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SESAR 3 ER 1 Green-GEAR – D5.6 – ECO-EVAL – Green route charging

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Abstract

Green-GEAR aims to enable and incentivise optimum green trajectories and airspace use through new ATM procedures; it develops three new SESAR Solutions to this end. This document provides the economic evaluation (ECO-EVAL) of the Green-GEAR solution 0408 "Green route charging", one part of which (Initial Solution) targets TRL 2, with the other part (Full Solution) targeting TRL1. The present ECO-EVAL assesses its potential benefits and costs for various stakeholders. The ECO-EVAL covers the period from 2026 to 2050 and evaluates the deployment of Green route charging compared to a current reference scenario.

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Green-GEAR

GREEN OPERATIONS WITH GEOMETRIC ALTITUDE, ADVANCED SEPARATION & ROUTE CHARGING SOLUTIONS

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1 Executive summary

This document provides the economic evaluation (ECO-EVAL) related to the ECAC level deployment of Green route charging (GRC) Solution #0408 that has been matured through validation activities to TRL2. GRC proposes novel charging mechanisms that incentivises trajectories with minimum climate impact, while reducing airspace congestion, through introduction of environmental modulation of charges. The GRC Solution developed the Initial (CO_2 and congestion) and Full Solution (full emissions and congestion).

The current route charging is in place in 41 Member States to the Multilateral Agreement on Route Charging, which is the area of eventual implementation of GRC Solution. The following Solutions could help in the eventual implementation: #0429 Climate optimised trajectories including non-CO2 effects, #0421 AEROPLANE Climate Services for climate change mitigation and adaptation in Aviation, #0374 E-CONTRAIL Climate Hotspot Prediction Service. Furthermore, it could both benefit from and constitute a use case for #0408 Green GEAR Separation Minima, allowing aircraft to fly closer together safely, enabling to mitigate the negative effects of detours / flight level changes to avoid climate hotspots.

The stakeholders impacted by the Solution are: **Airspace Users (AUs)**, **Air navigation service providers (ANSPs)**, Flight Dispatchers, Computerised Flight Plan Service Providers (CFSPs), National supervisory authorities (NSA), States, European Commission, Performance Review Board[2] (PRB), EUROCONTROL – CRCO, Central planners (new role), Network Manager (NM), MET providers.

The **Initial Solution**, demonstrates a reduction of CO_2 emissions (ENV1) by **0.25–1.36%,** with the most pronounced improvements observed for flights entirely within ECAC airspace. Congestion was significantly alleviated, with capacity violations decreasing by **91.2–94.1%** across the traffic periods assessed. While these results are promising, the validation scope has inherent limitations, including reliance on 2019 data and partial coverage of annual traffic variability, which was also raised in the stakeholder feedback (see Appendix B for details). The consistent performance across different scenarios strengthens confidence in the applicability of the environmental modulation for CO_2.

Full GRC Solution. Due to the complexity of non-CO_2 emissions, the project first assessed whether a climate hotspot-based approach was viable, requiring a simplified new model. Initial results tested the mechanism on a larger (but limited) sample, where it was demonstrated that most of KPIs were affected in a slightly negative or neutral manner, except the PI on full emissions, which shows **14% reduction** of full emissions impact (measured by ATR20).

The initial implementation costs would fall on ANPSs, AUs and a new function of Central planner, regarding the setup of novel route charging mechanisms (which is subject to EU regulations). Operating costs would be rather similar to those of today for the Initial Solution, while they might differ for the

[2] Performance Review Board is the new title, from REGULATION (EU) 2024/2803. Previously, it was the Performance Review Body.

Full Solution (need for daily weather forecasts). Other stakeholders would be impacted by the change in regulation, in case the proposed solution is accepted.

The validation results demonstrate promising trends in environmental efficiency, congestion reduction, and cost savings, supported by consistent performance across different traffic scenarios. However, the limited sample size and reliance on historical data temper the statistical certainty, while operational realism is constrained by the absence of edge cases. Needed next steps are detailed in the document.

2 Introduction

2.1 Purpose of the document

This document defines the economic evaluation (ECO-EVAL) for Green route charging (GRC) Solution #0408.

2.2 Scope

The GRC Solution defines a new route charging mechanism, and as such would be applicable for all the States adhering to the Multilateral Agreement on Route Charging, specifically for en-route charges; 41 contracting States include the 27 EU Member States. The operational scope is limited to en-route airspace. It is assumed that traffic, airspace, and airport characteristics are the same as today, as the GRC Solution can apply irrespective of the operational environment. The GRC's charging mechanism changes how the route charges are determined and charged, impacting the day-to-day operations only indirectly, through the modulation of unit rates.

New entrants (aircraft with electric or hybrid propulsion) are out of scope of the work here as there is insufficient data on their performance – from aircraft performance view, and on the potential inclusion in the airline networks.

The stakeholders impacted by the Solution are:

- Airlines,
- Flight Dispatchers,
- Computerised Flight Plan Service Providers (CFSPs),
- National supervisory authorities (NSA),
- States,
- Air navigation service providers (ANSP),
- European Commission,
- Performance Review Board[3] (PRB),
- EUROCONTROL – CRCO,

[3] Performance Review Board is the new title, from REGULATION (EU) 2024/2803. Previously, it was the Performance Review Body.

- Central planners (new role),
- Network Manager (NM),
- Weather data providers.

The GRC Solution explores two versions: Initial Solution that includes only CO_2 emissions, and the Full Solution that takes into account all emissions. The Initial Solution is at the higher maturity level. Both versions could be implemented within 2 years, if only implementation is taken into account. However, as route charges are subject to the Performance and Charging Scheme [26] and the SES2+ regulation [27], the GRC Solutions would need to obtain consensus and pass through the process of regulatory change. The SES2+ regulation took a very long time from the initial discussions to its final adoption, and from the feedback received during the project this topic is rather contentious, and as such it is rather difficult to foresee the time needed for regulatory change. Thus, we can only foresee the time that would be needed for the implementation itself (i.e. 2 years), after the regulation change, if it is accepted.

2.3 Intended readership

This document is aimed at the following stakeholders:

- All Green-GEAR consortium members who are contributing directly to the Solution research or contributing to related Solutions or work packages in the project (Airbus, DLR, EUROCONTROL, NATS, NLR, UNITS, UoW),
- Relevant SESAR projects,
- SJU Programme representatives,
- All interested stakeholders (see previous section, 2.2).

2.4 Background

This section presents the background on which the Green-GEAR project is building, focusing on previous work and existing systems that have influenced the project's direction [24].

2.4.1 Route charging regulations and route charging system

The Green-GEAR project builds upon the existing EUROCONTROL route charging system, a regional cost-recovery mechanism adhering to ICAO’s charging policies and the Single European Sky regulations [28][26][27]. EUROCONTROL contracting States apply a regional common route charging system specifically for en-route charges. Initially based on historical costs, the system moved to forecast costs in 1983, introducing the concept of under and over recovery of costs. The establishment of the Single European Sky in 2004 emphasised transparency and economic regulation, leading to the adoption of the determined costs method alongside the existing full cost recovery method. In 2020, the calculation method transitioned from charging on filed route to charging on actual route flown.

The purpose of the shift to actually flown route was twofold: to improve the cost-relatedness of revenue for the ANSPs and to increase predictability and efficient use of airspace. This change aimed to remove the incentive for airlines to file "route charges optimised" flight plans, which were not always adhered to and often led to less efficient use of airspace and reduced predictability for ANSPs.

Regulation (EU) 2024/2803 (the SES2+ regulation [27]) is a recent development, adopted on 23 October 2024, states the following on the establishment of (environmental) charges:

"5. The Commission shall, in consultation with the Member States, air traffic service providers and airspace users, **conduct a study** on the contribution of the modulation of charges to the achievement of the objectives of the Single European Sky, defined in Article 1(1) of this Regulation, and of Regulation (EU) 2021/1119. This study shall also **assess the feasibility of that modulation** and its impact on air traffic, service provision, administrative costs and stakeholders.

6. The result of the study referred to in paragraph 5 of this Article will provide the essential information for the Commission to determine whether to adopt an implementing act in accordance with Article 48(3), to ensure the uniform application of modulation of en route charges to encourage airspace users to support **improvements in climate and environmental performance** such as the use of the most fuel-efficient available routing, increased use of alternative clean propulsion technologies including sustainable alternative fuels, while maintaining an optimum safety level.

7. The modulation referred to in paragraph 6 shall consist of financial advantages or disadvantages and **shall be revenue neutral for air traffic service providers**.[27]"

The GRC Full Solution explores the feasibility of environmental modulation of charges, the topic itself being in line with the regulatory provisions. The main regulatory assumption used in the project is that environmental modulation is allowed. At this TRL level the project is only testing the general feasibility.

2.4.2 Origin-destination charging

The project also incorporates elements from an Origin-destination charging (ODC) mechanism, which aims to eliminate detouring incentives. Unlike the common unit rate system, ODC allows ANSPs to keep their own unit rates and contribute to reducing CO_2 emissions compared to the current charging on actual route system. The ODC concept was originally published under the name FRIDAY (Fixed Rate Incorporating Dynamic Allocation for optimal Yield) [25]. ODC aims to ensure that route charges are more predictable and environmentally driven, providing a fixed charge for routes based on the great circle path between origin and destination airports, thus reducing the incentive to detour when optimizing for the costs of fuel, flight time, and route charges.

2.4.3 Previous Research Projects

This project builds on a foundation of prior exploratory research activities both within and outside SESAR and falls within the scope of the effort made by the European Green Deal, the overarching policy framework striving for climate neutrality by 2050, which emphasises reducing emissions across various sectors, including aviation. Notably, several significant past projects have laid the groundwork:

- **SATURN (Strategic Allocation of Traffic Using Redistribution in the Network)**: Focused on the modulation of en-route charges to redistribute traffic across Europe, providing initial insights into how pricing strategies can influence traffic flow [32].

- **ADAPT (Advanced Prediction Models for Flexible Trajectory-Based Operations)**: Explored advanced prediction models aimed at enhancing flexible, trajectory-based operations, providing a basis for adaptive decision-making in air traffic management.
- **Pilot3 (from Clean Sky 2)**: Contributed by integrating environmentally focused initiatives under the Clean Sky 2 umbrella, emphasising sustainability in aviation through innovative approaches and technologies.
- **COCTA (Coordinated Capacity Ordering and Trajectory Pricing for Better-Performing ATM)**: Provided an in-depth examination of coordinated capacity ordering and trajectory pricing, aiming to improve air traffic management (ATM) performance through strategic pricing and capacity management.
- **CADENZA (Advanced Capacity and Demand Management for European Network Performance Optimization)**: Focused on reducing air traffic emissions and improving overall network performance through enhanced demand-capacity balancing strategies.
- **ATM4E**: Explored the feasibility of a concept for environmental assessment of ATM operations, working towards environmental optimisation of air traffic operations in the European airspace, considering climate, air quality, and noise impacts.
- **CONCERTO**: Currently running, aims to make eco-friendly flight trajectories an everyday occurrence, reducing both CO_2 and non-CO_2 emissions from aviation by integrating green Air Traffic Control (ATC) capacities with appropriate automation.
- **GEESE**: Currently running, aims to develop an initial concept of operations for enabling Weather-Efficient Routing (WER) from Europe to the North Atlantic, analysing safety aspects and impacts on legacy systems.
- **CICONIA**: Currently running, focuses on reducing aviation's climate effects through innovative CONOPS, closely examining non-CO_2 effects and exploring methods to measure them.

These preceding and currently ongoing projects contribute valuable insights and methodologies that inform the development of this project's route charging mechanisms. They illustrate the use of pricing mechanisms to effectively manage air traffic and foster environmentally sustainable operations.

2.4.4 CLIMaCCF / FlyATM 4E and ALARM Projects

The consortium used the CLIMaCCF V1.0 Python library for defining climate hotspots, which is a product of the FlyATM 4E and ALARM projects [33]. This library computes individual and merged non-CO_2 algorithmic climate change functions (aCCFs) and is still under development and validation. These projects provide advanced climate science tools that allow the Green-GEAR project to address both CO_2 and non-CO_2 emissions in its route charging mechanisms. By leveraging these models, the project aims to enhance the accuracy and effectiveness of its environmental impact assessments.

2.4.5 Monitoring and reporting regulation

Note that the latest Monitoring and Reporting Regulation (MRR) [29] of the Emissions Trading Scheme (ETS) sets an obligation on aircraft operators to report on the non-CO_2 impact of their flights, starting on January 1st, 2025. The models used in the Full Solution for environmental impact assessment are those set in the ETS regulation (aCCFs only), and the input data for weather forecast are foreseen to be the same, when available out of the NEATS tool. By the end of 2027, the Commission will deliver a report on the results of this reporting mechanism and if appropriate, make a legislative proposal to address non-CO_2 effects of aviation through the ETS.

The Full Solution, in Green-GEAR, explores **route charging modulation** to decrease the climate impact of aviation. The MRR and ETS **are not in scope** of the Solution.

However, the consortium would like to flag that having two regulations (i.e. Performance and Charging Scheme and MRR) trying to achieve the same goal, would require careful investigation on the exact goals of each regulation, the impacts of each, and careful delineation of eventually adopted goals under each.

2.5 Structure of the document

Section 2 (this section) provides the context for the project concept.

Section 3 is the main section that defines the objectives and the scope of the economic evaluation of the GRC Solution, which is split into an Initial GRC Solution – for which 2 options were explored – and a Full GRC Solution (longer term).

Section 4 describes the benefits that the GRC Solution could bring, while the section 5 describes qualitatively the costs that the implementation of the Solution would require. Section 9 discusses the recommendations and next steps needed to mature the GRC Solution (described in Appendix A). Appendix B includes the stakeholder feedback obtained regarding the solution.

Sections 6,7, and 8 do not apply at TRL2 maturity level that a part of this solution (Initial GRC Solution) reached.

2.6 Glossary of terms

Term	Definition	Source of the definition
En-route charging zone	A volume of airspace that extends from the ground up to - and including - upper airspace, where en-route air navigation services are provided and for which a single cost base and a single unit rate are established.	Single European Sky (SES) performance & charging scheme
Unit rate	The unit rate of charge is the charge applied in a charging zone to a flight.	EUROCONTROL 2022
Route charge	The route charge is a levy that is designed and applied specifically to *recover the costs* of providing facilities and services for civil aviation.	ICAO Doc 9082

Term	Definition	Source of the definition
Cost base	The cost base for en-route charges consists of the determined costs related to the provision of air navigation services in the charging zone concerned. Determined costs are the costs determined by the Contracting States at the level of the charging zone. These are the costs to be shared among airspace users.	SES performance & charging scheme EUROCONTROL 2022
Environmental impact (EI)	The total emissions, CO_2 and non-CO_2, produced by a flight or a set of flights, measured in general in nK of increase of temperature at the 20 years horizon (called also ATR20).	Using CLIMaCCF [33] ATR calculations
Environmental impact rate	The rate (euros per nK) at which the emissions at taxed in the full solution. This rate is set by a central agent like the Network manager.	Developed in project
Modulation of charges	"Member States may, on a non-discriminatory and transparent basis, modulate air navigation charges for airspace users to: (a) optimise the use of air navigation services; (b) reduce the environmental impact of flying; (c) reduce the level of congestion of the network in a specific area or on a specific route at specific times; (d) accelerate the deployment of SESAR ATM capabilities in anticipation of the time period set out in the common projects referred to in Article 15a(3) of Regulation (EC) No 550/2004,… Member States shall ensure that modulation of charges in respect of points (a) to (c) of this paragraph does not result in any overall change in annual revenue for the air navigation service provider compared to the situation where charges would not have been modulated. Over- or under recoveries shall result in an adjustment of the unit rate in year n+2."	SES Performance & Charging Scheme
NWP	Numerical Weather Prediction – Forecast of the climate hotspots, that will be issued by the MET Offices. It can be used as an input by the GRC Full solution	ETS Regulation

Term	Definition	Source of the definition
Performance & Charging Scheme	Commission Implementing Regulation (EU) 2019/317 of 11 February 2019 laying down a performance and charging scheme in the single European sky [26] and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013 (Text with EEA relevance.)	SES Performance & charging scheme

Table 1: Glossary of terms

2.7 List of acronyms

Term	Definition
aCCF	algorithmic climate change function
ANS	air navigation services
ANSP	air navigation service provider
ATFM	air traffic flow management
ATM	air traffic management
AU	airspace user
AUC3	Direct operating costs for an airspace user
CAP2	En-route throughput in challenging airspace per unit time
CFSP	Computerised Flight Plan Service Providers
CRCO	Central Route Charges Office
D<*no.*>	Deliverable <*no.*>
DES	Digital European Sky
EC	European Commission
ENV1	Actual Average CO_2 Emission per flight
ER	Exploratory Research
ERP	Exploratory Research Plan
ETS	Emissions Trading Scheme
EU	European Union

Term	Definition
FEFF1	The total amount of actual fuel burnt divided by the number of flights
Green-GEAR	Green operations with Geometric altitude, Advanced separation & Route charging Solutions
GRC	Green route charging
MET	Aviation meteorology
MRR	Monitoring and Reporting Regulation
MRV	monitoring, reporting, and verification
NEATS	Non-CO2 Aviation Effects Tracking System
NM	Network Manager
NSA	national supervisory authority
ODC	Origin-destination charging
OSED	Operational Service and Environment Description
RP	Reference period
SES	Single European Sky
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SP	Stated preference
SRIA	Strategic research and innovation agenda
TEFF6	Average of actual en-route durations
TRL	technology readiness level
UK	United Kingdom [of Great Britain and Northern Ireland]
UKRI	UK Research and Innovation
WTP	Willingness to pay

Table 2: List of acronyms

3 Objectives and scope of the ECO-EVAL

The GRC Solution, composed of the Initial and Full Solution, is aiming at creating charging mechanisms that would incentivise the use of environmentally friendly trajectories. The Initial GRC Solution takes into account only CO_2, while the Full Solution takes both CO_2 and non-CO_2 emissions into account.

3.1 Problem addressed by the SESAR solution

The current route charging mechanism is implemented by EUROCONTROL's Central Route Charges Office (CRCO), based on the Multilateral Route Charging System. Multilateral Route Charging System in the European Union was regulated by the Implementing Regulation IR 2019/317, the Single European Sky performance and charging scheme [24]. The new Regulation (EU) 2024/2803 of the European Parliament and of the Council of 23rd October 2024 on the implementation of the Single European Sky is now in force, describing performance and charging schemes. This regulation is termed as SES2+ [27].

Currently, the route charge "is a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation." The route charges recover only the costs of service provision, even if the IR 2019/317 [26] allowed modulation of charges to address congestion for example.

Current route charging does not take into account incentives for planning of environmentally friendly trajectories, which is now proposed in SES2+, under caveat that a feasibility study should be performed before setting any modulation of route charges.

3.2 SESAR Solution description

The GRC Solution is thus an enabler for the European airspace to become the most environmentally friendly in the world, as set in the SRIA and the ambitions of the European Green Deal, and enables aviation to become more environmentally efficient [30][31].The Green route charging (GRC) Solution developed the Initial and Full Solution and performed validation exercises [39].

The **Initial Solution** proposes a novel route charging mechanism aimed at improving horizontal flight efficiency and reducing the resulting CO_2 emissions. The Solution addresses **route charging,** which is determined **strategically** with respect to flight planning, providing a price signal to AUs that encourages more efficient flight planning, environment and capacity-wise, also resulting in better predictability and optimised use of capacity for ANSPs. For instance, the solution incentivises trajectories that avoid congested airspace at peak times, and it removes the incentive of flying detours to avoid expensive airspaces.

CO_2 emissions are assumed to be a proxy for flight distance. Vertical flight efficiency is not modelled at this TRL level. Other ATFM phases are not covered, as the setting of the unit rates for route charging is a strategic process that needs to be stable for at least a year of operations. The impact of the Solution on the daily operations is assessed during the validation exercises in this project, which will inform the further research needs for higher TRL levels.

From a regulatory perspective, the Solution must comply with the EU and ICAO rules and regulations (e.g. no discrimination, cost relatedness, proportionality, and revenue neutrality…) [26][27][28].

Two options were explored in the **Initial Solution**:

- **Introducing a 'Modulation of route charges' (MRC) mechanism**, applied to the current trajectory-based route charges. Modulation factor *M* is determined for each route of a given origin-destination traffic flow, with the objective to reduce the environmental impact of flying, while addressing the airspace congestion.

- **Introducing 'Origin-destination charging' (ODC) combined with the 'Modulation of route charges' (MRC) mechanism**, where ODC route charge is calculated on the great-circle path (GCP) between the origin and destination airports, therefore identical[4] for all routes of a given city pair, irrespective of the trajectory flown. ODC establishes a simple reference for airspace users, with an identical baseline charge for all possible routes of a given city-pair. By construction, the ODC baseline aggregated at network level is a "clean baseline" that does not include "route charges optimised" trajectories and is therefore not biased by difference in unit rates. The modulation factor *M* that the MRC model produces for each route *r* of a given origin-destination traffic flow (as described above) is then applied to the ODC baseline.

Both above-mentioned mechanisms showed very similar results in validation exercises (see the Final GRC ERR [39]). However, the MRC+ODC would require a significant change from the regulatory perspective. Since the MRC has much lower impact on the existing rules, the ECO-EVAL addresses only this simpler but equally performing framework.

The **Green Route Charging Full Solution** aims to incentivise the use of climate friendly trajectories, when considering both CO_2 and non-CO_2 emissions. The mechanism rewards avoidance of climate sensitive areas (i.e. climate hotspots, determined by calculating the CO_2 and non-CO_2 combined effects), while still leaving the flexibility for aircraft operators of using the said areas, against a higher charge, and keeping revenue neutrality.

3.2.1 SESAR Solution interdependencies

The GRC Solution could help in implementation/operations from the following Solutions:

- #0429 Climate optimised trajectories including non-CO_2 effects, which could help AUs and ANSPs in the trajectory optimisation to also benefit the most from the proposed route charging mechanisms,

- #0421 AEROPLANE Climate Services for climate change mitigation and adaptation in Aviation, which could help in a similar way,

[4] Identical for the distance factor of the route charge, while the weight factor remains dependant on the aircraft's MTOW. See section 3.3.1 and 3.3.2 for more details on the current and new charging methods.

- #0374 E-CONTRAIL Climate Hotspot Prediction Service, which could be included as the new 'MET service' function mentioned in the OSED [37], ERR [39] and section 3.4.

In turn, it could both benefit from and constitute a use case for:

- #0408 Green GEAR Separation Minima, allowing aircraft to fly closer together safely, enabling to mitigate the negative effects of detours / flight level changes applied to avoid climate hotspots.

3.3 Objectives of the ECO-EVAL

The objective of this TRL2 ECO-EVAL is to help build an assessment of whether the GRC Solution is worth deploying, across ECAC, from an economic perspective for the involved stakeholders. This ECO-EVAL provides a consolidated assessment of the costs and benefits of deploying the Solution in 41 EUROCONTROL contracting States adhering to the Multilateral Agreement on Route Charging, specifically for *en-route charges*. These 41 contracting States include the 27 EU Member States and are included in the ECO-EVAL solution scenario (see section 3.5.2).

This ECO-EVAL includes the evidence gathered to estimate the benefits and costs of the solution. The output is an overview of the high-level impact of costs and benefits per stakeholder group, recommendations and next steps.

3.4 Stakeholder identification

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
ANSP	En-route ANS in entire FIR.	If Solution is adopted, it will be mandated by regulation (i.e. the Performance and Charging Scheme).	The ANSPs are paid through the collection of charges, which cover the costs of staff, and investments, aimed at provision of ANS. The Solution keeps revenue neutrality. Reduction of environmental impact of aviation and possibly congestion reduction.	Provided feedback in the project (NATS) and via workshops.

Airlines (scheduled, charter), business aviation, general aviation IFR	En-route airspace.	If Solution is adopted, it will be mandated by regulation (i.e. the Performance and Charging Scheme).	The GRC Solution mechanisms incentivise more environmentally friendly routes, expecting to decrease environmental impact (CO_2 and non-CO_2), route-charges (on average) and congestion.	Feedback through workshops, participation in the survey, review of deliverables and provision of official position regarding the proposed Solution.
CRCO	En-route airspace under its mandate.	If Solution is adopted, it will be mandated by regulation (i.e. the Performance and Charging Scheme).	N/A	Feedback in workshops.
Network Manager	En-route airspace.	Following regulation.	GRC could change the traffic flows. MRC is designed to take the capacity into account when setting the modulation charges, which could decrease the capacity saturation, thus maybe avoiding a part of the capacity related ATFM regulations. The impact of the Full GRC would probably have more impact as it is harder to predict the state of the atmosphere, even if the Full Solution takes the capacity into account.	N/A

MET provider	All States adhering to Multilateral Agreement	If Solution is adopted, it will be mandated by regulation (i.e. Performance and charging scheme).	N/A	N/A
Central planner	41 States adhering to Multilateral Agreement on Route Charges	If Solution is adopted, it will be mandated by regulation (i.e. Performance and charging scheme).	N/A	N/A – new function.
State	State's airspace	If Solution is adopted, it will be mandated by regulation (i.e. Performance and charging scheme).	Reduction of aviation's environmental impact, while recovering revenue for ANS provision.	N/A
Rotorcraft, general aviation VFR, UAS operators, military, common information service provider (CISP), U-space service provider (USSP), Other impacted stakeholders (ground handling, …)	N/A	N/A	N/A	N/A

Table 3: GRC Solution ECO-EVAL stakeholders and impacts

3.5 ECO-EVAL scenarios and assumptions

This section describes the scenarios that are compared in the ECO-EVAL. The aim is to reflect the delta (difference) between the ECO-EVAL reference scenario (where the SESAR solution is not deployed, bottom box in Figure 1) and the ECO-EVAL solution scenario (reflecting the proposed deployment of the SESAR solution across ECAC, box in Figure 1). The comparison between the ECO-EVAL scenarios considers the point in time when the solution is available to be deployed and hence differs for each solution.

The delta approach means that the focus is on identifying the impact of the changes between the ECO-EVAL reference and ECO-EVAL solution scenarios. Defining the ECO-EVAL reference scenario has proven to be challenging because of the assumptions that need to be made regarding the 'ongoing deployments' that are relevant for the solution and their impacts. To avoid being blocked by this issue, some elements of this ECO-EVAL focus on the difference between the current situation and the ECO-EVAL solution scenario. This is reflected in the scenario descriptions, available in the following sections.

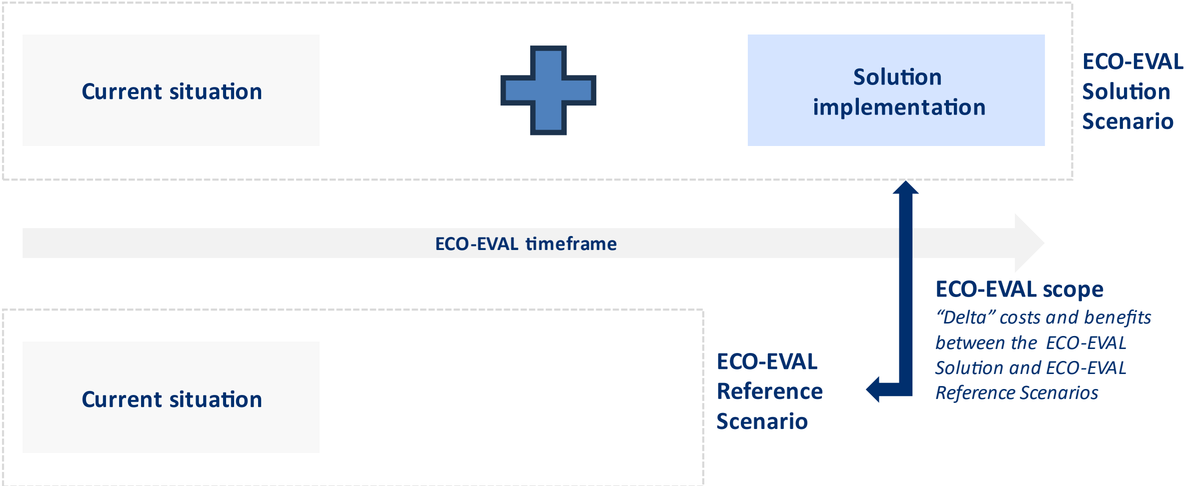

Figure 1: GRC Solution ECO-EVAL scenario overview

3.5.1 ECO-EVAL reference scenario

The reference scenarios refer to the current status quo on roue charging, which is described in detail in D5.4 Final OSED [37] . No other developments are taken into account, as at the time of the writing there are no Solutions that would impact the route charging directly. The Solutions that could help in the implementation are identified in section 3.2.1, but those are also at a very low TRL level.

The **Initial GRC Solution** is tested on a set of instances of real European air traffic data from 2019. Data sets consisting of 56 days of traffic have been chosen: 28 days of congested traffic and 28 days of low traffic volume (details in section B.1.5.1 of ERR [39]). Such a choice allows to validate the effectiveness of the calculated route charging schemes under different levels of traffic, enabling the comparison with the actual historical situation.

For the validation of the exercise the reference scenario is simply represented by the traffic of the selected days. It is important to note the distinction in how these benchmarks are derived. Congestion levels and delays are directly extracted from the available flight data, providing immediate and accurate measures. In contrast, environmental effects and operational costs require estimation through post-processing techniques, as direct data for these factors are not available in the dataset.

The Full GRC Solution reference scenario uses flights between 10 busiest airports in Europe, covering a wide geographical area, but not the full ECAC area and traffic. The Full GRC Solution reached TRL1 only.

3.5.2 ECO-EVAL solution scenario

The GRC Solution represents novel route charging mechanisms. As such, the Solution is an administrative procedure through which the ANSPs collect charges for navigation services provision. The novelty of the GRC Solution lies in the implementation of the environmental modulation of route charges. See section 3.2 for more details.

Route charging has been in use for decades. Here, we are testing what impact an environmental route charge modulation would have on aviation emissions in the ECAC area. As such, the Solution scenario is composed of the reference traffic, when the proposed GRC Solution is implemented. To compare the performance of the network with the actual traffic, the Solution scenario is represented by the simulated traffic resulting from the implementation of the computed new route charges on the same days with respect to the ones of the reference scenarios.

Initial GRC Solution	
Scenario	**Description**
Reference scenario	Planned traffic (FTFM) for the 2 AIRAC cycles in 2019.
Solution scenario	Same traffic as reference scenario to which the modulation mechanisms are applied.
Full GRC Solution	
Scenario	**Description**
Reference scenario 'cap'	The sample of flights for 10 busiest airports in Europe, run on an average day of flights based on 2 weeks traffic in 1910 AIRAC. This is an optimised scenario where capacity constraints are enforced through strategic delays, applied on the sectors. This is the closest scenario to the present situation.
Solution scenario – 'full'	The same traffic sample as above is used in this optimised scenario where a central planner minimises the environmental impact while capacity constraints are enforced. This represents the closest situation to what the system with the full solution would look like. In this situation, the central planner can play with the EI rate, a multiplicator factor to decrease the revenue of the route charges (to keep revenue neutrality), and delays applied to sectors.

Table 4: Summary of reference and solution scenarios for GRC Solution

ECO-EVAL timeline

The ECO-EVAL covers the period from 2026 to 2050 as defined in the common assumptions [5]. This means that the net present value is calculated by discounting cashflows back to 2026 (the end of DES wave 1).

The GRC Solution explores two versions: Initial Solution that includes only CO_2 emissions, and the Full Solution that takes into account all emissions. The Initial Solution is at the higher maturity level (TRL2, see Appendix A). Both versions could be implemented within 2-3 years, if only implementation is taken into account. However, as the route charges are subject to Performance and charging scheme [26] and the SES2+ regulation [27], the GRC Solutions would need to obtain the stakeholder consensus and pass through the process of regulation change. The SES2+ regulation took a very long time from the initial discussions to its final adoption, and from the feedback received during the project this topic is rather contentious, and as such it is rather difficult to foresee the time needed for regulation change. Thus, we can only foresee the time that would be needed for the implementation itself (i.e. 2-3 years), after the regulation change, if it is accepted. Due to this uncertainty, we denote the start date as 203X.

Table 5 lists the key dates used in the ECO-EVAL and Figure 2 shows them over a timeline.

Dates	#0408 GRC Solution
Start of deployment date (SOD): the start of investments for the first deployment location	203X
End of deployment date: the end of the investments for the final deployment location, same as FOC	203X+3
Initial operating capability (IOC): the time when the first benefits occur following the *minimum deployment* necessary to provide them. Costs continue after this date as further deployment occurs at other locations.	203X+2
Final operating capability (FOC): maximum benefits from the *full deployment*[5] of the SESAR solution at applicable locations. Investment costs are considered to end[6] here although any operating cost impacts would continue.	203X+3

Table 5: ECO-EVAL investment and benefit dates

[5] Where ***full deployment*** means deploying the SESAR solution in all the locations where it makes sense to deploy it (i.e. it does not mean it has to be deployed everywhere)

[6] The basic assumption is that infrastructure does not need to be replaced during the ECO-EVAL period.

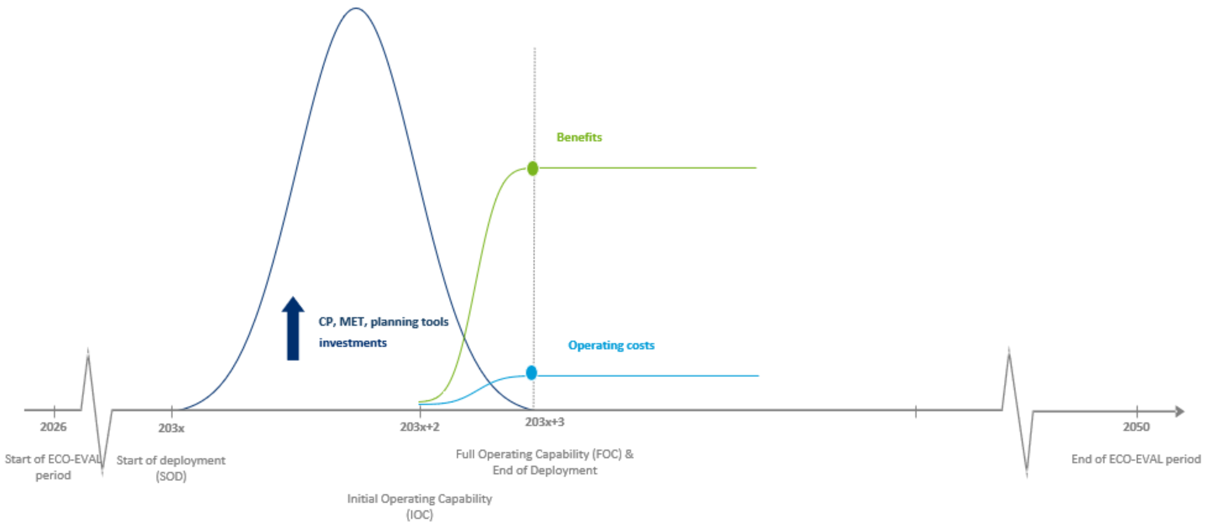

Figure 2: GRC Solution overview of ECO-EVAL dates

Figure 2 shows that:

- Investment costs relate to investments needed to implement the Central planner and MET provision functions and to update the flight planning tools in use by airlines to be able to integrate the new route charges mechanisms in the flight planning.
- Benefits ramp-up following an 'S' adoption curve between IOC and FOC and then continue up to the end of the ECO-EVAL period;
- Operating cost impacts (increases or decreases) would also start at IOC and ramp-up following an 'S' adoption curve to FOC before continuing for the rest of the ECO-EVAL duration.

3.5.3 Assumptions

Both Initial and Full GRC Solutions use the traffic from September (and February for Initial) 2019, as a representative of a year with the high traffic, the levels of which have not yet been achieved after COVID. Table 6 lists the assumptions common to both GRC Solutions, while **Table 7** lists the additional assumptions for Full GRC Solution. For detailed descriptions, refer to the Final ERR Green route charging [39].

Assumption title	Assumption description	Justification
Route charges	EU and ICAO rules and regulations hold. Route charges are calculated according to the current system.	Required as the baseline of the models.
Traffic	Historical traffic from DDR2 is similar to the current one and represents the current behaviour in the European airspace.	Required to set models' inputs.

Table 6: GRC Solution common assumptions

Description	Why?	Could be relaxed?
Each OD pair has only two routes available	Number of terms grows exponentially with number of routes available. Analytical computations are required in each case	Near impossible to relax with capacity constraints on top. But expression exists for infinite capacity case, so perturbative approximations[7] may be computed
Airlines choose route based on a linear deterministic utility function	To capture the sensitivity of airlines to delay and costs independently. We use deterministic utility function to simplify the integrals	Linearity could be relaxed via more complex analytical expression. Deterministic aspect could also be relaxed using numerical methods for the integral estimation
Fuel consumption and emissions are estimated using a typical aircraft engine	The CLIMaCCF library offers calculation for three generic types of engine. We decided to use single aisle estimation only, for simplicity, at this TRL level, and for checking the feasibility of the solution.	Hard to relax with the current modelling approach. Different fuel consumptions and emissions for the same trajectory require in general an added integration for each expression, which is computationally very expensive.
Emission estimates are accurate enough to define the hotspots	This is the core assumption of the solution. If this assumption fails, then by definition, ANY solution taking non-CO_2 emissions into account has to fail	We can relax the 'absolute accuracy' assumption by introducing an error term.
Delays experienced by flights are exponentially distributed	For technical feasibility. Exponential distributions allow us to compute analytically some of the terms. Note that evidence that delays are either exponential or Normal are numerous.	Normal distributions are harder but feasible. Arbitrary distributions require a different approach, at least with numerical integral estimations.

[7] Perturbative approximations are sometimes used when a full mathematical expression cannot be derived, but a particular case is known. In this case, the mathematical expression for an infinite capacity can be derived, so approximations may be computable for 'near infinite' capacities.

Description	Why?	Could be relaxed?
Behaviour of airlines is bundled in two categories	The two categories notionally represent low-cost and network carriers. This allows higher diversity of choices of routes when faced with high delays (due to congestion) or high costs (due to hotspots)	Same issue as for number of routes, it is very hard to generalise due to combinatorial issues

Table 7: Full GRC assumptions

4 Benefits

The validation exercises for the GRC Solution have demonstrated measurable performance improvements across key performance areas (KPAs) evaluated, supporting its potential to reduce environmental impact of aviation, and capacity saturation.

4.1 Benefits overview

This section contains benefits impact mechanisms identified for the GRC Solution options. Figure 3 depicts the benefits mechanisms identified for Initial GRC Solution options. Both mechanisms would impact the AUs' route choice, which, in the price signal contains the capacity considerations, and the need for the revenue neutrality.

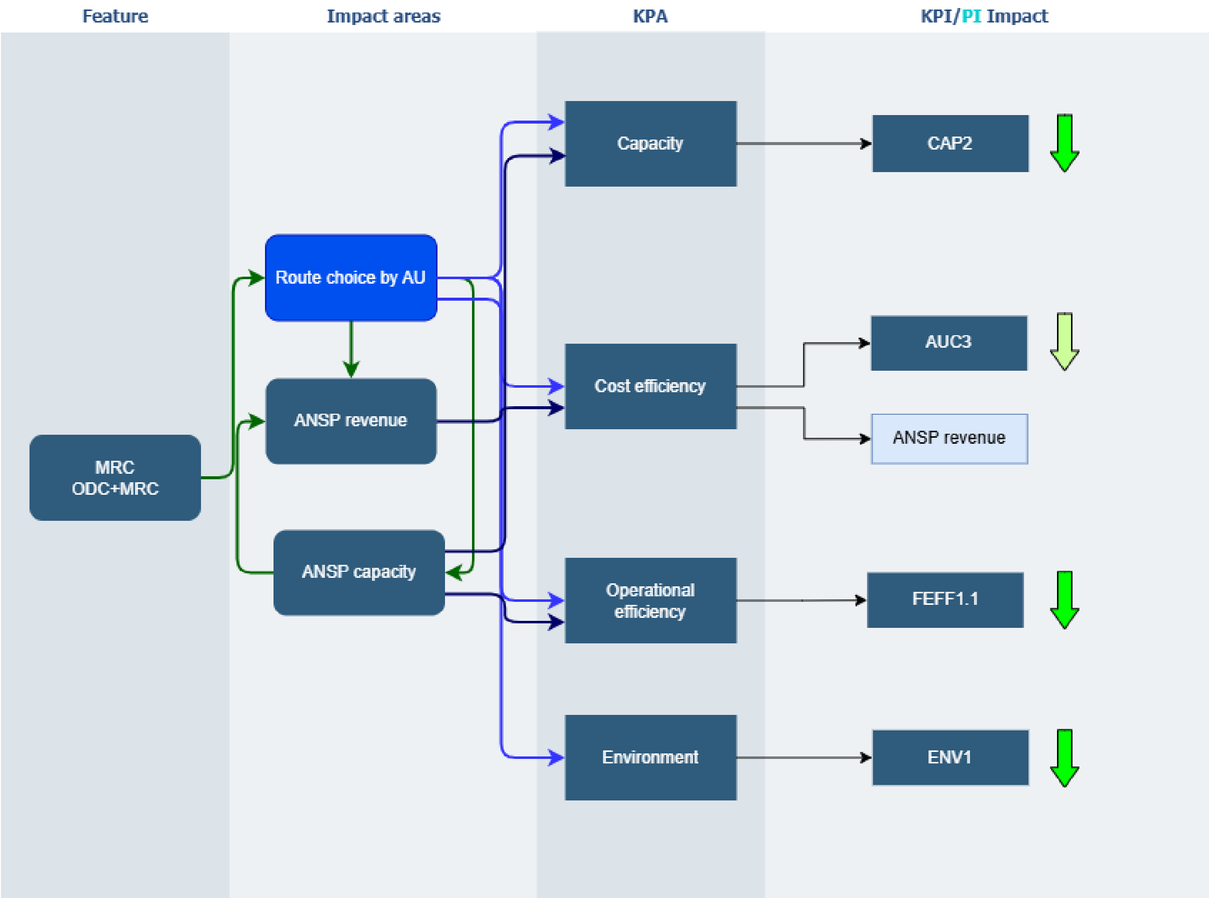

Figure 3: Benefits impact mechanism for MRC and ODC+MRC.

With capacity being taken into account in the route charge (i.e. price) setting, the expectation is that the number of flights planned to cross a certain sector in a certain time period would be aligned with its capacity. The KPI used in the assessment is *CAP2 The total number (and percentage) of movements per volume of En-Route airspace per hour for specific traffic mix and density (Very High, High and Medium Complexity) at peak demand hours [7].* As the expectation is that the price signal takes into account the capacity availability, it is expected that the number of flights planned to cross the sectors at specific time periods will be lower than today. The expectation is that the CAP2 will be lower than today (as measured), which does not mean that the capacity will be lower, but that the demand will be in line with the declared capacity.

The cost efficiency measured relates to the direct costs to AUs (i.e. fuel and route charges), as the mechanisms are designed to minimise the distance, and as such the fuel and route charges. Furthermore, the modulation of route charges must be compliant with the revenue neutrality principle, i.e., each ANSP receives the same income for the same amount of workload.

Operational efficiency. The **Initial Solution** options are designed to reduce the CO_2 emissions, mainly through the distance reduction. As the distance is proportional to the fuel consumption, which in turn is proportional to CO_2 emissions, we expect to decrease the fuel consumption.

As the **Initial Solution** options are designed to reduce the CO_2 emissions, which is confirmed in the results.

The Figure 4 depicts the benefits mechanisms identified for Full GRC Solution options. This mechanism has a very dynamic impact on capacity and the validations show slight capacity saturation at the points of network tested. Regarding operational efficiency the Full GRC Solution causes a slight increase in fuel consumption (<1%), stemming from the climate hotspot avoidance, as the main objective is the reduction of the total climate impact, not only the CO_2 part.

The Full GRC Solution does not reduce CO_2 emissions *per se*, as it is designed to avoid the portions of airspace that can create high climate impact (minimising the impact of the joint impact of both CO_2 and non-CO_2 effects). The total climate impact is reduced by ~14% at the network level, as measured by ATR20 indicator.

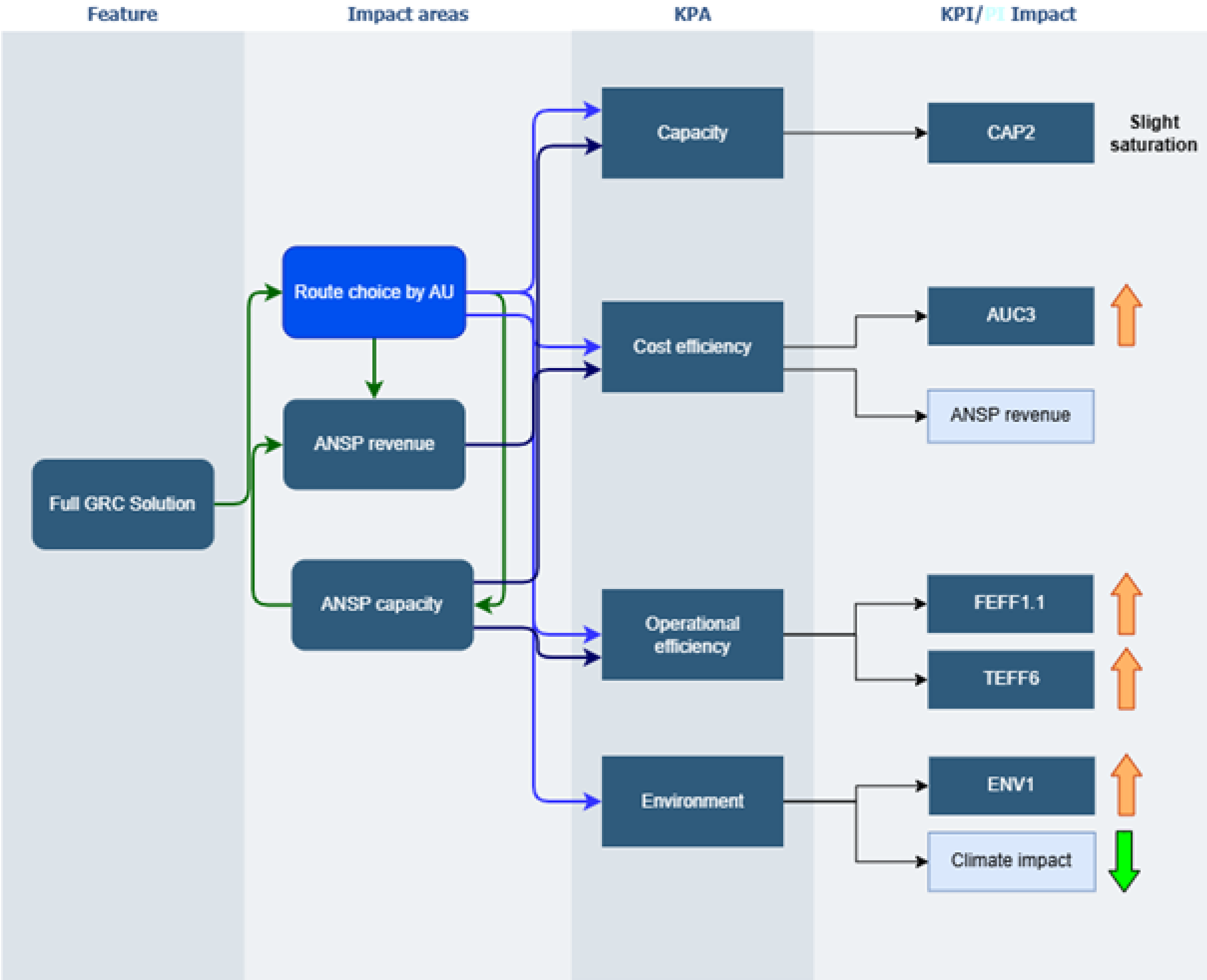

Figure 4: Full GRC Solution benefits mechanism draft.

4.2 Benefit summary

Table 8 summarises the Initial GRC Solution benefits, while Table 9 summarises the Full GRC Solution benefits, showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). It explains how the solution provides estimates. Note that Full GRC Solution is at TRL1 and that the results show the impact for 10 busiest airports in ECAC area.

KPI / PI	BIM impact	Magnitude	How the solution provides the benefit and evaluation (low, medium, high impact)
CAP2 like Capacity saturation n challenging airspace per unit time	Reduction in capacity saturation (ECAC level)	M	The results show a significant reduction in capacity violations (demand higher than available capacity) for both traffic periods. For the high traffic AIRAC 1910, violations decreased by 91.2%, while in the low traffic AIRAC 1902, the reduction reached 94.1%. This indicates a substantial improvement in network congestion.
AUC3 Direct operating costs for an airspace user	Reduction in fuel and route charges costs	L	The operating costs taken into account are fuel cost and route charges. There is a slight decrease in these costs by 0.1%.
FEFF1 Average fuel burn per flight	Reduction in fuel burn	L	There is a 0.25% reduction in fuel burn, in low traffic months, growing to 0.41% in high traffic months.

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KPI / PI	BIM impact	Magnitude	How the solution provides the benefit and evaluation (low, medium, high impact)
ENV1 Average CO_2 emissions per flight	Reduction in CO_2 emissions	L	There is a 0.25% reduction in CO_2 emissions, in low traffic months, growing to 0.41% in high traffic months.
ANSP revenue	Remains the same on average	=	ANSP revenue shows a slight decrease that is proportionally similar to the reduction in AUs' RC costs. The total Service Units decrease for some ANSPs, which is the reason behind this reduction. Some ANSPs also see an increase in Service Units and the related revenues. See the Final ERR GRC [39] for details.

Table 8: Initial GRC Solution performance benefits

KPI / PI	BIM impact	Magnitude	How the solution provides the benefit and evaluation (low, medium, high impact)
ATR20 Environmental impact	Reduction in ATR20	H	The **environmental impact** for all emissions, as measured by ATR20, is 14% lower in the solution scenario.
CAP2 like Capacity saturation n challenging airspace per unit time	Increase in capacity saturation (ECAC level)	L	Full Solution shows that traffic re-locates, but the capacity with the Full Solution could become slightly more saturated. An important, linked finding is that when there is a lack of capacity, it is much less possible to reduce environmental impact of flights, as there is no space for manoeuvre left.

KPI / PI	BIM impact	Magnitude	How the solution provides the benefit and evaluation (low, medium, high impact)
AUC3 Direct operating costs for an airspace user	Slight increase in fuel and route charges costs	L	The incentivisation to minimise the environmental impacts, slightly increases the costs to airlines (AUC3), less than 1%. This is due to higher fuel consumption, and EI modulation rate.
FEFF1 Average fuel burn per flight	Slight increase in fuel burn	L	For **the efficiency**, the FEFF1 and TEFF6 are slightly higher (less than 1%) in the solution scenario than in the reference one, which is an expected consequence of minimising the emissions instead of fuel.
TEFF6 Time efficiency	Slight increase in flight time	L	
ENV1 Average CO2 emissions per flight	Slight increase in CO_2 emissions	L	The same increase as FEFF1, as the ENV1 is obtained from FEFF1.
ANSP revenue	Constant	=	ANSP revenues are held constant, which is aligned with only slight increase in capacity saturation.

Table 9: Full GRC Solution performance benefits.

4.3 Capacity

Initial GRC Solution. In capacity, the MRC model achieved substantial congestion reduction, decreasing capacity violations by 91.2–94.1% across both high and low traffic periods. This confirms the models' effectiveness in balancing demand with available resources through routing and environmental charge modulation.

Full GRC Solution. The Full Solution shows that traffic flows change in order to avoid climate sensitive areas, but the capacity with the Full Solution could become slightly more saturated. Furthermore, an important finding is that when there is a lack of capacity, it is much less possible to reduce the environmental impact of flights, as there is no space for manoeuvre left.

4.4 Time efficiency (TEFF6)

Full GRC Solution. The en-route time, TEFF6 is slightly higher (less than 1%) in the solution scenario than in the reference one (see Figure 17, of the Final ERR GRC [39] for details), which is an expected consequence of minimising emissions instead of fuel.

4.5 Fuel efficiency (FEFF1) CO_2 (ENV1), and non-CO_2

Initial GRC Solution. The FEFF1 and ENV1 are estimated here. For all flights involving ECAC and adjacent states, distance flown decreased by 0.66%, FEFF1 by 0.41%, and ENV1 by 0.41%. The effect is more pronounced for flights entirely within ECAC, where distance dropped by 1.38%, fuel by 1.36%, and ENV1 by 1.36%.

Full GRC Solution. FEFF1 is slightly higher (less than 1%) in the solution scenario than in the reference one, which is a normal consequence of minimising emissions instead of fuel. The environmental impact for all emissions (CO_2 and non-CO_2), as measured by ATR20, is **14% lower** in the solution scenario.

4.6 Cost efficiency (AUC3), and ANSP revenue neutrality

Initial GRC Solution. The solution maintained revenue neutrality for ANSPs while reducing overall airline costs (AUC3) through fuel savings. Route charge modulation remained within ±10% tolerances, ensuring financial stability for ANSPs.

Full GRC Solution. The incentivisation to minimise environmental impacts, slightly increases the costs to airlines (AUC3), by less than 1%. This is due to higher fuel consumption, and EI modulation rate. The ANSP revenues are held constant, which is aligned with only slight increase in capacity saturation.

5 Cost assessment

This section contains the qualitative cost assessment for implementation and operation of the GRC Solution. Table 10 contains the summary of impacted stakeholders and their foreseen costs and cost drivers. Some stakeholders would be impacted in one or the other Solution (denoted in the table), while others would be impacted by both. Subsequent sections describe costs for the stakeholders that effectively would incur costs.

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
ANSPs	Investment cost	Yes	Initial change to the new route charging accounting	En-route airspace
	Operating cost	No		
Airlines	Investment cost	Yes	Change to flight planning software	Flight planning, operations
	Operating cost	Yes	Route charges, as in current system, and in Full Solution the fuel costs might be a bit higher	
CRCO	Investment cost	Yes	Change to the route charges accounting and disbursal system	Route charges collection, validation and disbursement
	Operating cost	No		
Network Manager	Investment cost	No		ATFM regulations
	Operating cost	No		
Central planner	Investment cost	Yes	New function to calculate the modulation factors	New function, could be a part of CRCO
	Operating cost	Yes	Running the function, as it needs input data and sharing of	

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Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
			modulation information	
MET provider*	Investment cost	Yes	Might need to setup a new forecast service	For all stakeholders in the route charging
	Operating cost	Yes	Daily provision of weather forecast for climate impact	
State	Investment cost	No	Should only follow a different regulation, and as such should have no additional costs	Performance and Charging Scheme
Other stakeholders	Investment cost	No	-	-
	Operating cost	No	-	

Table 10: Identification of solution's cost drivers and deployment locations (*only in Full GRC Solution)

5.1 ANSPs costs

Here, there would be an initial change to the new route charging accounting. The ANSPs would need to change the administrative procedures used in the Performance and Charging Scheme. The magnitude would depend on the eventual changes to Performance and Charging Scheme that would be needed to implement the GRC Solution.

5.2 Airlines (Airspace users) costs

The airlines would need to update the flight planning software to include the changes required by the GRC Solution (e.g. inclusion of modulation factors), if they have in-house flight planning software. If they use third-party providers, this might well impact subscription rates.

In operations, as today, airlines will be subject to the route charges. The Initial Solution might lower these costs, while the Full Solution lowers the route charges costs, but might increase the fuel costs (used to avoid climate sensitive areas).

5.3 CRCO costs

CRCO would be subject to initial investment in order to change to the route charges accounting and disbursal system to accommodate the GRC Solution.

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5.4 Network manager costs

The Network Manager would not be subject to costs, but the new route charging might have an impact on the ATFM procedures, so that climate impact avoidance can be accommodated at the network level.

5.5 Central planner

Central planner is a new function needed by the GRC Solution. The main task is to calculate the modulation factors, and the investment costs would be needed to setup the function.

The operating costs would involve running the function, as it needs input data and sharing of modulation information.

It is not necessary that this function is a standalone stakeholder, it could be a part of CRCO for example.

5.6 MET provider

For the Full Solution, the MET providers might need to setup a new forecast service, for identification of climate sensitive areas. The initial investment would be needed to tailor the existing NWP products, if needed.

The operating costs would regard the daily provision of weather forecast for climate impact to all the involved stakeholders.

6 CBA model

This chapter shall be completed in the CBA deliverable that is expected for solutions aiming at a higher maturity level than TRL2.

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7 CBA results

This chapter shall be completed in the CBA deliverable that is expected for solutions aiming at a higher maturity level than TRL2.

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8 Sensitivity and risk analysis

This chapter shall be completed in the CBA deliverable that is expected for solutions aiming at a higher maturity level than TRL2.

9 Recommendations and next steps

9.1 Summary of GRC Solution findings

The GRC Solution has been developed in two stages: the Initial Solution, addressing horizontal inefficiencies related to unit rates, and the Full Solution, aimed at encouraging climate-friendly trajectories by considering both CO_2 and non-CO_2 emissions.

The **Initial Solution**, has now been validated up to TRL2, across several scenarios, confirming its feasibility and effectiveness in reducing horizontal inefficiencies, capacity violations and route charges for AUs (on average). Furthermore, the Solution demonstrates a reduction of CO_2 emissions (ENV1) by 0.25–1.36%, with the most pronounced improvements observed for flights entirely within ECAC airspace. Congestion was significantly alleviated, with capacity violations decreasing by 91.2–94.1% across the traffic periods assessed. While these results are promising, the validation scope has inherent limitations, including reliance on 2019 data and partial coverage of annual traffic variability, which was also raised in the stakeholder feedback (see Appendix B for details). The sensitivity of outcomes to fuel cost assumptions and the absence of extreme operational conditions underscore the need for continued refinement and expanded testing. Nevertheless, the consistent performance across different scenarios strengthens confidence in the applicability of the environmental modulation for CO_2.

Full GRC Solution. This solution adds full climate considerations. Due to the complexity of non-CO_2 emissions, the project first assessed whether a climate hotspot-based approach was viable, requiring a simplified new model. Initial results, tested the mechanism on a larger (but limited) sample, where it was demonstrated that most of KPIs were affected in a slightly negative or neutral manner, except the PI on full emissions, which shows **14% reduction** of full emissions impact (measured by ATR20). The inclusion of CO_2 emissions in the total impact led to less marked changes in fuel consumption, and thus impacts airlines much less in terms of cost.

Both mechanisms under development marked a significant step in maturity level. For the Full solution, starting from TRL0, the level reached is TRL1. The Initial Solution started at TRL1 and reached TRL2 (see maturity assessment in the upcoming Project Summary Report, with considerations on this report's contribution to maturity in Appendix A).

The **Initial GRC Solution**'s core concept - modulating route charges to incentivise optimal routing while maintaining revenue neutrality, demonstrated its ability to maintain compliance with stakeholder (general) requirements and operational constraints, and it achieved measurable performance improvements across the metrics measured. The results show that the solution is capable of balancing multiple objectives including efficiency, capacity and environmental benefits.

The **Full GRC Solution** concept builds logically on these validated principles by incorporating additional climate considerations. Due to the dynamical nature of the non-CO_2 emissions, the project needed to clarify whether a concept based on climate hotspots would be applicable. It has been shown that (see Final ERR GRC [39] for details):

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- Environmental modulation can be an incentive to choose a more environmentally friendly trajectory, based on a solution using hotspot determination;
- Automatic flight level changes to avoid hotspots could greatly enhance the efficiency of the solution;
- A solution based on a full emissions scheme (paying for all emissions instead of hotspot-based) may not be much more efficient;
- Congestion (i.e. lack of airspace capacity) decreases the efficiency of the mechanism;
- Most KPIs are slightly or neutrally impacted by the Full Solution, except for a PI on full emissions, which shows significant improvement (14% reduction);
- The inclusion of CO_2 emissions in the total impact leads to less significant changes of fuel consumption, and thus impacts airlines much less in terms of costs.

The GRC Solutions propose new route charging mechanisms. As such, these are not ATM Solutions *per se*, as no ATM system would be impacted. However, throughout the duration of the project, several aspects of the concept were clarified and the following new functions needed, were identified:

- A central planner that would determine the environmental modulation (in both the Initial and Full Solution), and hotspots in the case of the Full Solution, and then communicates the information to the airlines;
- MET provision of forecast for hotspot determination. Forecasts are already being provided in aviation. However, the required forecast might need some specific additional requirements that should be further investigated;
- Flight planning software being able to take new information (e.g. EI rate) to properly optimise trajectories.

Initial GRC Solution. The solution would bring measurable performance improvements across key performance areas (KPAs), supporting its potential to reduce environmental impact of aviation while improving other KPAs (see section 4).

Full GRC Solution. The work so far demonstrates the initial feasibility of the route charging mechanism that takes into account all emissions. The solution has a potential of reducing the total environmental impact, with just a slight increase in other KPAs (see section 4 for details). An important finding is that when there is a lack of capacity, it is much less possible to reduce the environmental impact of flights, as there is no space for manoeuvre left.

9.2 Stakeholder feedback

The GRC team organised two workshops to present and discuss the GRC Solution. The first workshop was held on 14th May 2024 with the members of Advisory Board, which is composed of airline, ANSP, EC, and ATCO representatives. The second workshop was held on 29th April 2025, and was open to all interested stakeholders, where CRCO and flight planning group representatives participated as well (see minutes of the second workshop in section B.3).

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The main requirement from the CRCO, and ANSP representatives was to propose a system that would be as simple as possible, with the view that any implementation would require a relatively simple system. For example, the current route charging formula is very simple, even if the process behind the calculation of traffic, service unit and cost forecast is much less so. The GRC Solutions would require a slight adjustment of the formula to include modulations for routes, but could essentially stay the same (Initial Solution, cf. the Full Solution would be more complex for implementation). The determination of the modulation factors would require a set up of a new function, and the verification system would also need adjustments.

The IATA representatives participated in the design of the survey that was a part of the work in the development of the Full GRC Solution, and in the workshops. IATA provided their official feedback on the survey (see section B.1 for details), and on the GRC Solution overall (see section B.2).

The gist of the provided feedback is the strong opposition to any environmental route charging modulation. For example, regarding the Initial Solution and the levers it employs (CO_2 and congestion minimisation): “Such scenario is biased to focus on changing the customers’ behavior without considering behaviors on the providers’ side. The economic regulation on monopolistic business should not be turned against the customers, potentially increasing the monopolies’ rewards for inefficiencies.” Further criticism revolved around the perceived immaturity of science behind the prediction and monitoring of non-CO_2 emissions. Due to that, the non-CO_2 emissions should not be a subject of research on route charge environmental modulation, it was stated.

While measures like changes in aircraft propulsion (electric or hydrogen powered aircraft, wide-spread use of Sustainable Aviation Fuel (SAF) will have a significant bearing on the environmental footprint of aviation it will likely be decades before they produce a full effect[8], and hence shorter-term solutions are needed. The GRC Solution investigated options with highest impact and feasibility for the ATM operations, and optimising flight trajectories in relatively short-term. We strongly believe that we cannot wait for the science to be fully established and only then try to figure out how to use it to the best extent.

Even if the IATA position shows strong opposition to the idea of environmental route charge modulation, several of their observations are found to be aligned with the GRC team’s description of limitations and the need for further investigation and refinement. For example: the data sample should be more diverse (e.g., more AIRAC cycles, extreme traffic conditions), and to incorporate recent operational data and up-to-date/new aircraft fuel consumption performance data; improve capacity input data and test its impact on the traffic re-distribution and environmental impact values. The assessment of equity for different AUs and ANSPs, should be performed, to ensure proper cost benefit analyses. The forecast uncertainties on the proposed mechanisms should be assessed and how those impact the Solution.

The following two subsections detail recommendations on further validations of the proposed Solutions, and the other, related research needs.

[8] ReFuelEU Aviation sets the goals of reaching 70% share of SAF in all EU airports by **2050.**

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9.3 Recommendations

9.3.1 Recommendations for next R&I phase

The validation results demonstrate promising trends in environmental efficiency, congestion reduction, and cost savings, supported by consistent performance across different traffic scenarios. However, the limited sample size and reliance on historical data temper the statistical certainty, while operational realism is constrained by the absence of edge cases, and potential shifts in aviation dynamics since 2019.

To strengthen the concept and the significance of results, future research/validations should:

- Increase sample diversity (e.g., more AIRAC cycles, extreme traffic conditions).
- Incorporate recent operational data to reflect current aviation trends.
- Incorporate up-to-date/new aircraft fuel consumption performance data.
- Conduct sensitivity testing on critical assumptions to assess their influence on model outcomes.
- Improve the capacity input data and test its impact on the traffic re-distribution and environmental impact values.
- Include the assessment of equity for different AUs and ANSPs.
- Assess the impact of forecast uncertainties on the proposed mechanisms (see next section for detailed discussion).
- Perform targeted Monte-Carlo simulations with the full solution and/or develop new analytical methods to deal with the dimensionality of problem (many routes, many airlines).
- Requirements analysis (from technical and operational points of view) for the three identified new functions: central planner, MET provision of non-CO_2 forecast and inclusion in flight planning software.

The forecasting for climate impact determination still needs research in terms of uncertainties and setting of the appropriate threshold for minimisation of aviation climate impact. This would need discussions between atmospheric scientists and operational stakeholders (AUs and ANSPs) to understand the climate impact and what can be done operationally to diminish it. Furthermore, given the necessity for transparency in charges, it is crucial that all stakeholders utilise the same information, which would require the establishment of new functions to source, compute, and disseminate this information among all stakeholders (see bullet points above).

9.3.2 Recommendations for future R&I activities

The validation exercises have identified several promising research avenues that warrant further investigation in future SESAR or other R&I programs.

First of all, to consider expanded operational scenarios. Future validation should include more diverse traffic conditions (e.g., extreme weather, major disruptions) to assess robustness under atypical operational environments.

A second improvement would be to merge the Initial and Full Solution concepts into a single mechanism. One could set modulations based on congestion and environmental considerations at the same time, thus solving both problems at the same time while reducing operational complexity. The modulation could also be tailored to specific aircraft type or engines, if we assume that a central entity will set and communicate these modulations in advance. The modulations in question may be extremely hard to compute, and further research effort is needed. In addition, dynamic pricing could also be the scope of further studies, to investigate the impact of varying charge modulation strategies at the tactical level. This last issue might need the deployment of machine learning enhancements, since AI-driven optimisations might improve real-time decision-making for route and charge adjustments.

Uncertainty is also a significant issue, especially for the non-CO_2 emissions. The accuracy of the models, the dynamicity of the atmosphere, and the heterogeneity of the aircraft and engines flying in Europe imply that any mechanism based on these considerations has to make extra effort to determine the acceptable level of uncertainty. A significant research effort in this area, first to reduce the uncertainty and then to manage it more rationally, is needed.

New aircraft types should be included in further research regarding the environmental modulation of route charges, from both emissions (none, or very much reduced) and congestion point of view (which portions of airspace (and flight levels) are these more likely to occupy).

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10 References

10.1 Applicable documents

This ECO-EVAL complies with the requirements set out in the following documents:

SESAR solution pack

[1] SESAR DES Solution Definitions Green-GEAR V1.0, 3rd June 2024.

[2] SESAR Operation Concept Document OCD 2023, 02.00.00, 14th July 2023.

[3] SESAR DES & DSD Solutions slides 2023 (1_0).pptx

Content integration

[4] Content Integration – Executive Overview, Edition 00.01, 16th February 2023.

[5] DES Common Assumptions, Edition 00.02.01, 29th June 2023.

[6] DES Performance Framework, Edition 00.01.04, 29th June 2023.

[7] DES Performance Framework – U-space Companion Document, Edition 00.01.02, 3rd April 2023.

Content development

[8] SESAR 3 Joint Undertaking – Communication Guidelines 2022-2027, Edition 0.03, 23rd November 2022.

System and service development

Performance management

[9] Performance Assessment and Gap Analysis Report (PAGAR) 2019 – updated version, Edition 00.01.00, 20th May 2021.

[10] SESAR Solution Cost Benefit Analysis (CBA) Quick Start Guide (1_0).docx

[11] SESAR ECO-EVAL Quick Start Guide (1_0).docx

[12] Performance Assessment and Gap Analysis Report (2019), Edition 00.01.02, 13th December 2019.

Validation

[13] DES HE requirements and validation /demonstration guidelines, Edition 3.00, 15th September 2023.

[14] DES SESAR Maturity Criteria and sub-Criteria_01_01 (1_1).xls

System engineering

Safety

[15] DES expanded safety reference material (E-SRM), Edition 1.2, 17th November 2023.

[16] Guideline to Applying the Extended Safety Reference Material (E-SRM), Edition 1.1, 17th November 2023.

Human performance

[17] SESAR DES Human Performance Assessment Process TRL0-TRL8, Edition 00.03.01, November 2022.

Environment assessment

[18] SESAR Environment Assessment Process, Edition 05.00.00, 23rd July 2024.

Security

Programme management

[19] Green-GEAR Grant Agreement No. 101114789, version 1, signed 11th May 2023.

[20] SESAR 3 JU Project Handbook – Programme Execution Framework, Ed. 01.00, 11th April 2022.

[21] Common Taxonomy Description (1_0).pdf, Edition 1.0, 7th February 2023.

[22] Horizon Europe ethics guidelines – essentials_1 (1_0).pptx

[23] Project Reviews 2024_guidance for IR1 & ER1 (1_0).pptx

10.2 Reference documents

[24] Green-GEAR Grant Agreement No. 101114789, version 1'. May 11, 2023

[25] EUROCONTROL's Standard Inputs for Economic Analyses, release 10.0.3

[26] Commission Implementing 'Regulation (EU) 2019/317' of 11 February 2019 laying down a performance and charging scheme in the single European sky and repealing Implementing Regulations (EU) No 390/2013 and (EU) No 391/2013 (Text with EEA relevance.),

(Regulation 2019/317)'. [Online]. Available: https://eur-lex.europa.eu/eli/reg_impl/2019/317/oj

[27] SES2+, European Parliament and Council. Regulation (EU) 2024/2803 of the European Parliament and of the Council of 23 October 2024 on the implementation of the Single European Sky (recast), Official Journal of the European Union, L, vol. 2024/2803, pp. 1–66, 2024

[28] International Civil Aviation Organization, ICAO's policies on charges for airports and air navigation services (Vol. 9082). International Civil Aviation Organization., Ninth Edition 2012

[29] Commission Implementing Regulation (EU) 2024/2493 of 23 September 2024 amending Implementing Regulation (EU) 2018/2066 as regards updating the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council

[30] SESAR JU, 'Strategic research and innovation agenda (SRIA)'. [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/reports/SRIA%20Final.pdf

[31] 'Green Deal'. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[32] 'Strategic Allocation of Traffic Using Redistribution in the Network (SATURN) report', 2015. [Online]. Available: https://innaxis-comm.s3.eu-central-1.amazonaws.com/ENGAGE/WIKI/DELIVERABLES/WPE/E+02+33-D05-SATURN-D6+5-Final+Report+(Dissemination)+-V.01.00.00(w).pdf

[33] S. Dietmüller et al., 'A Python library for computing individual and merged non-CO2 algorithmic climate change functions: CLIMaCCF V1.0', Geosci. Model Dev., vol. 16, no. 15, pp. 4405–4425, 2023, doi: https://doi.org/10.5194/gmd-16-4405-2023.

[34] «SESAR 3 ER 1 Green-GEAR – D5.1 – Initial OSED – Green Route Charging», ed. 01.00, 29th June 2024.

[35] «SESAR 3 ER 1 Green-GEAR – D5.2 – ERP – Green Route Charging», ed. 01.00, 22nd November 2024.

[36] «SESAR 3 ER 1 Green-GEAR – D5.3 – Intermediate ERR – Green Route Charging», Ed 01.00, 12th February 2025.

[37] «SESAR 3 ER 1 Green-GEAR – D5.4 – Final OSED – Green Route Charging», Ed 01.00, submitted 30th June 2025.

[38] «SESAR 3 ER 1 Green-GEAR – D5.5 – FRD – Green Route Charging», Ed 01.00, submitted 30th June 2025.

[39] «SESAR 3 ER 1 Green-GEAR – D5.7 – Final ERR – Green Route Charging», Ed 01.00, submitted 30th June 2025.

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Appendix A Maturity criteria (self-assessment)

A.1 Initial Solution maturity assessment

The only maturity criterion identified as relevant for the ECO-EVAL is PER.TRL2.3.

Does the TRL2 ECO-EVAL contain a qualitative (order of magnitude) description of the costs and benefits of the solution that allows the different impacted stakeholders to have confidence on the continuation of further research for the proposed ATM solution?

Yes, costs as well as benefits have been outlined qualitatively. Given the low TRL of 2, quantitative numbers have been evaluated only partially and on particular validation scenarios; their evaluation is described in section 4.6.

Are the following elements clearly described in the TRL2 ECO-EVAL:

(1) scope of the solution (in particular considering the cost-drivers).

Yes, the scope of the solution is described in section 2.2 and cost-drivers are described in section 5.

(2) interdependencies with other solutions.

Yes, interdependencies with other solutions are described in section 3.2.1.

(3) implementation/deployment options.

Yes, implementation and deployment options are described in section 3.5.

(4) identification of the impacted stakeholders.

Yes, the impacted stakeholders have been identified and described in section 3.4.

(5) qualitative description of the benefits, in line with the BIMs in the OSED TRL2, including the most impacted KPAs and KPIs.

Yes, the benefits have been described in accordance with the BIM and related to the investigated KPIs (see section 4).

(6) identification of cost drivers.

Yes, the major cost drivers have been identified and described in section 5.

A.2 Full Solution maturity assessment

The Full Solution addresses only TRL1. Therefore, PER.TRL2.3 is not applicable. However, we note that in respect to

TRL1.9: "Have stakeholders been identified, consulted and involved in the assessment of the results? Has their feedback been documented in project deliverables? Have stakeholders shown their interest on the proposed solution?

the present report, in addition to identification of stakeholders and their needs already documented in the ERP (D5.2) [35], Final ERR (D5.7) [39] and Final OSED (D5.4) [37], contains further stakeholder feedback plus the project's position in Appendix B. Both a IATA position paper (appendix B.2) and the minutes from the second Advisory Board workshop (appendix B.3) can be found in the next chapter.

Appendix B Stakeholder feedback

The GRC team organised two workshops to present and discuss the GRC Solution. First workshop was held on 14th May 2024 with the members of Advisory Board, which is composed of airline, ANSP, EC, and ATCO representatives. The second workshop was held on 29th April 2025, and was open to all interested stakeholders, where CRCO and flight planning group representatives participated as well (see minutes of the second workshop in section B.3).

The IATA representatives participated in the design of the survey that was a part of the work in the development of the Full GRC Solution, and in the workshops. The IATA provided their official feedback on the survey (see section B.1 for details), and on the GRC Solution overall (see section B.2).

B.1 SP survey

B.1.1 IATA feedback

Green GEAR – Stated Preference Survey

Lot 1 – IATA feedback. December 2024.

Objective

This document reports the feedback obtained by IATA through its member airlines during the "Stated Preference Survey" run by the Green-GEAR project.

Context

The survey is framed in the third solution of the Green-GEAR project, called "Green Route Charging", which explores modulation of ATC charges mechanisms to incentivize the use of environmentally friendly trajectories. Only CO2 in an initial step, and subsequently the total climate impact also accounting non-CO2 effects.

The project's methodology considers as first step the calibration of airlines' cost sensitivity to gain a better understanding of the main drivers of airlines' decision-making and route choices. The so-called "Stated Preference Survey" was therefore designed to adjust the project's modulation of charges models and to develop Solutions. Consequently, this first step is a primary input for the project to develop the charging modulation mechanisms.

Once the project team designed and published the survey, IATA distributed[1] it to the target profiles[2] amongst a selection of airlines representatives that work in relevant working groups[3] and governance structure[4] of IATA, all of them knowledgeable in ATC charges and involved airline disciplines.

In total, it was distributed to 47 different contacts from +30 airlines operating in Europe, comprising airlines operating intra-European flights, short and mid-haul, as well as carriers from out of the region, long-haul with intercontinental and transoceanic flights. All kinds of IATA member airlines were consulted.

During the survey campaign, IATA caught up with several airlines, with the project team, as well as internally with several IATA units, including global IATA's HQ handling ATC charges.

Scope

The following sections summarize the facts found during the survey campaign and the feedback collected amongst the consulted airlines.

This report remains as much factual as possible, limiting its contents at describing the feedback received by the IATA member airlines during the survey process, and also matching or linking that feedback with IATA formal and published positions on the subject matter.

The conclusions are structured by showing the overall perspectives of the airlines on the project, as well as the views of the airlines on the objectivity, completeness, representativeness, and usability of the survey.

[1] IATA member airlines contact details were not shared, as per our IATA applicable rules on confidentiality, data privacy, GDPR
[2] Dispatchers, flight planners, financial department, flight planning, route/network planning
[3] IATA's ATC Charges Working Group
[4] IATA's Regional Coordination Group

Facts found during the survey

Perspectives of the airlines on the survey

The following appreciations were raised by some airlines when dealing with the survey.

- **Survey length and complexity**: the survey was found as long and repetitive. Despite it was designed and aimed to be completed in an average time of 20', respondents found conceptual doubts in the questions. This slowed down the completion of the survey and was the root cause of several cases in which some airlines did not complete the process.
- **Format issues**: some airlines also found the format as not favoring a consolidated response at airline level, as the completion had to be done in a single browser session in front of the screen. This factor could also generate some giving ups.
- **Survey not compatible to provide a response at Group Level**: airline groups encompassing different business models are unable to select multiple options simultaneously.
- **Characterization of the model**: apart from the format, several airlines found the model as simplified. Aspects as connecting flights, flight and cabin crew rotations, curfews, passengers in transit, regulated airports, ATFM delays, weather events, etc., were not part of the survey model. Airlines expressed that without considering these impacts, the model would stay at a too simple level.
- **Perceived bias**: few airlines noticed the way of how the questions were formulated as biased, as predicting conclusions, with the possibility of omitting / ignoring some choices, being the user obliged to click on an undesired option.
- **Potential pre-judgment**: The survey was perceived as designed to confirm an ex-ante perception that airlines prioritize other business criteria over environmental efficiency. In combination with the abovementioned perceived bias, some airlines might have preferred to decline contributing to what seems a potential predefined conclusion.

Perspectives of the airlines on the overall project

The following considerations have been collected from the IATA member airlines in relation to the overall objective of the Green Route Charging Solution:

- **Non-CO2 effects not understood yet**:
  - Several airlines expressed they are already actively investing by means of participating in different projects (IR, DSD) aimed at a better characterization of the behavior of the non-CO2 effects, its impact on climate, and potential mitigation minimizing means.
  - Developing models of modulation of charges balancing CO2 and non-CO2 were found as premature and only leading to decrease the airlines' community trust on R&D. Including CO2 and non-CO2 effects of aviation in the charging scheme precedes today's science.
  - Airlines are already financially penalized by sub-optimal ANSP performance. Modulation of charges applied to an environment that needs fixing was found as not pertinent.
  - The trade-offs are still to be understood and the confidence levels are still not reliable to consider a modulation of charges mechanisms.

    [Lot1 (IATA, ERA, EL AL) conveyed messages aligned with these considerations during the Green GEAR Advisory Board meeting on the 14th of May 2024]

- **Concerns of project's outcomes:** despite knowing the project is Exploratory Research type, there were also expressed concerns from any potential policy or regulatory recommendations included in any project's deliverable on modulating charging models for environmental purposes. Any recommended policy or regulatory action eventually submitted to the SESAR 3 JU and ultimately to the EC was perceived as a risk.

IATA

Perspectives on the overall project

IATA's formal position, published publicly at "Aviation Charges & Climate Change", is related and aligned with some of the previous facts:

- *To the extent that charges may act as an incentive, it is important to be aware that the modulation of charges on the basis of too many variables will make the charges meaningless and could lead to undesirable trade-offs. It is well-established that there can be trade-offs and interdependencies between various environmental measures.*
- *Modulating ANSP charges [...] would not reflect the fact that many airlines are already financially penalized by the lack of optimized ANSP services, creating an increase in fuel burn and compliance costs associated with the resulting emissions (e.g. CORSIA, EU ETS).*
- *ANSP charges should only be imposed for services and functions provided to airspace users and services provided for aircraft ground operations (arrivals, departures, taxiing)*
- *As CO2 emissions are directly related to fuel use, a CO2 component in the structure of charges would be equivalent to a levy on fuel and violate Article 24* [of the Chicago Convention] *and most air services agreements.*
- *ANSP CO2-related charges would inevitably lead to duplicative and uncoordinated policy measures and regulations. Emissions from international aviation are already subject to CORSIA, and some countries already impose duplicative measures such as EU ETS and taxes.*
- *While they may be well-intentioned, uncoordinated initiatives are counterproductive, as they will erode support for a global approach to aviation's emissions.*

IATA's commitment to the project: IATA remains available for this project to further explore the limitations of modulation mechanisms and their adequacy for the desired purpose.

For instance, it would be important to address (non- exhaustive list):

- Consideration of known interdependencies: ANSP capacity – flight efficiency; CO2 versus non-CO2 emissions, etc.
- Avoidance of potential penalties for causes out of the control of the airline (weather, ANSPs' constraints, unavailable airspaces, etc.).
- Evaluation of the added complexity to track the impact to the charging scheme, e.g.: revenue guarantee provision, effect on the predictability of unit rates (new need for adjustments), potential gaming when calculating adjustment factors, etc.

Conclusions

As final wrap-up, the survey has had a moderate outreach amongst the airlines' community (a total of 13 answers) due to the following aspects:

- Lack of a user-friendly format, time consuming, not adaptable to different organizational realities from airlines and groups of airlines.
- Simplicity of the model characterizing airlines' operations business drivers.
- Bias perceived from airlines.
- Airlines' concerns on the nature and objective of the project, researching on a substantial change of the ATC route charges for CO2 and non-CO2 effects, which are not well understood nowadays yet and being under research in parallel.

3 Green GEAR – Stated Preference Survey

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B.1.2 GRC team position

The team developed and tested the **stated preference (SP) survey** with the IATA delegates/Advisory Board members. Part of the testing covered the wording of survey introduction, that explains the goals and practicalities. This text needs to be balanced between too much and too little information. Within the tests, the participants accepted as sufficient the final explanation, which was probably due to the extensive discussions during the testing. However, from the feedback in the section above, it is obvious that the survey introduction could have been better explained, which might have avoided some of the obstacles pointed out by AUs. In particular, these points should have been covered better:

- Explain what an SP is – a tool to test the hypothetical, new situation, by offering competing choices, aimed at collecting the participant's stated preferences for such hypothetical choices. As such, the questions are indeed repetitive, and the number of given questions can vary, depending on responses.
- Explain that survey should be completed by a single participant, following the current, or potential business model of the company. The SP survey, by definition, is not geared for a 'group' or collective response.

These two points could have avoided, or at least mitigated the first 4 bullet points in the 'Perspective of the airlines on the survey'.

Regarding the 'Characterisation of the model' issue, the team had to strike a balance between oversimplification and overcomplication. The choice was to use the high-level description of possible matters regarding the costs, delay and environmental impact. Note that environmental impact is the novelty introduced, in order to test the perceived sensitivities or airlines to the need to balance avoidance of higher environmental impact creation with other business priorities, expressed in terms of cost and delay (and connecting passengers). As such, the survey does not present a model, but tests the perceived sensitivities to certain characteristics, when these are in competition.

The point of the SP survey is to present a high number of choices, each having a slightly different combination of tested characteristics (i.e. cost, delay and environmental impact). The team designed an adaptive SP survey, which adapts, by design, the subsequent choices offered. The adaptation is based on already-submitted choices, with the goal of exploring as many different options as possible. True, it can happen that there are no desired choices within one of the questions. Those are due to the fact that even in the current (actual) system, it is difficult to have an optimal choice for all the flights (due to myriad constraints), and to the fact that the survey adapts the choices offered based on previously-received answers. Again, the goal is to test sensitivity, not to obtain an absolute number or a value.

The survey was designed to test the sensitivity to a hypothetical situation where crossing climate sensitive areas implies higher route charges (i.e. costs). The point is to obtain the information on important trade-offs. For example, if there are X connecting passengers, which route would one choose, if the choices have certain costs, delays and environmental impact, as happens in operational practice as well. In hindsight, the team could have probably insisted on an information session to the potential participants, to explain better what the adaptive SP survey is and what are the goals. Due to GDPR matters, IATA was not able to accommodate our request for such an information session.

(Some) airlines perceive that **non-CO_2 effects** are not well understood yet, and as such there should be no research on the modulation of charges designed to reduce all aviation emissions. The GRC team firmly disagrees with that perception. Due to the need to reduce climate impact, which is one of the main goals of DES, and even more, due to the need to better understand if it is possible to meaningfully reduce the climate impact of aviation, it is necessary to explore various topics related to non-CO_2 emissions reduction. The Full GRC Solution proposes a novel route charging designed to incentivise the avoidance of climate sensitive areas (taking airspace capacity into account). At TRL1 the Solution is mainly investigating whether the proposed environmental modulation (new route charging scheme) would be able to create a desired effect, i.e. the reduction of climate impact, at the network level. Closely linked question is what would be the magnitude of this effect, and what are the trade-offs needed to achieve it.

The validation exercises show that the mechanism has a potential to reduce the total environmental impact on the order of 10%, while increasing the fuel consumption by less than 1%. This is one of the identified trade-offs that requires further investigation, to make sure that reduced route charges for avoiding climate sensitive areas offset the additional fuel costs. The initial results show that the sum of fuel costs and route charges would increase for about 1%, on average. This needs further investigation in terms of who is impacted, in what way, and if it is possible to adjust the proposed mechanism to avoid the fuel cost increase for AUs. Results also show that the lack of airspace capacity is a limiting factor – in saturated airspace, there is no space for manoeuvre to avoid climate sensitive areas. Further research is needed, on a larger scenario (ECAC network), and with more reliable data on available capacity.

The future work identified by the GRC team, that is needed to better inform on the possible complexity, linked uncertainties and trade-offs for different stakeholders, aligns with questions raised by IATA. Section 9.3 offers a detailed description of future steps, here we just mention a few:

- The environmental modulation for non-CO_2 should not be concurrent to ETS in case it is decided that non-CO_2 impacts should fall under the similar trading scheme as CO_2 (see details in section 9.3),
- The proposed route charging scheme should be assessed on a larger scale, simulating daily operations, to ascertain whether the trade-offs examined so far hold on a larger scale, and to check the availability of environmentally friendly trajectories, and what can be done if those are not available.
- Design and test the mechanism for route charge collection and redistribution, as well what would be needed for monitoring and verification of such a novel mechanism.

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B.2 IATA position on the GRC Solution

B.2.1 IATA feedback

Lot1 ad-hoc report: Green-GEAR Project – Green Route Charging Solution

CONTEXT

Lot1 (IATA, EL AL and ERA), under the contractual framework "Airspace Users Support to the SESAR 3 Programme", provide airlines' perspectives feedback, input and support on the different projects, for the SESAR 3 JU (S3JU hereinafter) to evaluate the progress, maturity, and user acceptability.

Under that contract, the task order coded as IATA-2025-006 consists in the provision of inputs and support to the Green-GEAR Advisory Board, and delivery of an ad-hoc report on the Green Route Charging Solution.

The Green Route Charging Solution deals with the modulation of route charges for environmental reasons. The solution also extends to address modulation for capacity reasons.

The contents of this report are the result of the evaluation of airlines done on the concepts developed by the Green Route Charging Solution evaluated in 2024 and presented during the workshop that the Green-GEAR project team delivered on the 29th of April 2025.

INTRODUCTION

This paper provides input gathered from airlines after the workshop held on 29th of April 2025 on the "Green charges solutions". The inputs have been coordinated with EL AL, ERA, and IATA member airlines participating in IATA's governance expert groups on ATC charges, and other airspace users' associations.

Airlines are concerned that insufficiently explored and immature modulation of charging mechanisms could cause undesired effects, and/or results opposite to the ones originally intended. As expressed in the Green-GEAR workshop on the 29th of April, it is fundamental to avoid pre-conceived, inaccurate and misleading assumptions such as that the great circle distance is always the most environmentally friendly route, or that airlines systematically avoid expensive airspaces. When defining new charging mechanisms, we should not assume that the system is unconstrained, or capacity is infinite. Presently, the principal causes of route deviations are airspace closures (for example, due to military activity) and capacity constraints.

Such scenario is biased to focus on changing the customers' behavior without considering behaviors on the providers' side. The economic regulation on monopolistic business should not be turned against the customers, potentially increasing the monopolies' rewards for inefficiencies.

With multiple already existing environmental regulations on airlines, new actions should focus on strategic collaboration, instead of additional charging mechanisms that could turn into inefficient resource allocation while not bringing any tangible decarbonization benefits. Such charges would also fail to meet agreed international policies, notably the principles that emissions should only be accounted for once and that charges should be related to the provision of infrastructure and services provided.

Before entering in detailed comments on the proposals presented during the workshop and the documentation distributed in advance, Lot1 invites the project team to read the currently published positions on the relevant topics at IATA - Sustainability Report Library and Aviation Charges & Climate Change.

The subsequent the sections in the document address the following points:

- The Performance and Charging Regulation, and whether the Green Route Charging proposed mechanisms are fit for purpose.

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- The proposals for modulation based on environmental and capacity criteria.
- The Origin-Destination charging solution.
- The "full GRC solution".
- Conclusions and recommendations.

PERFORMANCE AND ECONOMIC REGULATION

The performance and charging scheme (Reg. EU 2019/317) aims to improve air navigation services in the areas of safety, environment, capacity and cost efficiency. The ANSPs (Air Navigation Services Providers) are natural monopolies with, otherwise, insufficient incentives for cost-efficiently improving the quality of service.

The effectiveness of this regulation can be improved. The European ANS environment is the most expensive globally. Prices have been increasing at a rate of 1B€ per year, while the quality of service is worsening, even with the traffic not fully recovered to pre-pandemic levels at network level.

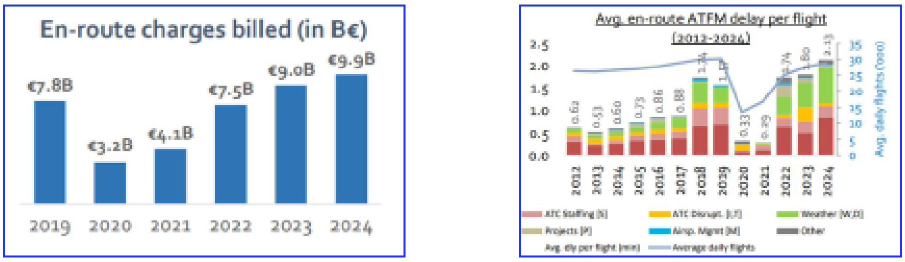

Figure 2: Current European system performance (Performance Review Report 2024, PRC March 2025)

ATFM delays, besides causing significant indirect costs to airlines, also have an environmental effect. PRB's studies quantify 0.14 additional percentage points of horizontal flight inefficiency per minute of average en-route ATFM delay[1]. It is crucial to end the preconceived ideas that the route diversions and the environmental impacts in aviation are solely the airlines' fault.

The use of the same economic regulation for both ANSPs and airlines might lead to additional market distortion. With this mechanism a stakeholder receives a financial impact direct or indirectly due to another stakeholder's actions. In the current context of economic and operational inefficiencies at the ANSP's side, additional opportunities to increase income might send them the wrong signals, as they could benefit from keeping the status-quo and be demotivated to implement some necessary structural changes, for instance regarding lack of capacity. We strongly believe that the Green Route charging solutions could seriously distort the economic regulation on ANSPs, whose potential change of behavior also needs to be explored.

- The premise of the study is that airlines fly inefficiently to avoid expensive airspaces. Airlines' routing decisions are more complex, also based on other factors such as aircraft parameters, weather forecasts (e.g. thunderstorms, turbulences and winds), available information on planned airspace closures or expectations related to runways in use. Importantly, considering the price of service is a "normal" behavior in any competitive market. Judging it "wrong", and to be changed/penalized, removes ANSP's motivation for cost-efficiency, as demand will be disincentivized to fly a more competitive airspace. This opposes the objectives of economic regulation on ANSPs.

[1] https://eu-single-sky.transport.ec.europa.eu/prb-report-interdependency-between-environment-and-capacity-kpis_en

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- The great circle distance is not necessarily the most environmentally friendly. Flying longer may reduce the fuel burn and the CO_2 emissions. Flight levels also influence the fuel burnt, flying longer at optimal levels might burn less fuel than flying a shorter distance at suboptimal levels. The wind can also be favourable or unfavourable to the flight, the shorter route might also require more fuel if the flight needs to compensate wind resistance. Many factors influence to optimize/reduce fuel consumption, which airlines already consider, as burning less fuel also saves them money. Considering only distance is an oversimplification that might lead to price modulation upwards for doing the "right" thing, environmentally speaking. Inefficiencies of the route system could reward the ANSP, disincentivizing airspace design improvements[2], against the objective of the project. Promotion of the GCD, as no routes can be shorter than GCD, will make total charges paid equal to or higher than the current ones.
- Modulation to redistribute demand instead of improving capacity makes current problems appear as the demand's fault, as if additional capacity would not be needed and the existing one could be paid even higher. Flights diverting from GCD due to congestion could receive cumulative penalties (modulation upwards for both congestion and deviation, additional price of fuel, cost of delays if applicable, etc.). The cost for the airline can only be higher than the present one. Assuming that acceptance of time-shifts could eventually make the cost of the flight cheaper, as suggested in the workshop, this would only work until new congestion appears where it did not exist before. The true solution is to ensure sufficient provision of capacity.
- Origin-destination pricing. As the premise is the avoidance of the expensive airspace and the price would be calculated from a reference route that crosses it, it could only lead to increase of prices with respect to the present situation (flights whose GDC already crosses "cheap" airspaces should show no change in behavior or price with respect to current situation, according to the hypothesis).

Revenue neutrality's implications are not sufficiently explored. "The additional money will be put in a pot and be given back to the user's later", as explained in the workshop, is an oversimplification, implying initial overcharging and revenue increase for the ANSP. The implicit "revenue guarantee" reduces risks for ANSPs. Adjustments, especially downwards, are also undesirable for ANSPs and experience shows they react against them by increasing buffers when planning costs and trying to neutralize such downwards adjustments.

With the explanations given, modulation is more likely to happen upwards, results will not be cost neutral for airlines and even less will it result in cost reductions. The non-CO_2 effects modulation is of particular concern as there are presently no established methods available to accurately monitor and verify non-CO_2 emissions on a per flight basis or tools to mitigate them. It can therefore only increase costs for the airlines, especially as there is a penalty if you cross a hotspot, but if you don't, you burn more fuel and possibly get a penalty for flying longer than GCD, besides possibly suffering more ATFM delays, due to current system's inflexibility.

Overall, the message that the malfunctioning of the monopolistic services market is the customers' fault is perturbating, as it is to re-focus the economic regulation on ANSPs towards intervention of a fully competitive market.

As a last reflection, in the context of the implementation of the ReFuelEU Aviation regulation (Regulation (EU) 2023/2405) SAF mandate of 2%, gradually increasing each 5 years going forward, it is crucial for all stakeholders to engage in strategic collaboration.

Modulation based on environmental or sustainability concerns (CO_2, non-CO_2, noise), is not supported as it might lead to inefficient resource allocation while not bringing any tangible benefits. Also, the emergence of a patchwork of charges purporting to address climate change obstructs the multilateral cooperation required for global progress and may impede more enduring and effective climate action through more appropriate

[2] If longer routes increase the ANSP's income, there might be a disincentive at their side to promote optimal flights, make available reserved areas, improve entry/exit points, promote free route, etc.

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mechanisms. Such charges would also fail to meet agreed international policies, notably the principles that emissions should only be accounted for once and that charges should be related to the provision of infrastructure and services provided.

PROPOSED MODULATION OF ROUTE-CHARGES (MRC)

Although the project showed relative symmetric benefit/disbenefit for the users, routes cannot be better than the GCD. We doubt that the modulation on extended routes can ever work as a bonus instead of a penalty for airspace users.

The vertical dimension (flight levels) and the wind effects influence the amount of fuel burnt. It is unclear how the simulations have counted the environmental negative effects of more efficient flights initially longer than GCD changing to GCD. Some deviations from GCD are also due to uncontrollable factors, e.g., weather, airspace closure, strikes, technical outages, etc. The mechanism would unfairly penalize those flights.

Deviations from GCD for capacity reasons already occur today. Those flights could be penalized despite contributing to decongestion. It is unclear if both modulation mechanisms combined would neutralize this effect. But that would mean that congestion alleviation is promoted over environmental impact, in contradiction with the primary purpose of the project. Also, it would mean that additional emissions for helping the ANS business are acceptable, while for helping airlines' they are not (e.g. longer but faster route to bring passengers to their destination on time), which appears to be a biased approach.

Although modulation for congestion could revert in higher prices at busy hours and lower otherwise, we do not see how the mechanism would ensure that sufficient capacity is provided by the ANSP. Capacity targets could be met because the airlines actions instead of ANSPs', potentially deriving in an additional bonus for the ANSP.

It is not clear whether modulation for congestion would work only for fixed prices at different times of the day or also in the short term when a flight is subject to current time-shifts mechanisms (ATFM delays). Anyway, discrimination by the time of the day sends a wrong signal for ANSPs about willingness to pay a higher price for a capacity that is already financed through the cost envelopes planned in the performance plans. The mechanism to guarantee that quality of service is delivered at busy hours is missing. Therefore, we only see signals for the ANSP to increase the price of capacity. The time-shifts idea also needs to be checked against operational and market reality, like opening hours at airports, airports processes, slots management rules, airline-customer commitment, passengers' times preferences, etc.

Airlines believe that compensation mechanisms for the lack of capacity other than modulation are preferable. The lack of focus on ANSPs performance ignores the present reality, as working assumptions presume a perfect air navigation system with unlimited capacity, which is unrealistic. Other assumptions also need revision:

- The project calculates 6% of CO2 emissions due to "route extension to avoid expensive airspaces", while CRCO indicated in the workshop that they estimate this impact in around 1.6% of CO2 emissions.
- The data used for the simulation are from 2019, a year known for the "capacity crunch" and with many RAD restrictions. The system also worked differently then (charges per planned route instead of the current actual flown route). This change has already supposedly discouraged the planning of longer routes than necessary. 2019 data might show a worse situation with respect to the project's premises, as flights were affected by many other uncontrollable factors. Conclusions on these data can be misleading, or the calculated benefits can be overestimated.

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- The indicators KEP and KEA[3] have always shown differences, KEP always being higher than KEA. The good news is that the actual flight is more efficient than the planned one. Efforts have been in place for a while to improve the flight planning, modulation should not tamper with this process or focus only on it.

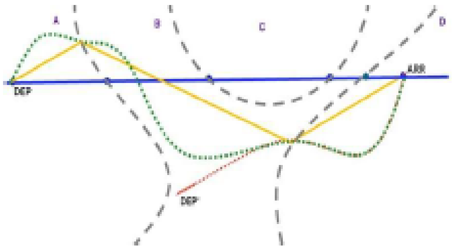
Although the project team defended that, on average, the mechanism would have neutral revenue effects, there would be additional revenues to some ANSPs, if only temporally, unrelated to cost. Also, the scheme gets complex to understand and apply when several effects overlap.

We recommend the revision of the hypotheses and/or the introduction of clear caveats in the conclusions of the study to visualize the limitations and inaccuracies in the underlying premises. It is also recommended to improve the dataset, as the one utilized is obsolete, and to consider a change to actual routes instead of planned ones, as well as excluding from the data all flight diversions that were not driven by airline's choice. Finally, if data are not "cleaned" by removing all instances where route extensions were impossible to avoid, or where they were actually beneficial, the excessive optimism of the results it terms of potential benefits needs to be remarked.

ORIGIN-DESTINATION CHARGING (ODC)

Lot1 appreciates that this point was addressed out of the agenda during the workshop. As the idea is to combine it with modulation and it is perceived as most likely to increase the prices, it is of the utmost importance. Not truly being a modulation scheme, but a pricing one, it is unclear whether revenue neutrality would apply in order to compensate for its effects, which can be wider than the impact on airlines prices.

The following picture, based on the documentation distributed, will be used to illustrate the comments:



- Market distortion: The unit rate of one country would determine the income of another country.
- Cost-(un)relatedness: The working assumption is that ANSP C would only be avoided if the charge between A and D through only B (yellow line) is less expensive than through B + C (blue line). Therefore, ODC (blue) will always be more expensive for the airline, as they will always have to pay as if they were flying through the most expensive airspace. The proposed method removes any attempt of competitiveness for C, as the measure tries to incentivize the blue route.
- The mechanism also remunerates ANSPs A, B and C at a higher price than their nominal, increasing their income for no reason other than having an expensive neighbor, violating the principle of cost-relatedness. They could also get motivated to increase their own costs and prices, as they get used to higher revenues and liquidity. If a flight avoids C for environmental reasons (fuel savings) it would receive a penalty (higher price) for the wrong reason.
- The project does not consider that, if the problem is the high price in C, we should act on the root cause.
- If C were less expensive than B, diversion would rarely happen, according to the assumption. Maybe due to uncontrollable factors (e.g. airspace closed). In such case, the yellow charge would remunerate the ANSPs A, B, D less than their nominal price, penalizing them for having a neighbor in trouble. This could also disincentivize the provision of additional capacity as it could be remunerated lower than its cost. Modulations for uncontrollable factors could have undesirable effects not sufficiently explored.

[3] KEP (Horizontal inefficiency of the planned flight). KEA (horizontal inefficiency of the actual route flown.

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- Discrimination: In the example, both the red and the green flights fly the same distance in airspace D. However, the price paid in D would be different only due to different departure airports, and the green flight is affected by the price in C. This is against users' equity principles in State D.

A pricing system discriminating flights in one State depending on the origin, or the States the route overflies, or "should" overfly, is conceptually wrong. Such practice might divert in geopolitical complex considerations,

Lot1 is not supportive of proposals trying to "homogenize pricing", diverting from competition and getting into repartition schemes. Discussions on centralized repartition can derive in undesired behaviors at ANSPs, such as increase of complexity, less transparency, protective additional buffers in cost estimations, etc.

Overall, this proposal represents a paradigmatic change in price setting rules, that diverts from ICAO principles of cost-relatedness and non-discrimination, fails to promote ANSPs' cost-effectiveness and market-like behavior and fails to protect the customer against price abuse. Our recommendation is the discontinuation of this line of research in the future.

"FULL GRC SOLUTION"

This proposal includes another layer of complexity for price calculation, the avoidance of "hotspots", areas especially sensitive to global warming, which depend on meteorological conditions. If understood correctly, the measuring unit of the impact is one nano-Kelvin (one on a billion degrees) in a 20-years' time, which does not initially look appropriate for modulation schemes per flight, as it is subject to uncertainty (20 years' time) and would require extraordinary accuracy of the models.

This part of the solution is clearly more immature. During the workshop, some of the numbers presented for capacity-related assumptions were referred as "somewhere in between crazy and perfect". Also, the non-CO2 effects are currently under research. Before proposing any mitigation, we need to truly understand the effects. Any proposal of modulation effects is more than premature.

Besides immaturity, this part of the research can also benefit from some operational reality. Results must not rely on assumptions of an unconstrained system and unlimited capacity. From Figure 1, it can already be observed that meteorological events significantly impact capacity, due to saturation of the neighboring airspace. The system is nowhere flexible enough to accommodate redistribution of traffic due to hotspots avoidance.

The impact on capacity is unlikely to be resolved with the other modulation mechanisms. Also, the concept deviates from the GCD and introduces increasing tradeoffs between the mechanisms and the problems they intend to fix. For instance, avoidance of the hotspot means deviation from the GDC and increases congestion, the priorities to fulfill become unclear. As per IATAs' published position[4], modulating on the basis of too many variables will make the charges meaningless and could lead to undesirable trade-offs.

The cumulation of proposals will make it impossible to avoid price increases for the airlines. Predictability in the network would also be seriously affected. Aviation's decarbonization towards Net Zero target in 2050 should focus on pathways with higher and clearer potential emissions reduction, such as research on better fuels, or better engines, rather than mechanisms focusing on penalizing airlines. Solutions should address the causes.

There is still insufficient recognition of airlines' efforts to try to alleviate aviation's impact on environment, through increased use of SAF and new generation aircraft, and engines with a reduction of up to 30% of fuel consumption, besides financing the ground investments in technologies to operationally improve the efficiency of flights. You are invited to learn more on airlines' sustainability initiatives at IATA Net Zero CO2 Roadmaps.

[4] Aviation Charges & Climate Change

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Our recommendation is to park the research of further penalties on airlines for non-CO2 emissions and rather focus the efforts in understanding the CO2 / non-CO2 effects and their trade-offs. Positive incentives could help to address the problems at the root cause, to derive permanent solutions for the benefit of the environment.

As a last comment, Lot1 regrets that simulations seem to ignore the comments previously conveyed by us in 2024 on the perceived bias of the "stated preference survey", which continues being the base of the model, despite the expressed limitations and the reduced number of answers to the questionnaire (13 is not statistically representative). Again, the results and conclusions of the study need to reflect the limitations of this tool, as the survey was found as designed under prejudices on airlines preferences and never got acceptance.

CONCLUSIONS

Lot1 (IATA, EL AL, ERA) continues to be concerned about the scope of the project being partial, focusing only on airlines under a preconceived idea that they are the sole responsible of the environmental inefficiencies of the European flights. The impact of current ANSP's underperformance is completely left out of the picture. As previously pointed out, there is insufficient recognition of airlines' efforts to alleviate aviation's impact on the environment.

The proposed solutions financially affect stakeholders with conflicting interests because of the actions of their counterparts. The working assumption is an incorrect theoretical behavior that the proposed solutions intend to correct, with cumulative proposals that are unlikely to be symmetrical. The bias and inaccuracy of some of the assumptions, datasets and operational implications have been highlighted along with the report, and any conclusions or reliability of the recommendations will be affected by them. Caveats covering these should be introduced in the final documentation of the project, especially those deliverables deriving any potential conclusions and recommendations in terms of policy and regulations.

The undesirable effects contradicting the normal functioning of economic regulation on ANSPs have not been sufficiently explored. The solutions only focus on airlines' behavior, without any consideration of the ground side. It shifts the focus of the regulation on monopolistic providers into actions on the customer's fully competitive market. This approach cannot be supported.

Operational and business realities are often neglected, such as the assumption that the system is unconstrained or the reality that airlines also have a business and financial commitment with their customers. Airlines should not bear more risks associated to ANSPs' revenues or be made responsible for resolving capacity issues with additional time-shifts. Other mechanisms to promote sufficient capacity in the system are preferred to this modulation. Regarding high prices, it seems that there are also simpler solutions than convoluted modulation schemes: lower those prices.

The origin-destination proposal is controversial, diverts from internationally agreed principles and can have unexplored undesired effects. Our recommendation is to discontinue it.

The research on non-CO2 effects is progressing, including under SESAR 3. However, to date, accurately predicting and mitigating the net climate effect of single flights would require the collection of technical and meteorological data through methods that are presently not available to the industry. Exploration of any potential remedial measures should be put on hold in order to avoid doing more harm than good. Anyway, the solutions to explore should rather address root causes than the symptoms. Positive incentives should be explored to promote the research of better fuels and engines.

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B.2.2 GRC team position

IATA states: "… it is fundamental to avoid pre-conceived, inaccurate and misleading assumptions such as that the great circle distance is always the most environmentally friendly route, or that airlines systematically avoid expensive airspaces. When defining new charging mechanisms, we should not assume that the system is unconstrained, or capacity is infinite… Such scenario is biased to focus on changing the customers' behavior without considering behaviors on the providers' side. The economic regulation on monopolistic business should not be turned against the customers, potentially increasing the monopolies' rewards for inefficiencies. "

The research behind the GRC solution/s **does not assume** that the great circle distance is the most environmentally friendly route. The routes taken into consideration are historical, routes as planned by airlines. The main assumption is that airlines try to minimise their costs (disutility) when planning trajectories (in majority of cases, unless other problems arise), which has been confirmed by participants in both workshops. Furthermore, the cost minimisation (or other types of minimisation, e.g. for flight time) in flight planning is usually obtained via flight planning software, where different software can be more or less complex in terms of input data and parameters. The route charges are a part of cost minimisation, and in some situations (e.g. long routes, when fuel is less expensive, etc.) those have an effect on route choice. The GRC team takes the cost minimisation approach into the modelling assumptions, and as such tries to mimic the AU's planning processes, albeit in simplified way (considering the TRL level addressed). One of the most important parts of the GRC solution/s is the fact that the proposed modulations **take into account the available capacity**. Current route charges do not take the capacity into account, nor is that information available to AUs when they need to plan their flights, unless in the form of ATFM regulations (which impose delays to alleviate capacity violations). Modulations from the GRC solution indicate which routes pass through congested airspace (via modulation factors higher than 1, thus increasing charges), or through less congested airspace (modulation factors less than 1, ***decreasing charges***[9]). The modulation factors, together with the unit rates can be used in flight planning software, as unit rates are used today, and based on particular situations they are in, AUs could use cost optimisation, time optimisation, or any other trajectory planning optimisation foreseen in their business model. Furthermore, as already explained several times in workshops, the mechanisms assume revenue neutrality (as per existing regulations), for the amount of work performed. Meaning that the modulation **would not bring higher revenues to ANSPs**, unless linked with the higher work provided (in terms of service units). We are aware that there are ANSPs that for one or the other reason do not deliver on the capacity provision, be it for lack of investment (note: every investment increases unit rates), or the staffing levels (again, higher levels, higher unit rates). The proposed mechanisms cannot improve the capacity provision, but are also not rewarding ANSPs, **as their revenues are kept to the level of work provided**.

It is mentioned several times, in the feedback that "The impact of current ANSP's underperformance is completely left out of the picture. " This is largely true, as the topic of the GRC solution is to investigate if the **route charge modulation** could be a tool to decrease environmental impact of aviation. Many other projects are addressing the capacity increase, as is Separation Minima Solution

[9] Which are in some cases linked with the shorter route, in the Initial Solution, and thus further reduce AU's costs. See Final ERR GRC for the detailed results.

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of the Green-GEAR that investigated the possibility of further reduction of vertical separation in the en-route airspace.

The major negative feedback relates to the inclusion of non-CO_2 effects into route charges modulation. The main reason here is that the science behind the prediction and related uncertainties is still not well established. The GRC team is aware of different efforts for reduction of aviation climate impact – new engines, new aircraft propulsion system (e.g. electric, hybrid, hydrogen), inclusion of SAFs. Most of these efforts will take years, if not decades before reaching the market or the full impact (SAF). The GRC Solution is one of the ***potential*** tools to try to decrease the climate impact in the meanwhile. We believe that it is important to understand what could and could not be achieved through the environmental route charging, assuming acceptable science and forecast, under operational constraints, e.g.:

- What would be effects at network level? Would the potential benefits offset costs and complexity?
- What are the trade-offs?
- How would environmental modulation impact different AUs, and different aircraft types?
- Is the route charging the appropriate tool, or could the same effect be achieved through other ways (e.g. MRV)?
- …

We strongly believe that we cannot wait for the science to be fully established and only then try to figure out how to use it to the best extent. We are reporting on this research and **not advocating** for any particular solution to be implemented, but we do advocate for the liberty of research to explore different options and report fully on those.

B.3 Second Advisory Board minutes

1. Agenda

Time (CEST)	Item
09:30	Welcome and introductions
09:45	Green route charging (GRC) context
10:00	Initial GRC Solution – CO_2 emissions
11:00	Break
11:15	Discussion of Initial Solution
12:00	Lunch
13:00	Full GRC Solution - all emissions
14:00	Break
14:15	Discussion of Full Solution
15:15	Summary, next steps
~15:45	Close

2. GRC Context

2.1 Summary

To stress that this is exploratory research targeting technology readiness level 2 (TRL2). In applied research like this one, TRL2 implies the definition of the concept, description of the application and development of analytical tools for simulation or analysis of the application and its concept.

The consortium is aware of the SES2+ and the addition of environmental charge modulation in it (subject to feasibility study), and of the Emissions Trading Scheme's monitoring, reporting and verification (MRV) scheme that just started. Here, the project is evaluating the options for route charge modulation, taking into account potential benefits and disbenefits, barriers and enablers and the stakeholder feedback. ***The consortium is reporting on this research and not advocating for any particular solution.***

Climate impact of aviation is composed of: CO_2 emissions, non-CO_2 emissions (more than 50% of climate impact): contrail cirrus, NO_x (O_3, CH_4, primary mode O_3 (CH_4-induced decrease)), water vapour, sulphate and other aerosols. Contrails represent largest single contribution of non-CO_2 impacts, but is also linked to large uncertainty. Non-CO_2 effects strongly depend on the state of the atmosphere.

GRC Solution uses the idea of **climate hotspot** - a volume of airspace where the atmospheric conditions are such that flying through it creates much higher climate impact.

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

2.2 Discussion

The participants asked where the concept of climate hotspot arises from as they have not found it.

The GRC uses climate hotspot, but could be also called climate sensitive area. Here is a short list of research papers on climate impact of aviation, that are linked to the similar research (note that the list is not exhaustive):

- A Python library for computing individual and merged non-CO2 algorithmic climate change functions: CLIMaCCF V1.0, https://doi.org/10.5194/gmd-16-4405-2023
- A Comprehensive Survey on Climate Optimal Aircraft Trajectory Planning, https://doi.org/10.3390/aerospace9030146
- Algorithmic climate change functions for the use in eco-efficient flight planning, 10.1016/j.trd.2018.12.016
- Climate-optimized flight planning can effectively reduce the environmental footprint of aviation in Europe at low operational costs, https://www.nature.com/articles/s43247-025-02031-8

Note that these works deal with individual trajectory optimisation/planning, but are basing those on the notion of climate hotspot or climate sensitive area.

3. Initial GRC Solution

3.1 Summary

Initial GRC Solution tackles the CO_2 emissions and congestion. The stakeholders – airspace network, ANSPs and airspace users (AUs) – have conflicting objectives, that the solution is taking into account. The goal of the Solution is to reduce total CO_2 emissions and avoid congestion. At the beginning of the year (season) the Central Planner (CP) identifies the set of the most common routes for each OD pair, uses traffic forecast to predict traffic flow. With that information CP computes and publishes modulation factor γ for each route in the set. Then a route charge along a chosen route becomes γ*route charge. The γ for a generic route (that is not in chosen set) is the same as that of the closest route to it in the chosen set.

The results indicate that with the modulation the distance flown and the fuel decrease. (For details see presentation).

3.2 Discussion

The normal text is the summary of participants' feedback, while the text in *italic font* represents the notes from the Green-GEAR consortium.

Discussion on assumptions. The observation raised several times relates to perception that with Initial Solution the airlines are penalised twice - via the modulation, and if forced to fly along the more expensive ANSPs which do not want to invest in the capacity provision in their airspace. In that light, the assumption of revenue neutrality and revenue distribution was not appreciated. The participants do not find equitable that the modulation is proposed on the customers (airlines) and not on the regulated entities (ANSPs). Distribution of demand is considered unfair, when the capacity provision, that is lacking, is not tackled in this solution.

The modulation factor can be positive or negative. When positive, the route charges would increase, and opposite in the case of negative modulation factor. The exact value of modulation factor depends on many factors – airspace capacity, congestion caused by demand, costs, etc. There are cases where the longer route has negative modulation factor, which could offset the fuel costs. There would not be the case that this route charging mechanism would 'force' airlines to use longer routes. The 'forcing' could come the way each airline optimises its trajectories, especially if the cost optimisation is used. The revenue neutrality is an assumption that follows current regulations (see SES2+). It could be relaxed. The Solution is investigating the feasibility of route charges, and as such is not looking into increase of capacity provision (there are many other projects that are working on that).

For a consortium to note that the preliminary flight plan initiative exist which would allow the airline to present the most environmentally friendly flight plan they would like to fly, and see how it differs from what they are then allowed to fly.

Noted, thank you.

The participants noted that the main drawback is the assumption of flying the minimum distance. It has been noted that it has been shown many times that the shortest route is not the most environmentally friendly, as the shortest route (i.e., great-circle distance) does not take into account the winds and other external factors. It was noted that the EUROCONTROL published that only 1.9% of flights could have had a different route.

Note: shortest path in the GRC context is the shortest available path (taken from historical planned trajectories). The model takes into account costs and congestions multiple flights face, and chooses the minimum distance flown IN THE SYSTEM. Meaning that some flights would fly shorter, and some longer routes. To keep in mind that the modulation can keep the route charges at the same level, lower, or increase them.

Participants note that the capacity should be taken into account and that currently the decongestion is taken into account through ATFM on daily bases.

Indeed, the solution takes into account the airspace capacities, at the strategic level. In theory, the models give a signal of where and when in the network the airspace is congested, but that would not resolve all the congestion problems, and the ATFM regulations will still be needed.

The participants note that planned with no wind and actually flown with the wind are very different, that it would be comparing the apples and pears.

The planned route is ftfm profile from DDR2 data, there is no time stamp on when it is received. The actual would be the ctfm profile. Note the ftfm is last filed flight plan, so in many cases it will have the wind impact included (as these plans are submitted around 3 hours prior to departure). These trajectories are not very precise in the airline trajectory optimisation sense, but are good enough approximations for the network level analyses.

The participants note that the airlines are constrained on the number of route choices, and are penalised due to the regulations and other constraints (military, closures, and similar).

There is a percentage of flights that indeed do not have a choice on trajectory, and those are taken into account in the model.

Discussion on revenue collection and redistribution.

The concern was raised of misalignment between the ANSP revenues and costs, and the predictability of traffic. Are new routes and closed airspace considered?

At the moment these are considered through the historical traffic. As this is a low maturity level, the feasibility study with such assumptions is a good starting point, that should be improved, if the benefits are shown to be at an acceptable level for continuation.

Would there be any adjustment mechanisms to reconcile what is predicted to be collected and what is collected? Like risk sharing mechanisms.

One of the next steps in our analysis, that indeed needs to be addressed.

CRCO operates a system that has been in the operation for 50 years, and is based on the very simple formula. The plea from States is to keep any changes simple, to keep the rate of claims small (i.e. for erroneous charges). The feeling, after reading the documents, is that the users are choosing the routes based only on route charges, which in operation is not necessarily true, as there are many other reasons that dictate the route choice. It seems that there is a complicated system proposed to address a very limited issue. Who would calculate the modulation factors and how would those be applied?

The Initial Solution takes into account the unit rates but also the congestion, and possible delays. The assumption is that the AUs choose the routes also (definitely not only) based on route charges, and those are significant enough to influence the choice in many cases.

Indeed, there would need to be a change in the process in a sense that there should be an entity that calculates the modulation factors and then distributes them. The exact application of this still needs to be formulated.

Further feedback. Suggestion to see from the results what are the areas in the network that need prioritisation, to have a better explanation of possible benefits and barriers.

4. Full GRC Solution

4.1 Summary

The Full Solution aims at the non-CO_2 reduction. The Full Solution would imply having a Central planner (or similar entity) that would determine the **environmental impact modulation rate (EI rate)**, to be applied if a flight traverses a climate hotspot. The Central planner would collect these extra revenues and redistribute to ANSPs, with the goal of **lowering the unit rates** in the next period, to keep revenue neutrality of ANSPs and cost neutrality (regarding route charges) for AUs.

The main working assumption here is that at the flight plan submission time the climate hotspots are known.

Two versions of the mechanism are being analysed:

- Any flight traversing the climate hotspot pays a fixed rate (per OD), or
- Any flight traversing the climate hotspot pays a rate proportional to EI produced

Note: Environmental impact (EI) is expressed in nK (amount of temperature increase at a 20-year time horizon). The exact mechanism of redistribution of modulation of charges is not tackled explicitly in the model, as the aim of this model is to set the modulation rate. The EI rate is set on a yearly basis (or other (fixed) time-horizons).

Core of the problem is to find out how to set the EI rate? How to forecast the average EI (and financial impact) with the additional modulation of charge given the airlines' reaction to the modulation?

The rate should be set in such a way that even if two routes are similar in terms of distributions of delays, EI, and cost of fuel, increasing EI rate should always decrease environmental impact.

The model is of the following form, involving the sensitivity to cost, to environmental impact and to delay.

$$u = \alpha p + (\beta + \alpha\lambda)c + \gamma\delta$$

Assumptions, for the Full Solution scenario, which is simplified with respect to the Initial Solution:

- Distributions of delays are exponential
- Two different types of airlines (notionally LCC and SCH) with different behaviours
- For now, only two routes per OD pair
- 'Tactical' vertical avoidance (can be switched on and off): assume airlines take minimum EI within 2 flight levels,

Results are shown for a small scenario with 2 OD pairs. Indicators measured are: Environmental impact, fuel consumed, ANSP revenues, capacity violations, airline costs. Parameters: Environmental impact (EI) modulation rates, route charges, delays (for capacity constraints).

Scenarios explored:

- 'Free computation': given traffic and all variables, compute the indicators,
- 'Capacity constraints': or basic optimisation - choose delays to minimise capacity violations,
- 'Full optimisation': choose the best route charges, delays, and EI rate to have minimum EI and minimum capacity violations.

Data sources: DDR data (traffic, delays, sector, route charges), CLIMaCCF library (EI) and Stated preference survey results, among others. These data are then used to choose origins, routes, sector configurations, compute EI distributions, fit delay distributions, compute average route charges per km, load airlines' behavioural parameters.

Take home points:

- EI modulation charge rate can be found and fixed per year,
- ANSPs are revenue neutral,
- Airlines can only lose in terms of fuel consumption,
- Assuming perfect forecast, the magnitude of difference of scenarios is:
  - 15% reduction in climate impact with basic optimisation,
  - +20% with vertical avoidance,
- Capacity shortage decreases efficiency of EI modulation charge mechanism.

Further details can be found in the presentation.

4.2 Discussion

The immaturity of science behind non-CO_2 emissions impact. The participants observe that the science on non-CO_2 emissions is still evolving, which they feel is the reason enough not to look into possibility of having route charging mechanisms for emission avoidance.

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The consortium is aware that the science is still evolving. However, this is a research project that is investigating if the modulation of route charges could be one of the instruments to help lower the total climate impact of European aviation, if and when the science behind the emissions improves.

Modulation of charges perceived as additional penalties on AUs and possibility for discrimination. It was pointed out that there should not be double penalties on airlines introduced, as the climate effects are being taken into account in the Emissions Trading Scheme, through MRV. The participants perceived that the GRC solution considers only penalisation of AUs (through the EI modulation rate), and that there is no thought of incentivisation. In SES2+ there is a possibility to use modulation of charges to influence airline behaviour with respect to environment. However, there are ETS and CORSIA for that, and in participant's view, the modulation to change behaviour with respect to environmental impact has little to no sense. Further, some felt that the Solution is proposing a pricing scheme that is contrary to the current performance and charging scheme.

Indeed, we agree that there should not be double penalties. At the moment, the MRV is focused on monitoring only. If the payment for non-CO_2 emissions would be introduced through the MRV, then the possibility of introducing the route charges mechanism with the same philosophy should not be done. However, both MRV and Full GRC are at the stage of exploration of what could work and in what measure. Furthermore, the proposed mechanism would indeed involve a higher modulation rate if passing through the climate hotspot. The mechanism further proposed that proceeds of modulation rates be used to lower the unit rates, thus lowering route charging costs overall. The modulation of charges for emissions is allowed in SES2+. No details on how this could be done are given, with the additional caveat that a feasibility study should be performed, before implementation could be contemplated.

It was observed that it might happen if an airline is located in the areas in Europe that have or not the climate hotspot, then this Solution would introduce discrimination as those that need to fly through the hotspots would be penalised. And this would penalise ANSPs as it would route traffic away, for no fault of their own.

From our initial analyses, it does not seem that there are areas that always have climate hotspots and those that do not. They seem to be spread, with maybe some areas with higher probability of having a hotspot. We have not found that there are areas that always have a hotspot. Indeed, the geographic location and hotspot distributions are under investigation, as they pertain to the model and to the question of fairness and equity.

Various factors were mentioned that could potentially be discriminatory (geographical location of hotspots, planned or actual trajectory, re-distribution of EI rate).

However, even the current system, in all its simplicity is discriminatory to some extent. The weight factor used discriminates on size of the aircraft even if they take roughly the same space (en-route). Then the distance factor is used even if the controller workload depends more on the time spent in controlling – where a faster aircraft would spend much less time in the sector than the slower one for example. But the current route charging has been in use for a long time and is accepted.

It was perceived that the modulation is adding penalties to airlines, while the constraint on ANSP revenue neutrality is benefitting ANSPs.

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Both the previous performance and charging scheme regulations and SES2+ explicitly say that any modulation or incentive schemes should result in ANSP revenue neutrality.

Who would receive the proceeds of EI rate and how would those be distributed?

The ANSPs would get as much as their unit rates would decrease. This redistribution part needs to be further investigated to suggest a proper way forward.

On what trajectory should this EI modulation charge be done – on the planned or on the actual, as we are now paying on the actual.

This is indeed for discussion, as we aim to reduce the real environmental impact, not the forecasted one, especially if the forecasted and real are widely different.

Climate hotspot discussion. What are the physical phenomena that are causing a hotspot? Pressure, temperature, thunderstorms?

It depends on the state of the atmosphere, so yes, pressure and temperature play a role, but also a concentration of various atmospheric species as that can create a feedback loop. The climate and weather prediction models can be used to predict this, with a level of uncertainty.

How can you forecast how many hotspot events would happen in Europe in a certain year?

The statistics of the environmental impact can be obtained based on the historical data of the state of the atmosphere, and also engine type and fuel properties. Statistically, these properties do not change too much year on year. The particular realisation of environmental impact depends on the state-of-the-atmosphere at particular time, location, altitude, engine type and fuel properties, and falls within statistical distribution.

From one of the projects that is trialling the contrail avoidance, CICONIA, one of the findings is that the contrail prediction is quite unreliable.

That is good to know that at this moment in time the models are not reliable. The GRC Solution, as it is at the low maturity level, is not deployable at the moment. The hope is that in the future the non-CO_2 (contrails and other effects) prediction gets better, which would enable the Solution.

Do you take into account the negative impact (cooling effect)?

Yes, it is taken into account, in the sum of all environmental effects. The sums however, are always positive.

Why is CO_2 considered in the emissions (in finding hotspot) when it has global, not local impact?

The hotspot avoidance might imply higher fuel burn, which produces more CO_2, but could avoid higher non-CO_2 impact. This is the reason we are taking into account CO_2 emissions as well.

Discussion regarding modelling assumptions. Why do you differentiate between the airline types? They all care about the cost and delay. Are you aware that the airlines have a very strong position on the reliability of the results of the SP survey? When replying they found they could not understand the choices and were not able to respond. There was a strong perception that the answer choices were biased.

Indeed, all airlines care about cost and delay, just in a slightly different manner, which is taken into account through the coefficients. These are based on the stated preference survey results. Regarding the SP survey, we obtained several responses and are using those in our work. The number of responses is low, and we are aware of its impact on reliability. As a slight mitigation, the coefficients that come out of the survey broadly agree with the past data on these points. Regarding the survey itself, we could have explained better how the survey was supposed to be undertaken, and the survey design, which was designed specifically to avoid bias.

If the flight level changes are +/- 2 flight levels, the + side might hit the operational ceiling of the aircraft, which would not be feasible.

True, the exact ceiling depends on the aircraft type performances. In these models, this is just used as an illustration of if it would be possible to avoid higher environmental impact by switching flight levels, and at the same time to gauge the extent of the change. A sort of sensitivity analysis. The final goal being the assessment of possibilities for avoiding high environmental impacts.

The participant observes that the prediction of the state of atmosphere is not possible for a year ahead of time, meaning that it is not possible to predict the climate hotspots a year before.

Indeed, we agree, but this is not what the proposed model would do. The model applies the statistical distributions, obtained from historical data. The model does not predict the exact occurrences, but uses probabilities of occurrence.

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