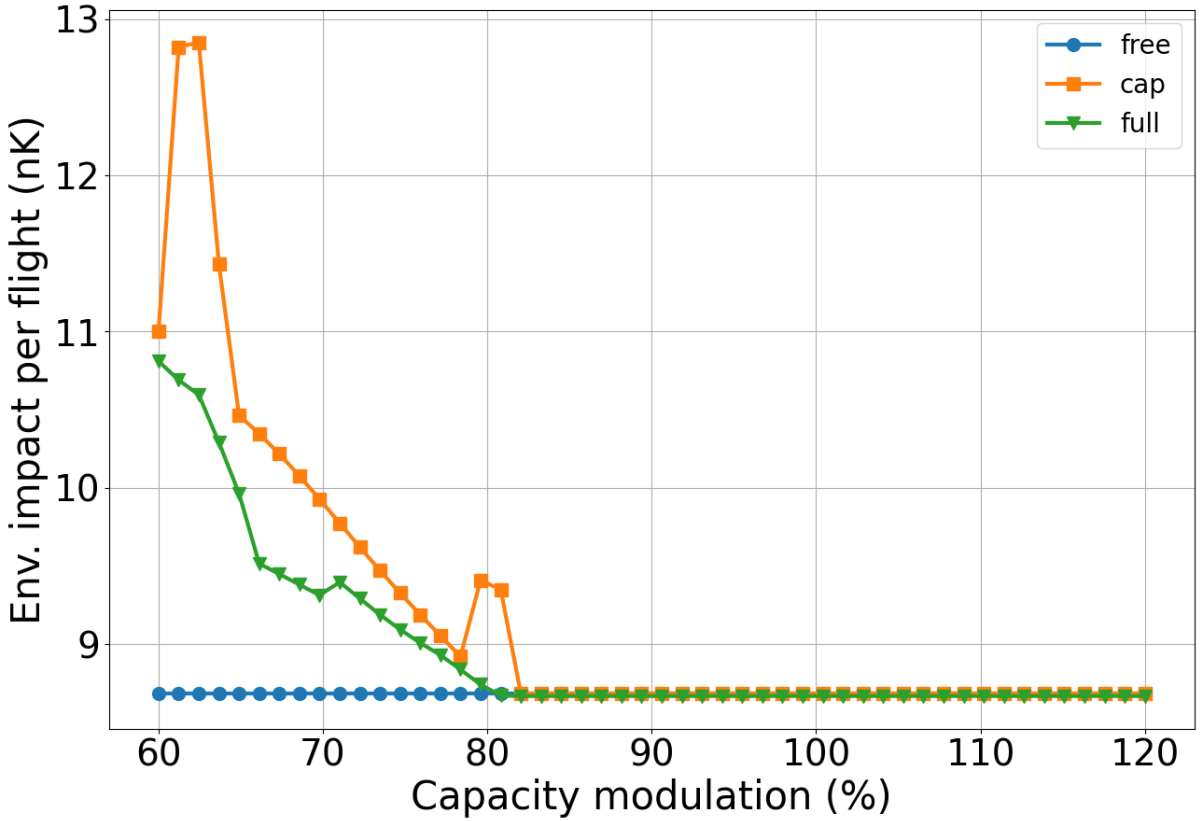


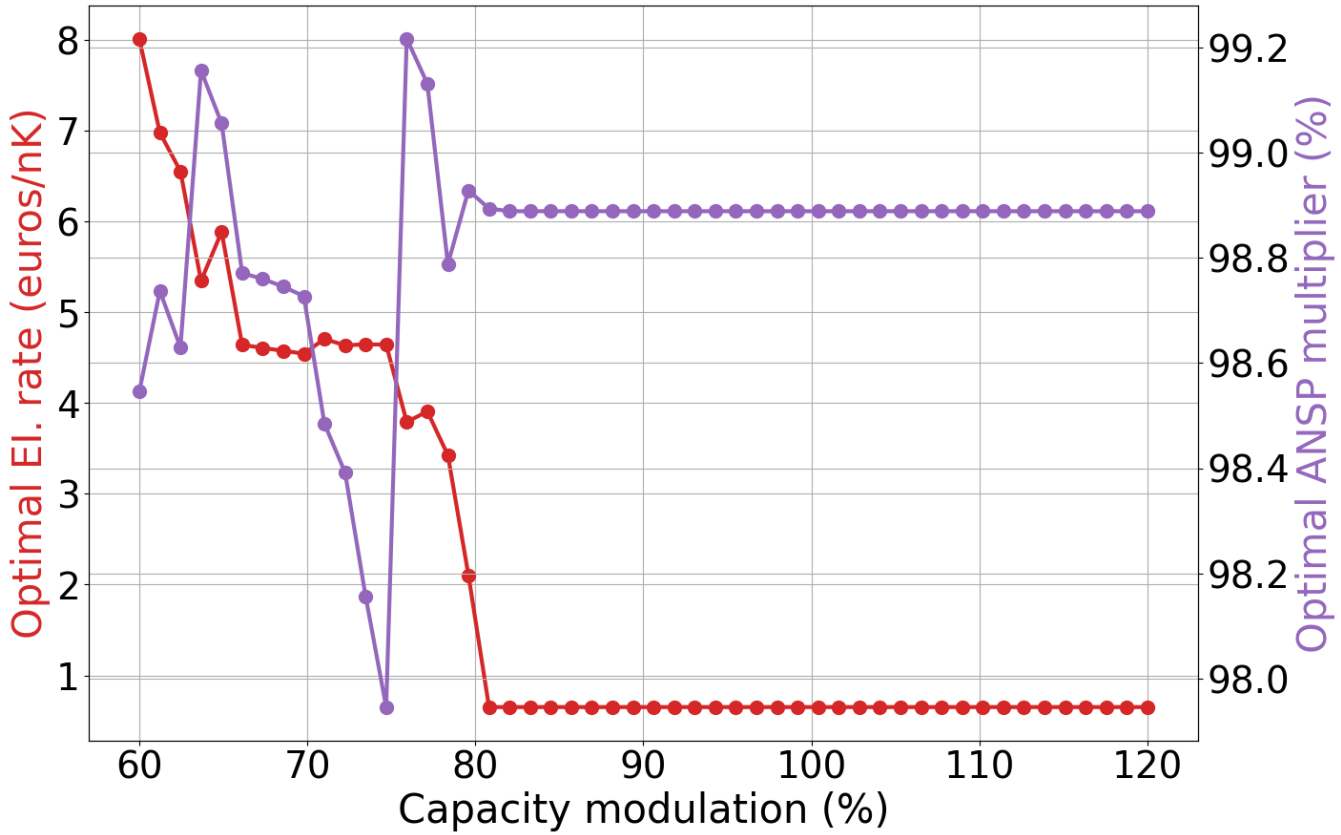
“Opt” computation: minimising EI

Assumptions:

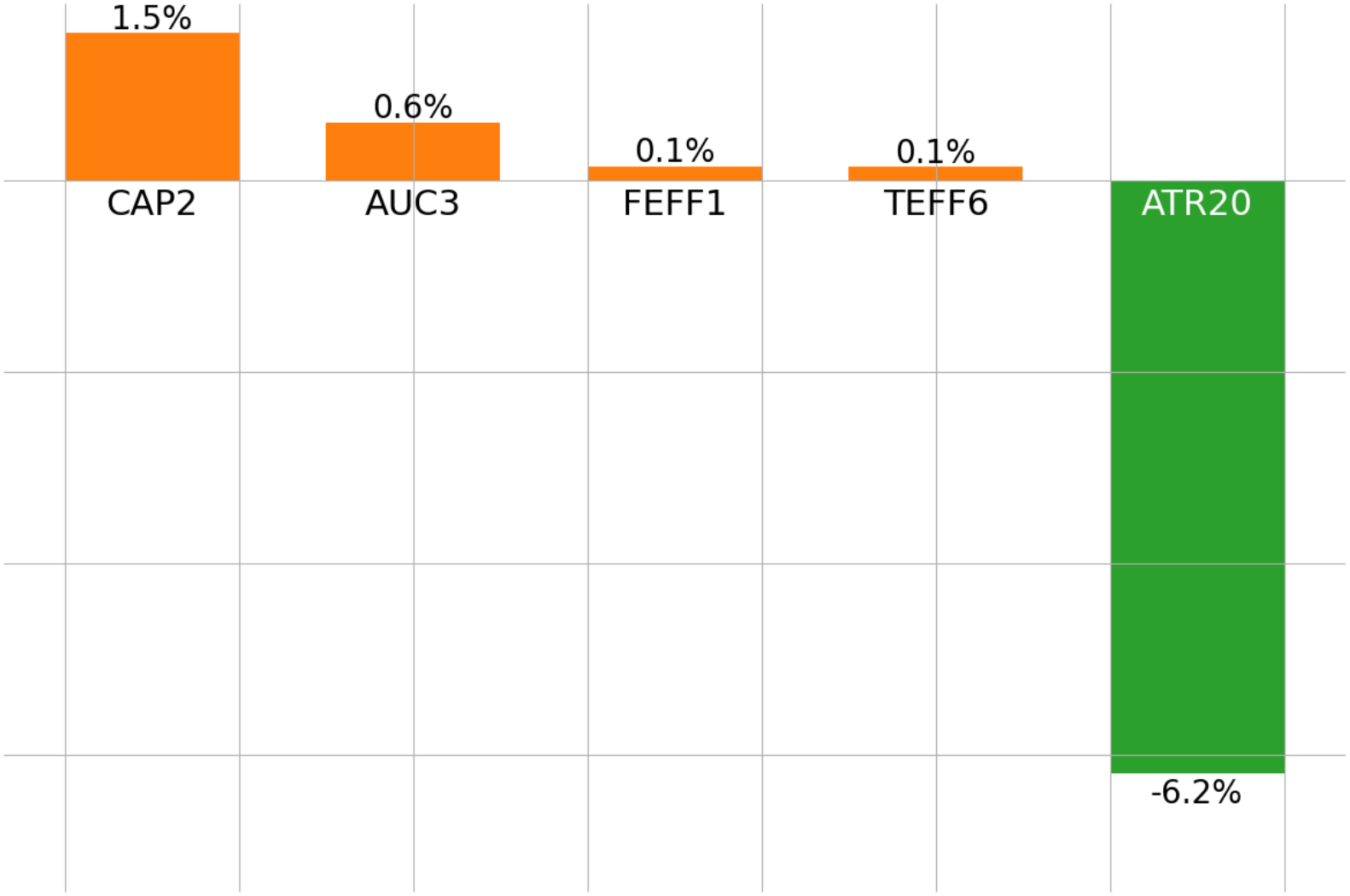
- Airlines choose minimum cost
- Redistribution of money
- Capacity constraints
- Optimiser finds best EI rate for system

Environment Impact and capacity





KPIs



Enablers and barriers

Required enablers:

- Accurate forecaster for hotspots a few hours before,
- Central planner computing the EI rate, or trusted service.
- Trajectory optimisers need access to this service.

Current barriers:

- Forecast of hotspots not good enough for implementation
- Approximation of hotspots for different flight/engines might be too coarse
- Total cost is higher with EI (it’s normal: we are minimising EI instead of cost): Who is the paying the extra cost?

GRC discussion

Implementation options

If some form of charge modulations were implemented, how might it work?

- ? Hotspot different for different engines
- **? airspace-based** (sector-based) / based on the **flight plan**
  - ? modulations in NOP Portal / CRCO ETNA Portal, annually / seasonally (pulled to FP systems)
  - ? modulations pushed to FP systems by other mechanism
- **? trajectory-based**
  - ? modulations based on **expected trajectories**
  - ? modulations based on **actual trajectories** (retrospective analysis)
  - ? no modulations! (voluntary / collaborative avoidance, cf. MUAC example)

Implementation options

- ? No modulation: statistical approach – e.g. based on ETS / MRV (update frequency?)
- ? Equity and stakeholder workload (other cost) implications
- ? Compatibility with other NM actions
  (e.g. enhanced network measures, summer 2019, via RAD)
- Policy issues:
  - ? What would be the correct time frame – year, season?
  - ? Unit rate reduction (redistribution of revenues)

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