European ATM Master Plan - Benefits and Investment Needs

Companion document

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Abstract

This document provides information detailing the methodology, key assumptions, and results included in the European ATM Master Plan Edition 2025.

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1 Introduction

This document details the methodology, and key assumptions behind SESAR's investment needs and the anticipated performance benefits from the planned rollout of the vision by 2045 described in the European ATM Master Plan. The investments and benefits have been identified and monetized through the work of a task force led by the SESAR 3 Joint Undertaking, in collaboration with EUROCONTROL, the Network Manager, the SESAR Deployment Manager and industrial partners. This document should be read in conjunction with Chapters 2 and 7 of the Master Plan, which provide the big picture for SESAR stakeholders.

2 Expected benefits and impact

2.1 Results

This section presents the quantified performance impacts of the vision as in section 7.1 of the European ATM Master Plan, emphasising significant improvements in areas such as airspace and airport capacity, fuel reduction, passenger time savings, and cost-efficiency. It illustrates how the phased implementation of the vision will enhance overall performance by 2050.

Performance impact (KPA)	Unit	Reference year (2023)(*)	CP1 (up to 2030)	CP1 + Phase C	Phase D	Expected impact by 2050
Airspace capacity (en-route and TMA)	%	8.5 million flights(*)	+ 34 %	+ 60 %	+ 40 % + 80 %	+ 100 % + 140 %
Airspace capacity	%	17.9 million movements(**)	–	+ 15 %	+ 1 % + 5 %	+ 16% + 20 %
Environment (fuel reduction)	kg / flight	6 400	– 22	– 109	– 491	– 600
	%		– 0.3 %	– 1.6 %	– 7.7 %	– 9.3 %
Passenger time saving (departure punctuality)	minute / flight	18	–	– 0.9	– 6.1 – 8.1	– 7 – 9
Cost-efficiency (air navigation services cost reduction)	EUR / flight	1 077	– 26	– 164	– 54	– 209

Table 14: Expected performance impact by 2050 compared with 2023

(*) There were 10.1 million actual flights, generating an average delay of 1.82 minutes/flight (based on Eurocontrol, *Performance Review Report 2023 – An assessment of air traffic management in Europe*). The total of 8.5 million flights refers to the number of flights that the network could handle, offering a quality of service of 0.5 minutes of en route ATFM delay per flight. This estimation is based on the formula used in Eurocontrol's 2001 performance review report to convert traffic into capacity.

(**) Instrument flight rule movements (arrivals and departures) at ECAC airports in 2023 (based on Eurocontrol, *Performance Review Report 2023 – An assessment of air traffic management in Europe*).

In Phase C, the vision leads to a 60% increase in airspace capacity and a 15% increase in airport capacity. Fuel consumption per flight is reduced by 109 kg, and ANS costs decrease by EUR 164 per flight. Additionally, passenger delays are anticipated to decrease by 0.9 minutes per flight.

In Phase D, airspace capacity is projected to increase further by 40-80%, while airport capacity may see an additional increase of 1-5%. Fuel consumption will drop by another 491 kg per flight, totalling 600 kg by 2050. Passenger delays are projected to be reduced by 6.1-8.1 minutes per flight, and ANS costs will be reduced by an additional EUR 45 per flight, resulting in total savings of EUR 209 per flight by 2050.

These performance impacts illustrate that all improvements in efficiency and capacity – such as airspace optimization, enhanced airport capacity, cost-efficiency, and passenger time savings - are aimed at achieving the most environmentally efficient sky to fly in the world. Each advancement contributes to minimise fuel consumption and emissions, supporting to the broader goal of creating a sustainable and eco-friendly aviation sector in line with policy and industry objectives.

Monetised benefits

This section offers a high-level overview of the monetization of expected benefits and impact extended up to year 2050, as detailed in Chapter 7, Table 15 of the Master Plan:

SESAR benefits (EUR billion) by 2050(**)	CP1(*) (up to 2040)	Phase C	Phase D	Total
Airspace capacity (en-route and TMA)	23.5	54	13	**90**
Airspace capacity	2	16	2.5	**20**
Environment (fuel and CO_2)	10	14	63	**87**
Passenger time saving (departure punctuality)	Counted in terms of airspace and airport capacity	14	66.5	**81**
Cost-efficiency (air navigation services cost reduction)	6	27.5	6.5	**40**
Total cumulative benefits	**41**	**126**	**151**	**318**

Table 15: SESAR benefits that can be monetised by 2050

(*) Cost–benefit analysis update 2024 (draft), version 1.01.
(**) All figures are rounded except those for CP1.

The reference for the full CP1 benefits is the *CBA Update 2024' draft (release 1.01)* report. Only the benefits reported for the five identified performance impact (KPA) are included in this table.

The monetisation of Phase C and D benefits is based on the *DES SESAR ATM Cost-Benefit Analysis (CBA) model guide*. This guide includes benefit monetisation diagrams and more detailed guidance for each KPA monetised in the Master Plan, as illustrated in Figure 1 :

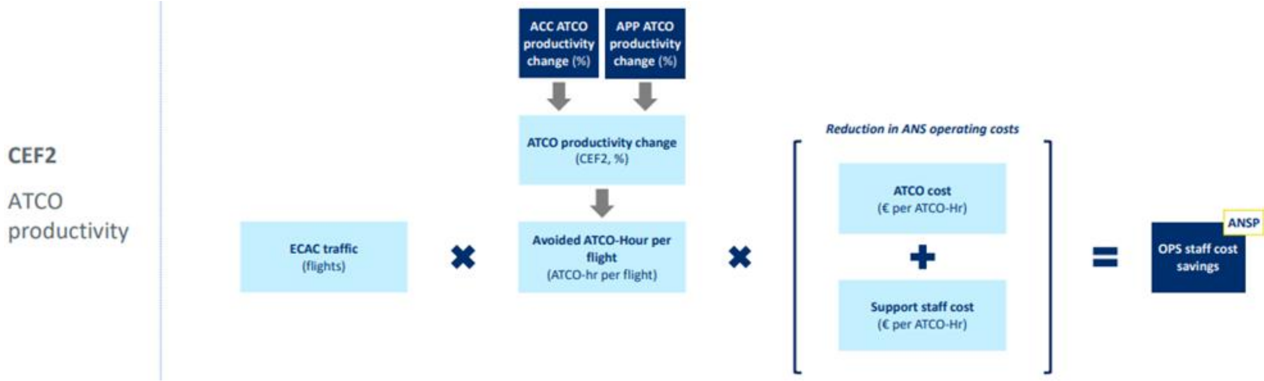

Figure 1: Example of KPA monetisation

The *DES SESAR ATM Cost-Benefit Analysis (CBA) model guide* also includes standard inputs and common assumptions, such as air traffic data, fuel-to-CO_2 ratios, jet fuel prices, and more. These were applied to monetize benefits in areas such as airspace capacity, airport capacity, fuel efficiency, departure punctuality, and cost-efficiency (decomposed into ATCO productivity and technology costs).

Benefits for the environment

This section details the assumptions used to quantify European ATM Master Plan vision's contribution to CO_2 emissions reduction, as illustrated in Figure 13 of the ATM Master Plan. It is important to note that the scope of the European ATM Master Plan is the ECAC region. To ensure comparability, CO_2 emissions from Sustainable Aviation Fuel (SAF) and Conventional Aviation Fuel (CAF) have been compared on a well-to-wake basis[1].

[1] The "well-to-wake" (WTW) concept in aviation is a life-cycle analysis approach that measures the total environmental impact of a fuel, from its production (well) to its combustion during flight (wake). This includes emissions and energy use from fuel extraction, processing, distribution, and final use in the aircraft, providing a full view of the fuel's carbon footprint.

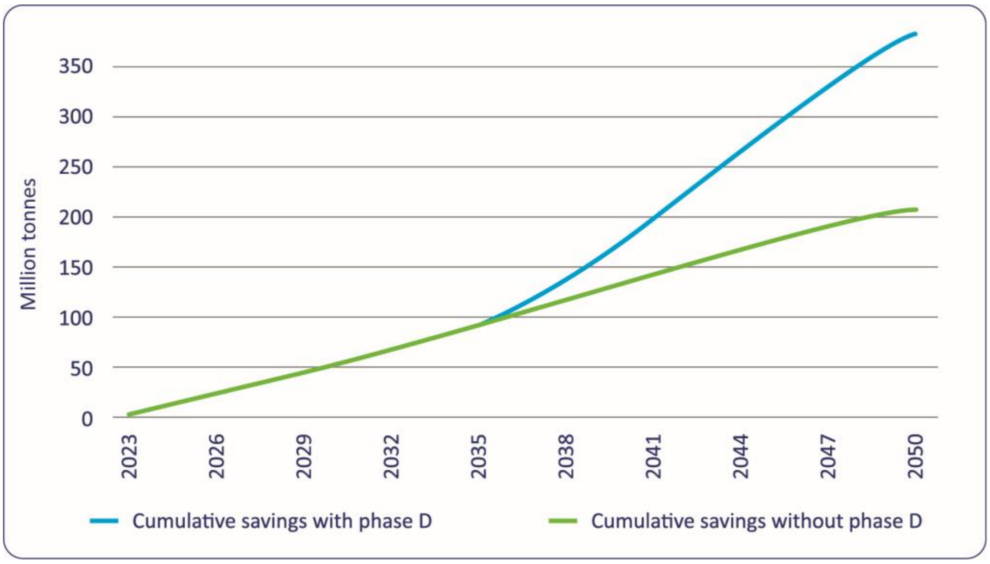

Figure 13: Contribution to CO_2 emissions reduction

The following key assumptions and calculations were considered:

Inputs/formulas	Assumption	Indicator	Source	Reference 2023	Reference 2050
a	Traffic	'000 movements	STATFOR base (Apr 2024) + 1.3% p.a. from 2029	10,144	15,634
b	Fuel consumption/flight	Kg fuel/flight	PRR 2023 + SJU assumption on constant fuel consumption per flight overtime	6,400	6,400
c	SAF	% of fuel	RefuelEU reg. (2023/2405)	0%	70%
d1	CO2 emissions (well to wake)	SAF	EUROCONTROL	0.95 kg CO2/kg fuel	
d2		CAF	EUROCONTROL	4.023 kg CO2/kg fuel	
e	SESAR cumulative improvement	% fuel reduction	SESAR R&I performance results/PRR	0.3%	9.3%
f=a*b*d2	Total CO2 emissions (well to wake) - No SAF and No SESAR	Yearly (Mt)	Calculated	261	403
		Cumulative (Mt)		261	9,456
g=f-(a*b*c*d1+a*b*(1-c)*d2)	CO2 emission (well to wake) with SAF only	Yearly (Mt)		261	187
		Cumulative (Mt)		261	7,792
h1=f-(g*e)	CO2 emissions (well to wake) with SAF and SESAR (including phase D contribution)	Yearly (Mt)		260	170
		Cumulative (Mt)		260	7,360
h2=f-(g*e) No DES contribution in e	CO2 emissions (well to wake) with SAF and SESAR (excluding phase D contribution)	Yearly (Mt)		260	181
		Cumulative (Mt)		260	7,577
i1=g-h	CO2 emission reductions (well to wake) from SESAR	Yearly (Mt)	Calculated	1	17
		Cumulative (Mt)		1	432
i2=g-h No DES contribution in e	CO2 emission reductions (well to wake) from SESAR excluding phase D contribution	Yearly (Mt)		1	6
		Cumulative (Mt)		1	215

Table 1[2]: key assumptions for CO_2 emissions reduction

[2] The STATFOR EUROCONTROL Seven-Year Forecast (2024-2030) from April 2024 serves as the reference for traffic values in Table 1. However, this traffic projection differs slightly from the STATFOR long-term traffic forecast applied in table 14 (April 2022) and that one applied by the NM simulation (STATFOR Seven-Year Forecast report (Oct 2023)).

2.2 Methodology

This section offers an overview of the methodology used to assess the impact across various phases of the vision. The state of the implementation outlines performance contributions from SESAR solutions developed and matured in the past based upon the reference year 2023 (see section 4.2 of the Master Plan).

The 2023 performance reference point replaces the 2012 baseline used in earlier editions of the Master Plan. This update aligns the reference more closely with current and pre-COVID conditions, allowing for more accurate quantification of benefits.

Since not all performance ambitions (see section 3.2 of the Master Plan) could be monetized, Table 14 in the Master Plan reflects those KPAs that could be both measured and monetized.

To adopt a conservative approach, the actual performance inefficiencies observed in 2023 were considered to represent the maximum benefit pool achievable through the implementation of SESAR, even though it is widely recognised that system performance would deteriorate further without SESAR. Additionally, to avoid double-counting, benefits in terms of passenger time savings are solely monetised under departure punctuality.

The SESAR Deployment Manager (SDM) provided the quantification of **CP1 benefits**, as detailed in the *SDM CBA update 2024 – draft release 1.01*.

For the first time in the Master Plan, **Phase C**'s impact was assessed by the Network Manager by conducting a Network-wide simulation, supplemented by results documented in the SESAR 2020 closure report for KPAs not covered by the simulation (see annex).

Performance experts estimated **Phase D**'s impact. A Quality of Service (QoS) approach has been applied to quantify performance ambitions across various KPAs, focusing on removing ATM inefficiencies relative to the 2023 baseline to meet the target QoS.

This analysis was conducted with support from the EUROCONTROL performance review unit (PRU), using the PRR 2023 data as reference. Additional models, such as the PRU model for CO_2 inefficiencies, were used when necessary.

The QoS methodology involves three key steps:

1) **Identification of ATM-Related Inefficiency Factors (2023 Baseline):** by using PRR 2023 data, ATM-related inefficiency factors are identified and isolated, excluding non-ATM-related factors.

2) **Quantification of ATM-Related Inefficiency Factors (2023-2050):** Inefficiencies are quantified with a focus on the 10th percentile of performance as the target QoS. The process aligns with strategic deployment objectives (SDO) quantification results (NM simulation) consolidated with expert judgment.

3) **Consolidation of Phase D Performance Ambition**: in the column “Phase D” of table 14 of the Master Plan, performance impact (KPA) ambitions are derived by subtracting the performance impact of Phase C (SDO deployment) from the expected impact by 2050, isolating improvements specific to Phase D. KPA ambitions are aligned with the QoS methodology, except for environmental targets, which aim to address the entire benefit pool identified in PRR 2023 (this ambition extends beyond the identified PRR2023 limitations on fully reducing inefficiencies to zero).

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This methodology allows for performance impacts to be expressed as ranges rather than fixed targets, supporting the "uncertainty" associated to interdependencies and trade-offs between key performance areas.

2.3 Key assumptions

Table 14 on Master Plan illustrates the quantitative impact of a successful vision roll-out, aligned with the timeline outlined in Chapter 4 of the Master Plan. **The assumptions applicable to all phases of the vision are the following**:

- Geographical scope: encompass the entire European Civil Aviation Conference (ECAC) region, including the section of North Atlantic oceanic airspace managed by European ANSPs.
- Reference year: The baseline year for measuring performance goals is set to 2023, an update from the 2012 baseline used in previous editions, which offers a closer alignment to current and pre-COVID conditions for more precise quantification of benefits.
- Traffic: projections are based on STATFOR's Long Term Traffic Forecasts[3].
- Financial values: are expressed in real terms (deflated) in EUR 2023 using EUROSTAT inflation rates, unless otherwise specified.

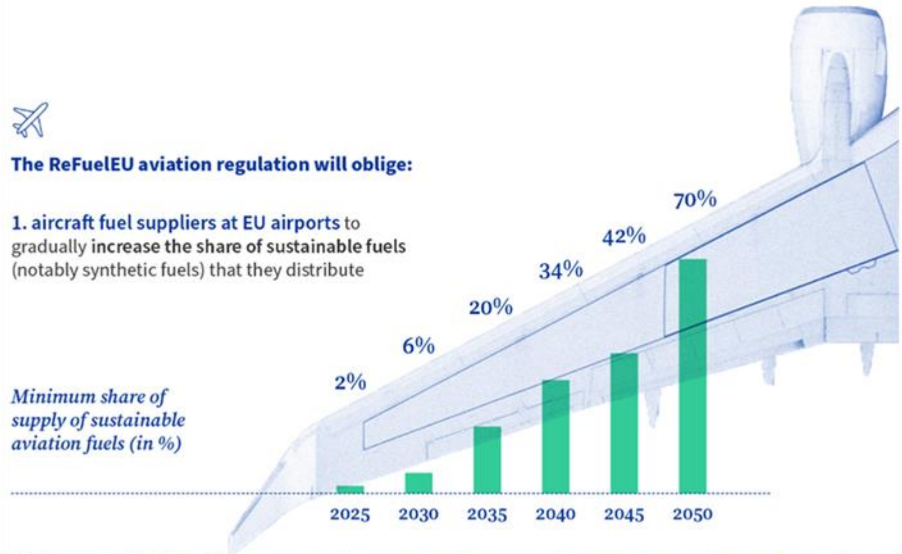
The percentage improvements reported for **CP1** were provided by the SESAR Deployment Manager (SDM; *CBA update 2024 – draft release 1.01*) and reflect performance gains up to 2030. The **contribution of CP1** has been combined with the overall improvements expected from the full implementation of Phase C in order to provide an as accurate as possible overall performance impact for the period starting from 2025.

Phase C aligns with the scope outlined for the SDOs, as detailed in Chapter 5 of the Master Plan. The **benefits of Phase C** have been estimated by the NM simulation with a bottom-up approach and have been projected beyond its full completion in 2035. The monetisation of these benefits extends to 2050. This year was selected to assess the benefits of the full deployment of the Digital European Sky, which aligns with the policy goal to decarbonise aviation.

The following key assumptions were considered to quantify the impact of Phase C:

- Environment: fuel savings per flight were calculated using results from the NM simulation (see annex). With the implementation of the ReFuelEU Aviation Regulation (EU 2023/2405) starting in 2025, the EU mandates a progressive increase in Sustainable Aviation Fuel (SAF) use across Member States (20% of SAF by 2035, see Figure 2). This requirement is expected to stimulate supply and demand of SAF in the market, supporting decarbonization efforts by reducing dependence on conventional fuels. The fuel savings achieved through SESAR's contributions will further enhance SAF availability by decreasing its overall demand.

[3] https://www.eurocontrol.int/forecasting



Reference: *"Fit for 55: increasing the uptake of greener fuels in the aviation and maritime sectors"* https://www.consilium.europa.eu/en/infographics/fit-for-55-refueleu-and-fueleu/

Figure 2: SAF uptake obligation under ReFuelEU regulation in time

• Airspace capacity: the reference measures the number of flights that the network can accommodate while achieving a quality-of-service target of 0.5 minutes of airport and en-route ATFM delay per flight by 2040. This value aligns with the target defined in the SES performance scheme. The contribution from Phase C was assessed using NM simulations (see annex). The traffic-to-capacity relationship is based on the formula established by the Performance Review Unit (PRU) in PRR 2001.

• Airport capacity: the reference takes into account the number of flights departing and landing within the ECAC region, excluding overflights. The percentage increase was derived from Performance Assessment results documented in SESAR 2020 closure report.

• Passenger time saving: the PRR 2023 report (June 2024) indicates an average departure delay of 18 minutes in 2023. Reducing this departure delay is essential to meet the ambition of 0.5 minutes of en-route ATFM delay per flight by 2040, a goal consistent with SES Performance Scheme target.

The main underlying assumptions are as follows:

- Enhanced trajectories and network predictability compared to the 2023 baseline, resulting in better performance regarding departure delay.

- Synchronization of capacity increases across airports, TMA, and en-route sectors to prevent bottlenecks and enabling unconstrained traffic growth.

- The potential for reducing reactionary delays[4] in Phase C is viewed as minimal, with no anticipated decrease from the 2023 baseline, since the strategic deployment objectives (SDOs) for Phase C do not specifically target this issue.

• Cost-efficiency: the reference is based on the ATM cost-effectiveness (ACE) 2024 gate-to-gate ANS cost per flight, initially expressed in EUR 2022 and converted to EUR 2023. It takes into account the downward trend in ANS unit costs from 2012 to 2019. The ambition is to achieve a 19% reduction in gate-to-gate ANS costs per flight by 2050, despite a projected 57% increase in traffic. The slower rate of improvement in cost efficiency is influenced by the need to target the lower range of the ambition, supporting the environmental and capacity objectives through technological investments such as deployment of new TMA/en-route and airport platforms that incur technologic costs.

A dual approach was employed, integrating bottom-up (NM simulations) and top-down methods (starting from ACE 2023 data), based on the key assumption that productivity gains from automation will surpass the increasing technological costs.

Phase D involves the roll-out of development priorities outlined in Chapter 6 of the Master Plan. The **ambitions defined for that phase** are based on the overarching vision and represent the expected impacts by 2050, after the vision is deployed in 2045. A five-year timeframe is allocated to fully capture the benefits of the solutions put in place.

The following key assumptions were used to define the expected impact of Phase D:

• Environment: the ambition is to eliminate 9.3% of ATM inefficiency identified in PRR 2023. The average fuel burn per flight, estimated at 6,400 kg in 2023 (PRR 2023), reflects the average amount of fuel used by an aircraft during a single flight in the ECAC airspace. This metric is essential for evaluating both the environmental and operational efficiency of ATM systems. Higher fuel consumption correlates with increased greenhouse gas emissions, such as CO_2, and elevated operational costs for airlines. By monitoring this indicator, ATM systems can assess the effectiveness of measures aimed at reducing fuel usage, optimising flight paths, and minimizing the overall environmental impact of aviation. The implementation of the RefuelEU Regulation (EU 2023/2405) mandates 42% of SAF uptake for Phase D by 2045.

• Airspace capacity: additional capacity is essential to meet traffic demands (base or high STATFOR scenarios) and improve the quality of service, targeting a maximum of 0.35 minutes of en-route ATFM delay per flight.

To emphasise environmental improvements, this extra capacity supports efficient trajectory management, ensuring that airspace capacity does not become a limiting factor. However, increasing capacity to help minimise environmental impact may involve trade-offs with other KPAs, such as cost efficiency.

[4] Delay caused by late arrival of aircraft, crew, passengers or baggage from previous journeys.

The relationship between traffic and capacity is based on the PRU formula established in PRR 2001.

• Airport capacity: the ambition is to reduce the average en-route ATFM delay from 0.5 minutes to 0.35 minutes.

• Passenger time saving: changes in departure delays are based on a statistical model that correlates primary delay causes with reactionary delays. This reduction is anticipated through enhanced coordination and full digital collaboration among stakeholders (refer to the vision in Chapter 3 of the Master Plan), focusing on synchronising operations to effectively manage demand and minimise reactionary delays.

This ambition aligns with the goal of reducing en-route and airport ATFM delay to 0.35 minutes per flight by 2050. It assumes a substantial increase in TMA and en-route capacity. Additionally, it depends on key vision components such as trajectory-based operations (TBO) to facilitate high trajectory and network predictability, while also assuming that reactionary delays will at least follow existing historical patterns.

• Cost-efficiency: investments in Phase D will be balanced by increased ATCO productivity resulting from higher levels of automation and improved machine-to-machine (M2M) information exchange. This is expected to lead to a reduction of the overall direct gate-to-gate ANS cost per flight, estimated to drop between EUR 45 and EUR 63 per flight. However, the lower end of this range (EUR 45) has been used to account for the necessary investments in capacity that support ambitious quality of service targets (0.35 minutes of en-route ATFM delay per flight) and maximize fuel efficiency (environmental performance) by 2050.

3 Investment needs

This chapter details the projected results, methodology, and key assumptions, and projected results associated with the investments required to implement the vision.

3.1 Results

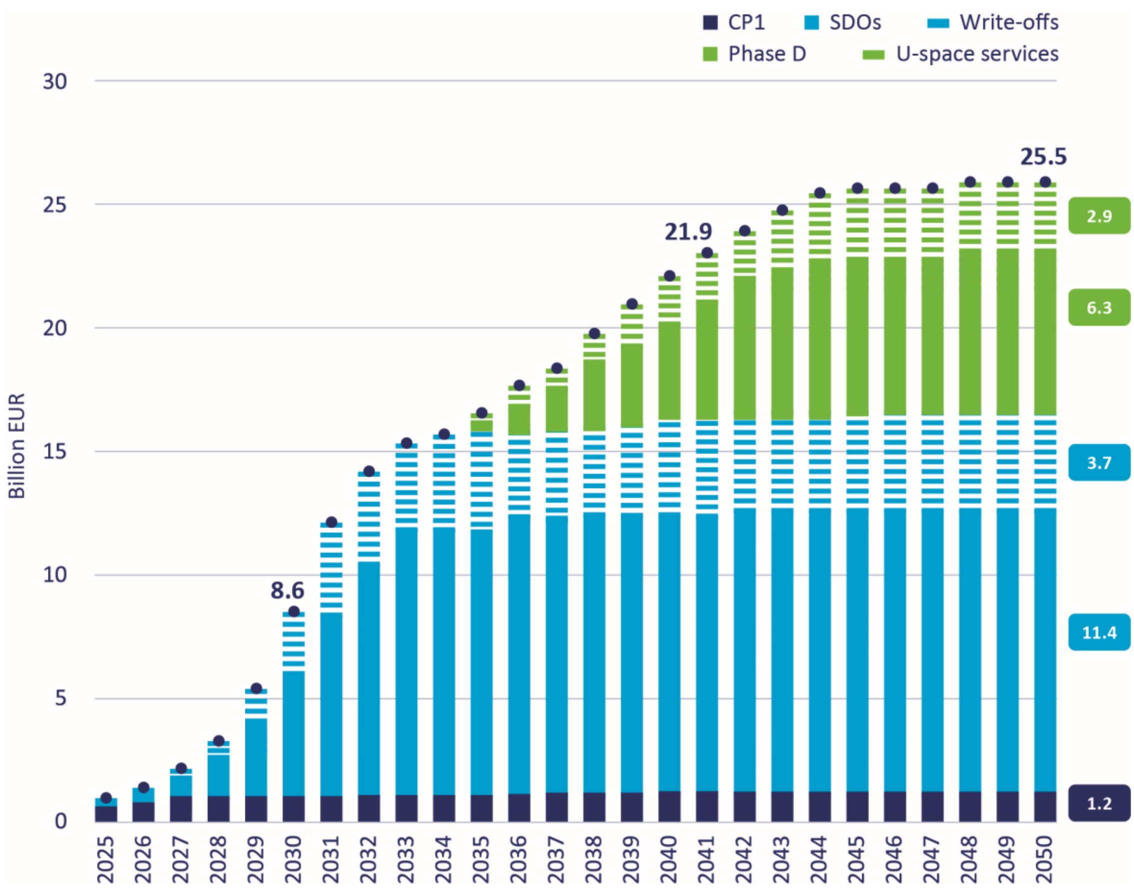


Figure 14: Cumulative investment needs to deploy SESAR

The remaining investment required to fully deploy **CP1** is estimated to be up to EUR 1.2 billion, based on data provided by the SDM in their *CBA update 2024 – draft release 1.01*. Approximately 90% of this total (EUR 1.1 billion) is needed to complete ground deployment by the end of 2027.

For Phase C, the total investment needs are derived from the individual investments for each SDO with capital expenditure (CAPEX) estimated at approximately EUR 11.4 billion.

	SDO title	ANSP	AO	AU	MIL	NM	TOTAL
1	Alerts for reduction of collision risks on taxiways & runways	€43m	-	-	-	-	€43m
2	Optimising airport and TMA environmental footprint	€863m	€175m	€38m	-	€15m	€1092m
3	Dynamic airspace configuration	€885m	-	-	€422m	€80m	€1388m
4	Increased automation support	€600m	-	-	-	-	€600m
5	Transition to TBO	€1975m	-	€1208m	-	€90m	€3273m
6	Virtualisation of operations *(Note: ANSP figures include investment in Remote Tower infrastructure)*	€1920m	-	-	-	€20m	€1940m
7	Transition towards hyperconnected air-ground communication	-	-	€471m	-	-	€471m
8	New service-oriented delivery model (data driven and cloud based)	€1500m	-	-	€9m	€42m	€1551m
9	CNS rationalisation	€133m	-	-	-	€4m	€137m
	Acronyms: ANSP: Air Navigation Service Provider; AO: Airport Operator; AU: Airspace User; MIL: Military; NM: Network Manager — TOTAL	€7919m	€175m	€1717m	€431m	€250m	€10.5bn
		ANSP	CISP	VTOL	RPAS	USSP	TOTAL
10	Innovative Air Mobility (IAM)	€210m	€83m	€375m	€48m	€160m	€876m
	Acronyms: ANSP: Air Navigation Service Provider; CISP: Common Information Service Provider; VTOL: vertical take-off landing aircraft; RPAS: Remotely Piloted Aircraft Systems; USSP: U-space Service Provider — TOTAL						€11.4bn

Table 1: CAPEX per SDO and stakeholder

An additional EUR 3.7 billion has been accounted for as a write-off to accelerate the transition and ensure the prompt implementation of the new service delivery approach (SDO8) and CNS optimization (SDO9).

ANSPs play a pivotal role in accelerating the market uptake of SDO-related solutions. For the EU ANSP, their investments take place in the context of the SES performance and charging scheme. As illustrated in Figure 15 of the Master Plan, the planned investments during reference period 4 (RP4 for the years 2025-2029) amount to a total of EUR 4.0 billion investment for SDOs. The bulk of ANSP investments are expected to occur in the next reference period (RP5 for the years 2030 -2034), requiring an estimated EUR 8.3 billion. These CAPEX volumes are broadly speaking in line with historic CAPEX volumes for ANSPs; however, SESAR investment needs may put pressure on other CAPEX-intensive investments not related to the Master Plan (e.g. towers buildings and facilities). The investment assigned to ANSPs corresponds to the consolidation of the amounts detailed in the individual CBAs. Investment needs not associated with the Master Plan are not included in the calculations.

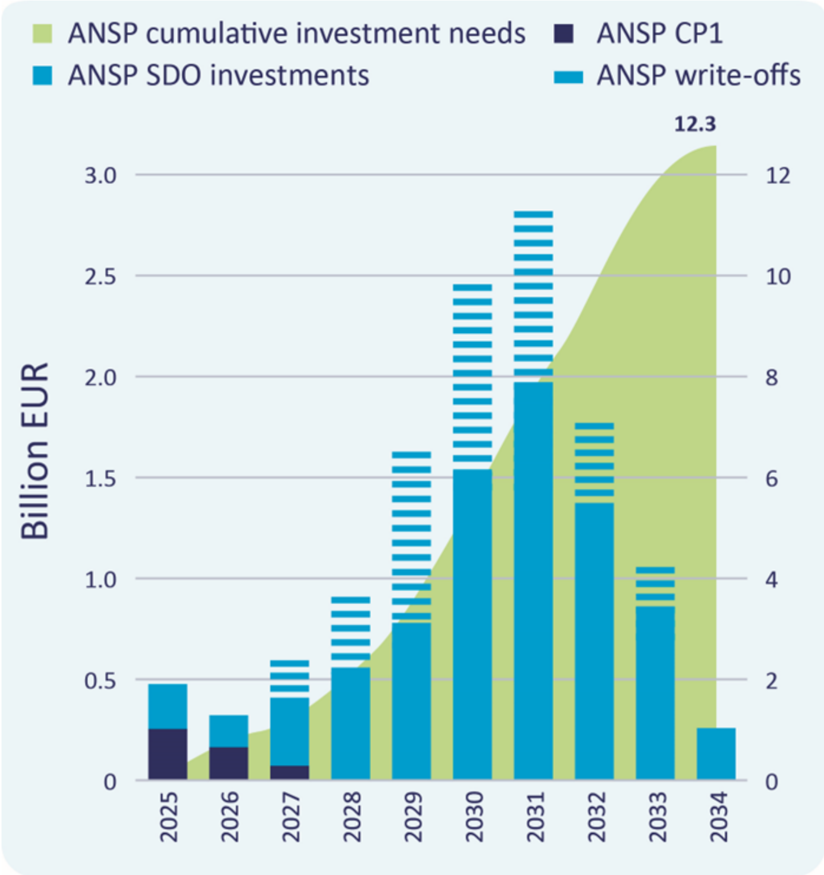


Figure 15: ANSP investments

The NM investment account for about 2% of the total investments by the ANSP, amounting to up to EUR 250 million. Despite the lower level of investment foreseen for other major stakeholders, their contribution will be key to increasing the overall performance benefits.

For Phase D (see Figure 14 of the Master Plan), the investment needs account for EUR 6.3 billion. Additionally, the investment allocated to U-space services (i.e. EUR 2.9 billion) aligns with the assumptions made in the 2020 edition of the Master Plan, with around one-third of U-space investment allocated to the deployment of U3 and U4 services (impacting U-space service providers, drone operators, etc…).

3.2 Methodology

The methodology applied is structured around the planned cumulative investments for the different phases of the vision.

The remaining **CP1** investments as from 2025 align with figures reported by the SESAR Deployment Manager (SDM) in their 2*024 CBA update – draft release 1.01*.

For the **SDOs**, the investments were determined by consolidating the available CBA of each solution that contributes to each SDO.

Projected write-offs are included in the calculations, as they are essential for phasing out outdated systems and enabling the rollout of new digital services. The following assumptions have been considered:

- Significant ATC upgrades at the 67 ACCs in the ECAC region are expected to occur approximately every 20 years, with an average cost of EUR 110 million per ACC.
- Some of these investments will be written off to support the completion of Phase C by 2035, along with the new service delivery model.

The methodology for estimating investments for **Phase D** relies on expert judgement providing a median value within the EUR 5-10 billion range as estimated in the Master Plan 2020. For **U-space services** the methodology adheres to the same assumptions detailed in the Master Plan 2020 (the investment allocated to U-space services (i.e. EUR 2.9 billion) aligns with the assumptions made in the 2020 edition of the Master Plan, with around one-third of U-space investment allocated to the deployment of U3 and U4 services (impacting U-space service providers, drone operators, etc…).

3.3 Key assumptions

The assumptions regarding **CP1** investments are outlined in the SESAR Deployment Manager's report, *CBA Update 2024 – Draft Release 1.01*.

The **SDO** investment assessment follows a bottom-up approach, based on three key inputs for each SESAR solution included in the SDOs as per SESAR CBA methodology:

1) Unit cost per stakeholder: for each SESAR solution listed in the SDOs, unit cost data per stakeholder (e.g., EUR 1 million per airport) is gathered from various sources, when available:

   • Existing CBA reports produced under the SESAR projects.

   • Relevant input from the Network Manager based on the NM high-level CONOPS.

   • Past CBA reports developed by the SESAR Deployment Manager where applicable.

2) Deployment locations: the CBA model calculated the unit cost per stakeholder multiplied by the number of deployment locations within the appropriate sub-operating environment (OEs) for each solution:

   • Applicable sub-OEs for each solution (e.g., very-high complexity en-route airspace) are consolidated through stakeholder consultation during the European ATM Master Plan campaign.

   • The number of deployment locations within each sub-OEs (e.g., 8 ACCs) is based on SESAR assumptions used in the development framework.

   • Adjustments are made when necessary to avoid double counting of costs, particularly for mutually exclusive solutions.

3) Deployment dates: the CBA model allocates investment costs between the start of deployment (SOD) year and the full operational capability (FOC) year:

   • Deployment dates for each solution (e.g., 2030-2035) are consolidated through stakeholder consultations conducted during the European ATM master plan campaign.

These three inputs facilitate the calculation of the total implementation, deployment and investment cost per solution. Additional inputs used in the CBA model include:

Input to CBA model	2025	2030	2035	2040	2045	2050
Traffic *(Source: STATFOR)*	11.3m	12.1m	12.7m	13.7m	14.7m	16.0m
Fuel price *(Source: STATFOR)*	€539/tonne	€604/tonne	€669/tonne	€735/tonne	€800/tonne	€866/tonne
Cost of CO_2 *(Source: STATFOR)*	€68/tonne	€78/tonne	€89/tonne	€99/tonne	€110/tonne	€120/tonne
Fuel to CO_2 ratio *(Note: considering SAF/eSAF)*	3.10	3.00	2.64	2.28	2.07	1.31
SAF + eSAF blend *(Source: ATM MP WG#06)*	2%	6%	20%	34%	34%	34%
Aircraft fleet (SA) *(Sources: EUROSTAT + traffic growth)*	5,642	5,947	6,182	6,605	7,003	7,472
Aircraft fleet (BA) *(Sources: EBAA + traffic growth)*	3,277	3,445	3,620	3,805	3,999	4,203

Note: The figures above represent the baseline used in the CBA calculations. STATFOR values correspond to the "Base" scenario of EUROCONTROL STATFOR "Aviation Outlook 2050"

Acronyms:
CO_2: Carbon dioxide; SAF: Sustainable Aviation Fuel; SA: Scheduled Aviation; BA: Business Aviation

Table 2: inputs to CBA model

For **Phase D**, the assumptions include forward-looking calculations that take into account technological advancements, expected regulatory changes, and historical cost data from earlier phases. These assumptions are consistent with those established in the Master Plan 2020.

4 Return on investment

Return on Investment (ROI) measures an investment's profitability by dividing its benefit or loss by its cost.

4.1 Results

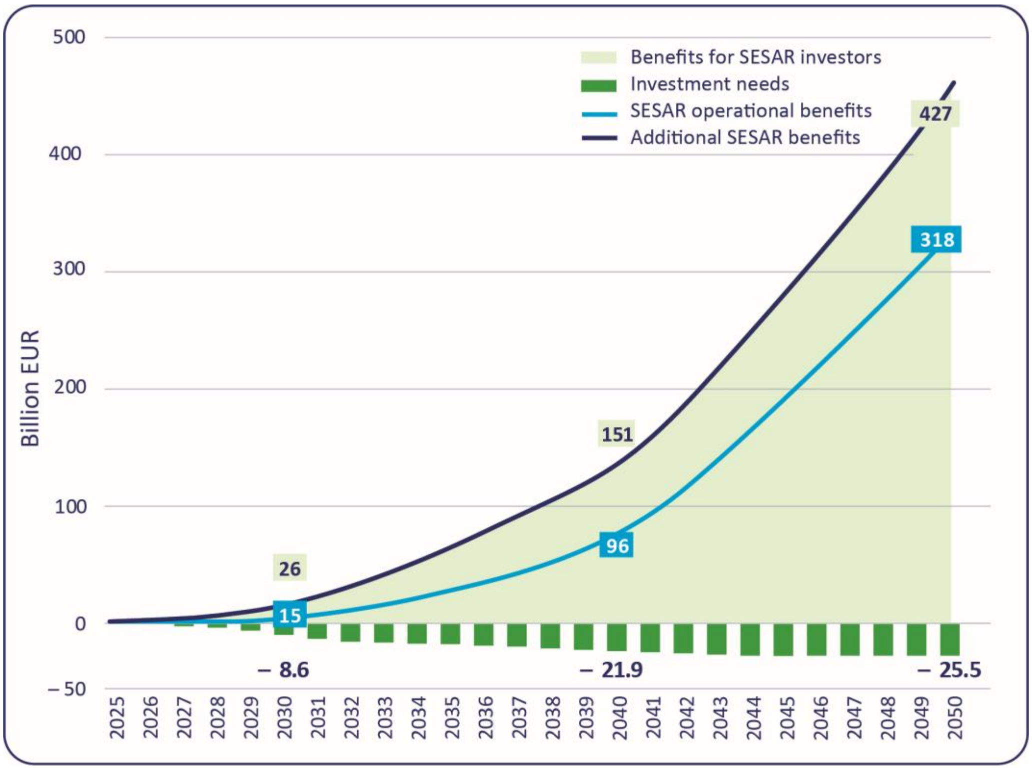


Figure 16: Cumulative performance benefits and investments [5]

Figure 16 of the Master Plan illustrates a significant positive ROI for SESAR by 2050, where benefits greatly exceeding investment costs. The initial phase requires significant investments, particularly from ANSPs; however, the return on investment is already considerable as of 2035. By the completion of Phase C in 2035, SESAR operational benefits along with additional SESAR benefits, deliver strong financial returns, yielding over EUR 3 for every euro invested in SESAR.

[5] The figure takes into account investments in both crewed and uncrewed aviation but excludes benefits for U-space and RPAS.

The steep upward curve from 2040 onward indicates that the full benefits of SESAR solutions implemented in Phase D, especially regarding capacity and environmental efficiency, contribute significantly to the long-term value of the SESAR vision.

In summary, while the early phases demand substantial investment, the benefits result in a favourable ROI by 2030, with cumulative benefits significantly outpacing investment needs by 2040.

The ROI for investors[6] is projected to be EUR 7 for every euro invested in SESAR by 2040. This is based on a comparison of the total cumulative benefits - both SESAR operational and additional SESAR benefits - totalling EUR 151 billion against the total investment of EUR 22 billion by 2040. By 2050, the ROI is expected to raise even further, estimated at EUR 17 per euro invested, reflecting significant cumulative benefits of EUR 427 billion compared to a total investment of EUR 25.5 billion by 2050.

The analysis is conservative as it does not include benefits related to uncrewed aviation and U-space.

4.2 Methodology

The return on investment, as shown in Figure 16 of the Master Plan, quantifies the cumulative operational benefits derived from the deployment of SESAR Solutions across various performance areas, including airspace and airport capacity, fuel efficiency, CO_2 emission reductions, passenger time savings, and cost efficiencies (see light blue line in Figure 16 of the Master Plan).

The analysis also encompasses additional cumulative SESAR benefits (see dark blue line and explanation following Figure 17 of the Master Plan). This is based on a comparison of the total cumulative benefits - both SESAR operational and additional SESAR benefits - against the total investment.

It is important to note that the return on investment calculation does not apply any discounting to future benefits and costs.

The methodology for quantifying SESAR's long-term societal impact follows the approach from the Master Plan 2020, ensuring consistency and alignment with recognised principles. The long-term societal impact of SESAR encompasses the broader, lasting benefits that improved ATM brings to society.

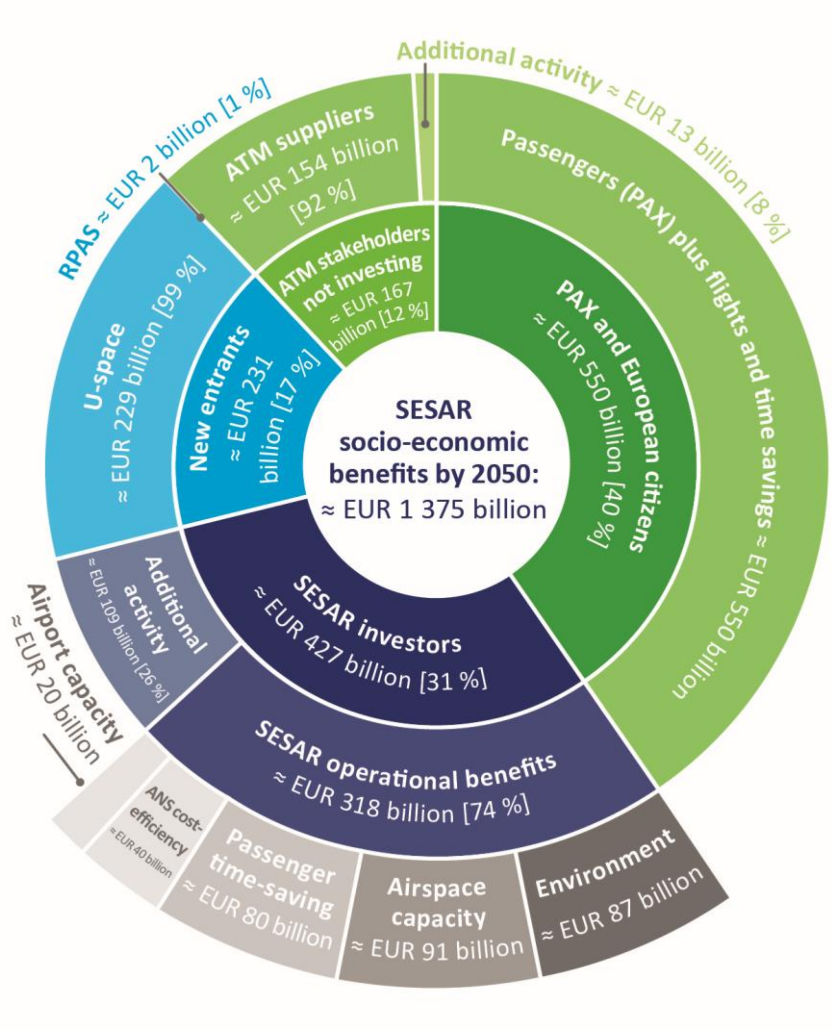
4.3 Key assumptions

The assumptions for the ROI are based on the same foundational assumptions used to estimate both benefits and investments.

[6] Targeted investors: air navigation service providers (ANSP), airspace users (AU), airport operators (AO), network manager (NM), U-space service provider (USSP), information service provider (CISP), Drone/UAS operators, vertiport operators, military (MIL).

These assumptions provide a solid foundation for calculating ROI, ensuring that both investment needs and projected benefits are derived from a consistent and coherent methodology that aligns with SESAR's vision.

The socio-economic benefits (corresponding to 'Additional SESAR benefits' in the legend of Figure 16 of the Master Plan) are illustrated in figure 17 of the Master Plan:



The methodology behind Figure 17 of the Master Plan, which highlights the socio-economic benefits expected by 2050, assesses the direct impact of SESAR deployment on the European economy and society. The analysis identifies a range of beneficiaries, with SESAR investors contributing roughly 31% to the total socio-economic benefits, projected to amount to approximatively EUR 1,375 billion by 2050. The ROI rises to EUR 54 per euro invested when taking into account the long-term cumulative socio-economic benefits by that year.

The economic value generated by SESAR for the four main stakeholder groups is detailed as follows:

1) **Direct impact on the ATM value chain (SESAR investors): this encompasses**:

- Operational benefits generated by SESAR solutions, such as capacity increase, improved environmental efficiency, enhanced operational efficiency, and cost savings, leading to lower ANS unit costs per flight.

- Additional activities enabled by SESAR that contribute to profits across the value chain such as additional flights.

2) **U-space services (New entrants)**: U-space services, designed to integrate drones into European airspace, offer significant benefits, including economic growth (e.g., goods delivery, precision agriculture), environmental improvements, and enhanced safety. The quantification of these benefits aligns with the methodology applied in the Master Plan 2020. As this methodology does not follow the DES SESAR ATM Cost-Benefit Analysis (CBA) model guide used for all direct impact on the value chain, these benefits are not included in Figure 16 of the Master Plan.

3) **Indirect impact on suppliers (ATM stakeholders not investing)**: this refers to the Gross Domestic Product (GDP) generated by the increased activity of those supplying the aviation value chain. For example, it includes the GDP created by airline suppliers, following the direct impact on airlines. In order to capture the indirect impact of SESAR, the so-called GDP multiplier methodology based on OECD input-output tables is applied.

4) **Indirect impact on passenger and society**: This includes the measurable benefits to passengers and society resulting from SESAR, such as greater flight availability and time savings (due to reduced delays, shorter flights, and increased arrival punctuality). Additional impacts include lower air pollution and mitigated climate change effects due to decreased fuel consumption per flight.

Some macroeconomic studies examining the overall economic impact on industries or sectors consider additional "induced effects" such as increased consumer spending. However, these induced effects are not included in the Master Plan to avoid further inflating the positive impact on SESAR and to maintain a conservative approach.

For a more comprehensive explanation of established models, principles, and formulas employed by SESAR to quantify the socio-economic benefits, please refer to the companion document of the ATM Master Plan 2020 as the same were applied for this edition.

5 Sensitivity analysis

A sensitivity analysis is a valuable method for assessing how variations in key variables affect results, aiding in the evaluation of a strategy's robustness. In complex systems like ATM, numerous factors — such as macro-economic conditions and technological advancement — can influence outcomes.

For extensive, long-term projects like SESAR, which extends until 2045, a sensitivity analysis helps understand how changes in key assumptions—like traffic growth, costs, fuel efficiency, and timelines—might influence outcomes.

The selected approach for conducting the sensitivity analysis involves altering one input parameter at a time while keeping the others constant. Multiple scenarios were tested:

Sensitivity drivers	Value	Range	Net benefits(*) by 2050 (EUR 293 billion)
Deployment of phase D	2035 – 2045	+/- 5 years	– 36 / + 67
Traffic growth	STATFOR base + 57 %	0 % to 92 %	– 18 / + 89
Fuel efficiency potential for phase D	491 kg / flight	– 20 % to + 20 %	– 12 / + 12
Fuel price	STATFOR base (EUR / kg)	– 50 % to + 50 %	– 25 / + 25
Passenger time saving potential for phase D	8.1 min / flight	– 50 % to + 50 %	– 34 / + 34
Investments	EUR 25.5 billion	+ 20 % to – 30 %	– 2 / + 3

Several assumptions were considered to conducting sensitivity analysis:

1) **Delays in deployment of Phase D**: the analysis considered potential delays in the deployment of Phase D. This could affect the timing of benefit realization, either accelerating or delaying them, and subsequently alter the cumulative benefits by 2050. The analysis has aggregated the following benefits: fuel efficiency, capacity, departure punctuality, and cost-efficiency. These benefits are expected to begin accruing two years after the initial investments.

Given the complexity of the project, the likelihood of extended timelines and higher-than-anticipated costs was carefully considered, ensuring that even in such situations, the total benefits will still significantly outweigh the costs.

2) **Traffic growth scenarios**: the analysis evaluated various traffic growth projections to calculate operational benefits on a per-flight basis. Adjusting the total number of flights affects the monetisation of all performance indicators leading to either an increase or decrease in cumulative benefits by 2050. While the baseline assumption was positive growth, the analysis

also considered a pessimistic scenario where growth remains stagnant at 0% after 2040. The benefits assessed include fuel efficiency, capacity, departure punctuality, and cost-efficiency.

3) **Fuel efficiency, fuel price, and CO_2 emissions**: The analysis evaluated how changes in fuel efficiency and CO_2 emissions affect net benefits. While fuel prices influence traffic demand to a limited extent, this factor was not included in the analysis. The assumption used for traffic growth is STATFOR base scenario.

4) **Departure punctuality**: the improvement or deterioration of flight departure punctuality reveals that this factor has a significant impact on the overall profitability.

5) **Cost increases of Phase D**: the analysis accounted for the potential of significant cost overruns in the deployment of Phase D.

The sensitivity analysis revealed several key insights:

- **Impact of accelerated deployment**: the sensitivity analysis indicated that the benefits increase substantially with faster deployment of SESAR Solutions. This result underscores the importance of accelerating the innovation cycle to maximize the socio-economic and environmental returns on investment.

- **Resilience against zero-growth scenarios**: even in a scenario where air traffic growth halts completely after 2040, the benefits of SESAR Solutions significantly outweighed the costs. This highlights the project's strength, even in an economic downturn or stagnant traffic demand.

- **Minor sensitivity to fuel prices and efficiency**: reductions in fuel prices and efficiency were shown to have only a minor negative impact on the overall benefits. This suggests that while fuel efficiency is important, the project’s benefits are driven by broader factors such as traffic, capacity improvements, accelerated deployment of Phase D, and time savings.

- **Higher positive elasticity**: changes in benefits were not symmetric. Positive factors like accelerated deployment and higher traffic forecasts resulted in disproportionately higher benefits than the downside risk of negative factors like zero-growth or cost overruns. This asymmetry indicated a higher positive elasticity, reinforcing the need to focus on speeding up technology uptake.

6 References

The following references have been used along the document:

[1] European ATM Master Plan Edition 2025.

[2] EUROCONTROL PRR Report 2001

Downloadable via: https://www.eurocontrol.int/publication/performance-review-report-prr-2001

[3] EUROCONTROL PRR Report 2023

Downloadable via: https://www.eurocontrol.int/publication/performance-review-report-prr-2023

[4] EUROCONTROL Standards Inputs for Economic Analyses (ed. 9, 2019)

Downloadable via: https://www.eurocontrol.int/publication/eurocontrol-standard-inputs-economic-analyses

[5] EUROCONTROL CRCO Report (2019)

Downloadable via: https://www.eurocontrol.int/sites/default/files/2020-04/eurocontrol-crco-report-2019.pdf

[6] EUROCONTROL ACE Benchmarking Reports

Downloadable via: https://www.eurocontrol.int/air-navigation-services-performance-review

[7] EUROCONTROL STATFOR Aviation outlook 2050 (2022)

Downloadable via: https://www.eurocontrol.int/publication/eurocontrol-aviation-outlook-2050

[8] ACI Europe Airport Economics Report (2020)

Downloadable via: https://www.aci-europe.org/downloads/resources/ACI%20EUROPE%20Economics%20Report%202020.pdf

[9] SDM CBA update 2024 – draft release 1.01

[10] PRB Annual Monitoring Report 2022

[11] SESAR JU 2019. Airspace Architecture Study. Downloadable via https://www.sesarju.eu/node/3253

[12] Regulation (EC) No 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation).

[13] European Aviation Environmental Report by EEA, EASA and EUROCONTROL, January 2022.

Downloadable via: https://www.easa.europa.eu/eaer/

Appendix A Network Manager simulation in support of expected network performance impact for Phase C

The EUROCONTROL Network Manager (NM) has, for the first time, conducted a network performance impact assessment as part of the Master Plan update. This assessment is similar to the simulation carried out during the development of the Airspace Architecture Study. The simulation follows a structured methodology to evaluate the effects of the implementation of the Strategic Deployment Objectives (SDOs) on air traffic management (ATM) performance. The aim is to provide insights into how the future European ATM network will handle traffic growth, enhance capacity, and improve environmental sustainability outcomes by 2040. The simulation primarily leverages the Network Strategic Tool (NEST) and the Capacity Analysis (CAPAN), applying established methodologies for airspace design, planning, and sector capacity assessments.

A.1 Simulation tools and methodologies

Two primary tools were used to simulate the impact of SESAR solutions:

1. **NEST (Network Strategic Tool)**: this is a scenario-based simulation tool developed by EUROCONTROL used for network capacity planning, airspace design, and traffic flow management, allowing users to model and optimize airspace structure, capacity, and operational strategies by simulating 4D flight trajectories, future traffic samples, and ATFM delays, and performing detailed analyses at both local and network levels. Technological and airport related Solutions could not be simulated.

2. **CAPAN (Capacity Analysis)**: this is a methodology developed by EUROCONTROL that calculates air traffic sector capacities by evaluating air traffic controller workload through fast-time simulations, supporting airspace and capacity improvement proposals while being adaptable to different ATC systems and procedures.

A.2 Simulation scenarios

Two scenarios were simulated:

1. **"As-Is" scenario**: this scenario models the expected evolution of the ATM network up to 2040 without incorporating any significant SESAR developments (except the ones deployed through CP1). It considers planned projects and changes up to 2029 based on the Network Operations Plan (NOP) 2024-2029. This baseline projection is used to demonstrate the need for SESAR solutions by showing increasing delays and limited capacity growth under current plans.

2. **Updated SESAR ATM Master Plan scenario**: this scenario includes the potential benefits of the full implementation of a sub-set of SESAR solutions, contributing to environment, capacity, and ACC ATCO productivity. Consequently, those that enhance controller workload efficiency, datalink communications, and advanced traffic prediction systems. A 90% aircraft equipage with datalink technology is assumed by 2040.

A.3 General assumptions

Several assumptions were made in conducting the simulations:

- **Geographical scope**: the simulations cover the entire ECAC area.
- **Time horizon**: simulations are performed for the year 2040.
- **Traffic forecast**: Air traffic is predicted between all city-pairs and air traffic simulations are made starting from an average 2023 summer day. Traffic forecasts are based on STATFOR Seven-Year Forecast report (Oct 2023), extrapolated to 2040 assuming a 1.3% yearly growth rate in air traffic from 2029 to 2040.
- **Military activity**: no military zones or activities were included in the simulations.
- **Traffic demand**: the calculation of the traffic demand follows the same procedure as for the NOP and as described in the agreed capacity planning process.

EUROCONTROL STATFOR 7-YEAR FORECAST UPDATE

FLIGHT FORECAST (Autumn 2023)

Summary of flight forecast for Europe (ECAC)

ECAC*		2019	2020**	2021	2022	2023	2024**	2025	2026	2027	2028**	2029	AAGR 2023-2029	AAGR RP3 2020-2024	AAGR RP4 2025-2029
IFR Flight Movements (Thousands)	High	.	.	.	9,237	10,192	11,122	11,518	11,907	12,252	12,585	12,847	4.8%	0.1%	2.9%
	Base	11,085	4,979	6,230	9,237	10,187	10,888	11,076	11,297	11,490	11,682	11,800	3.6%	-0.4%	1.6%
	Low	.	.	.	9,237	10,048	10,640	10,632	10,690	10,718	10,755	10,727	2.2%	-0.8%	0.2%
Annual Growth (%) Compared to previous year.	High	.	.	.	48%	10%	9.1%	3.6%	3.4%	2.9%	2.7%	2.1%	4.8%	0.1%	2.9%
	Base	0.8%	-55%	25%	48%	10%	6.9%	1.7%	2.0%	1.7%	1.7%	1.0%	3.6%	-0.4%	1.6%
	Low	.	.	.	48%	9%	5.9%	-0.1%	0.5%	0.3%	0.4%	-0.3%	2.2%	-0.8%	0.2%
Daily Growth (%) Compared to previous year. Removing leap year effect.	High	.	.	.	48%	10%	8.8%	3.9%	3.4%	2.9%	2.4%	2.4%	4.8%	0.0%	3.0%
	Base	0.8%	-55%	25%	48%	10%	6.6%	2.0%	2.0%	1.7%	1.4%	1.3%	3.6%	-0.4%	1.7%
	Low	.	.	.	48%	8.8%	5.6%	0.2%	0.5%	0.3%	0.1%	0.0%	2.2%	-0.9%	0.2%
Fraction of 2019 (%) Compared to 2019 level.	High	.	.	.	83%	92%	100%	104%	107%	111%	114%	116%	-	-	-
	Base	100%	45%	56%	83%	92%	98%	100%	102%	104%	105%	106%	-	-	-
	Low	.	.	.	83%	91%	96%	96%	96%	97%	97%	97%	-	-	-

Source:
EUROCONTROL 7-year Forecast 2023-2029, Autumn 2023.

* ECAC is the European Civil Aviation Conference

** leap year

A.4 Assumptions for the ‘As Is’ scenario

The following assumptions were applied:

- All ACCs included in the February 2024 draft version of the NOP 2024-2029 were considered as part of the simulations.
- All evolutions related to CP1 deployment and other major projects, as covered by the local plans provided for the NOP by the ANSPs and reflected in the February 2024 draft version of the NOP 2024-2029, were included.

For the ACC capacity plans:

• Up to 2029, the latest NOP ACC capacity plans were taken into consideration, as per the February 2024 draft version of the NOP 2024-2029.

• After 2029, ACC capacities were calculated based on current ACC capacity with yearly growth rates of 1% for saturated ACCs and 2% for non-saturated ACCs:

- ✓ For ACCs with an annual delay forecast of 0.05 minutes/flight or lower in 2029, a 2% yearly capacity increase was considered feasible beyond 2029.
- ✓ For ACCs with an annual delay forecast higher than 0.05 minutes/flight in 2029, a 1% yearly capacity increase was deemed feasible due to increasing saturation in elementary sectors.
- ✓ As a result, from 2029 to 2040, a 2% yearly capacity increase was applied to 34 ACCs, while a 1% increase was applied to 33 ACCs.

No additional network-oriented operational or technical improvements were included.

A.5 Assumptions for the updated SESAR ATM Master Plan scenario

This simulation includes the benefits in terms of environmental performance and capacity improvements brought by a relevant subset of SESAR solutions, including the use of datalink as the primary means for air/ground (A/G) communications, assuming a 90% equipage rate. This latter technology contributes to capacity through the reduction of controller workload which has been incorporated into the simulation.

The CAPAN workload model used is uniform across all ECAC ACCs and is based on a high-performing European ACC, featuring an advanced ATM system, modern operational procedures, supporting tools, and high-complexity traffic. This model was adapted to account for the impact of the SESAR solutions. An expert evaluation was conducted by the Network Manager to assess how these SESAR solutions affected the tasks or task groups performed by air traffic controllers. After several iterations, final sector capacities were determined for each sector or configuration.

A.6 Simulation methodology

The NM simulation was conducted for the SDO solutions contributing to environment, capacity, and ACC ATCO productivity.

The NM used the following processes:

• The en-route ATFM delay forecast was conducted based on the methodology outlined in Appendix 1 of the European NOP 2013-2015 – Edition June 2013, Capacity Assessment and Planning Guidance. This methodology is consistently applied for en-route ATFM delay forecasts in each edition of the NOP.

• The airspace structures used in the simulations are from ERNIP Part 2 - ARN Version 2023-2030.

• No airspace restrictions were considered, and all evaluations excluded military activity to ensure the comparability of results.

• Optimum sectorisation was generated following the methodology and criteria described in the European Route Network Improvement Plan (ERNIP) – Part 1, which outlines general principles and technical specifications for airspace design.

• The traffic sample was assigned between city pairs along the shortest routes, utilizing full cross-border Free Route Airspace (FRA).

• All traffic flows were considered, including within, to/from, and overflying the NM area.

• The defined sectors were subjected to a CAPAN assessment, applying consistent CAPAN parameters across the study's geographic scope. The workload model was based on a high-performing ACC in Europe, featuring an advanced ATM system, modern procedures, and high-complexity traffic. Several iterations were conducted to finalize the sector capacities for various configurations.

• The KPI results related to the simulations have been complemented with Performance Assessment results from SESAR 2020 closure report, for the KPIs that were not covered in the simulation (e.g., airport capacity, departure punctuality, and safety). For these KPIs, the performance has been considered for all SDO Solutions (simulated and non-simulated), considering the interrelationships between them.

A.7 Key metrics and KPIs

The performance of the ATM network was evaluated through several KPIs as illustrated in the figure below:

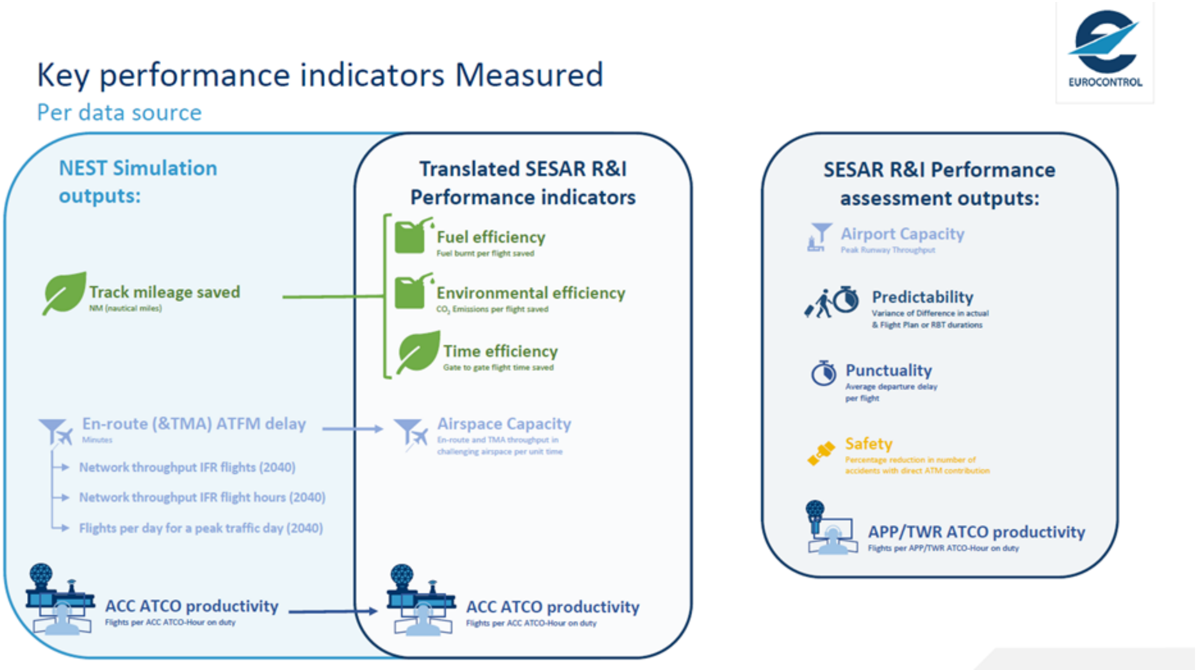


Figure 3: Key performance indicators measured in Network simulation

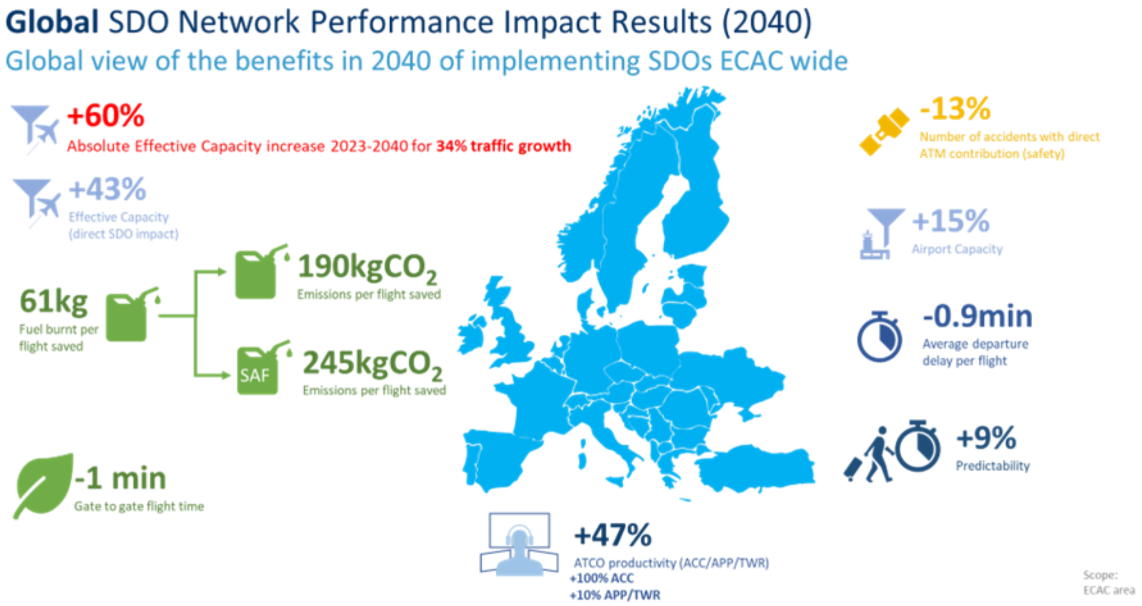
A.8 Simulation results

The following results were measured:

1) **"As-Is" Scenario**: as delays rose significantly for several ACCs, the delay forecast was capped at 5 minutes per flight for the summer season across 26 ACCs. By 2040, the forecasted annual delay per flight reaches 6.82 minutes. This increase in delays is projected to negatively impact flight efficiency, with route extensions expected to grow from 1.2 NM per flight in 2023 to approximately 9 NM per flight by 2040.

2) **Updated SESAR ATM Master Plan scenario**: in this scenario, the application of SESAR solutions significantly reduces air traffic controller workload, with a 50% reduction in average working time needed to process 100 flights. This results in a sector capacity increase from 45 flights/hour to approximately 97 flights/hour, effectively doubling sector capacity by 2040.

The CAPAN methodology was applied for the simulations, incorporating increased automation and datalink usage, which reduces manual intervention and improves conflict detection, planning, and productivity.



The **key messages** of the NM simulations are the following:

a) The "As-Is" scenario shows current plans are insufficient to handle traffic growth.

b) The 2040 scenario demonstrates SESAR solutions can provide enough capacity to meet future demand.

c) Between 2030-2040, approximately 340 million minutes of delay could be saved, equating to EUR 24 billion in savings.

d) From 2023-2040, effective capacity is expected to increase by 60%, while traffic grows by 34%.

e) SESAR solutions will directly contribute to a 43% increase in effective capacity in 2040.

f) ACC air traffic controller (ATCO) productivity is expected to double.

g) Network throughput will increase from 8.47 million movements in 2023 to 13.6 million in 2040, or about 46,580 flights per peak traffic day.

h) Flight hours will rise from 13.55 million in 2023 to EUR 21.76 million in 2040, with peak traffic days seeing 74,529 flight hours.

The following **flight efficiency and environmental benefits** have been quantified:

• Implementation of Airspace Changes (2023-2030): These changes will result in approximately 1 billion nautical miles savings by 2030, benefits which will continue until 2040.

• Additional Network Measures (2023-2029): These measures will save an additional 1.2 NM per flight, equating to 94 million nautical miles in total.

• Capacity Improvements: These will allow reductions in civilian restrictions (RAD), further enhancing flight efficiency.

• Distance savings: approximately 1.61 billion nautical miles, which translates to 3.7 million of flight hours or approximately 1 min/flight (time-efficiency).

• 13.2 million tonnes of fuel are expected to be saved, 61kg of fuel per flight. Therefore, 41.6 million tonnes of CO_2 emissions will be saved, 190 kg of CO_2 emissions per flight, which could mean EUR 8.1 billion saving.