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Skyward Action

Realizing Aviation's Sustainable Future

2025 ICAO Environmental Report

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2025 Environmental Report

Insights from the President of the ICAO Council

How do you see the ICAO's role to grow a momentum toward sustainable aviation, and how does the 2025 Environmental Report contribute to this effort?

As the global momentum toward sustainable aviation intensifies, the International Civil Aviation Organization (ICAO) remains steadfast in guiding the international aviation sector toward a cleaner and resilient future. The adoption of the Long-term Global Aspirational Goal (LTAG) of net-zero emissions by 2050 in 2022 marked a turning point, setting the course for a comprehensive transformation of aviation's environmental impact. Since then, our 193 Member States, industry partners, and key stakeholders have made tremendous progress in addressing emissions from international aviation, in support of the temperature goal of the Paris Agreement and the overall UN Sustainable Development Goals (SDGs).

The 2025 Environmental Report captures and reflects ICAO's enduring commitment to this agenda in the face of evolving global challenges. It highlights results of tireless and collaborative work by the ICAO Council and its subsidiary bodies, the continued engagement of Member States and all relevant stakeholders, and the dedicated efforts of the ICAO Secretariat, to drive forward innovative solutions to reduce environmental impacts and achieve our environmental Strategic Goal.

Major progress achieved during the 2023–2025 triennium is highlighted throughout the Report, including the adoption of the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, and subsequent approval of the implementation Roadmap by the Council, as well as the continued advancement of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The implementation support and financing initiatives such as the ICAO Assistance, Capacity Building and Training for SAF (ACT-SAF) Programme, the operationalization of ICAO Finvest Hub, and other successful advocacy and outreach events and publications, has been and should be further strengthened.

Together, these efforts illustrate ICAO's critical role, not only as a standard-setter, but as a catalyst for collaboration, innovation, and real-world action across the aviation sector.

How would you describe ICAO's leadership in advancing environmental protection?

ICAO's activities in advancing environmental protection are guided by the core principles of innovation, collaboration, inclusivity, and transparency, all in line with ICAO's *No Country Left Behind* strategic goal.

Innovation drives the development and deployment of new technologies, operational improvements, and sustainable energy solutions critical to reducing aviation's environmental footprint. Collaboration ensures that States, industry, research institutions, and civil society work together to deliver coordinated and impactful solutions, recognizing that no single actor can achieve the sector's ambitious climate goals alone.

Inclusivity remains central, ensuring that all ICAO Member States — regardless of their level of development and readiness — can participate and benefit from global environmental initiatives, with capacity-building and support tailored to their needs.

Transparency underpins ICAO's commitment to building mutual confidence and driving meaningful progress in environmental protection. By fostering openness and accountability, ICAO ensures that all States and stakeholders can track progress, share best practices, and identify areas for further action and advancement.

What should be the collective priorities for the aviation sector, as we approach the 42nd Session of the ICAO Assembly?

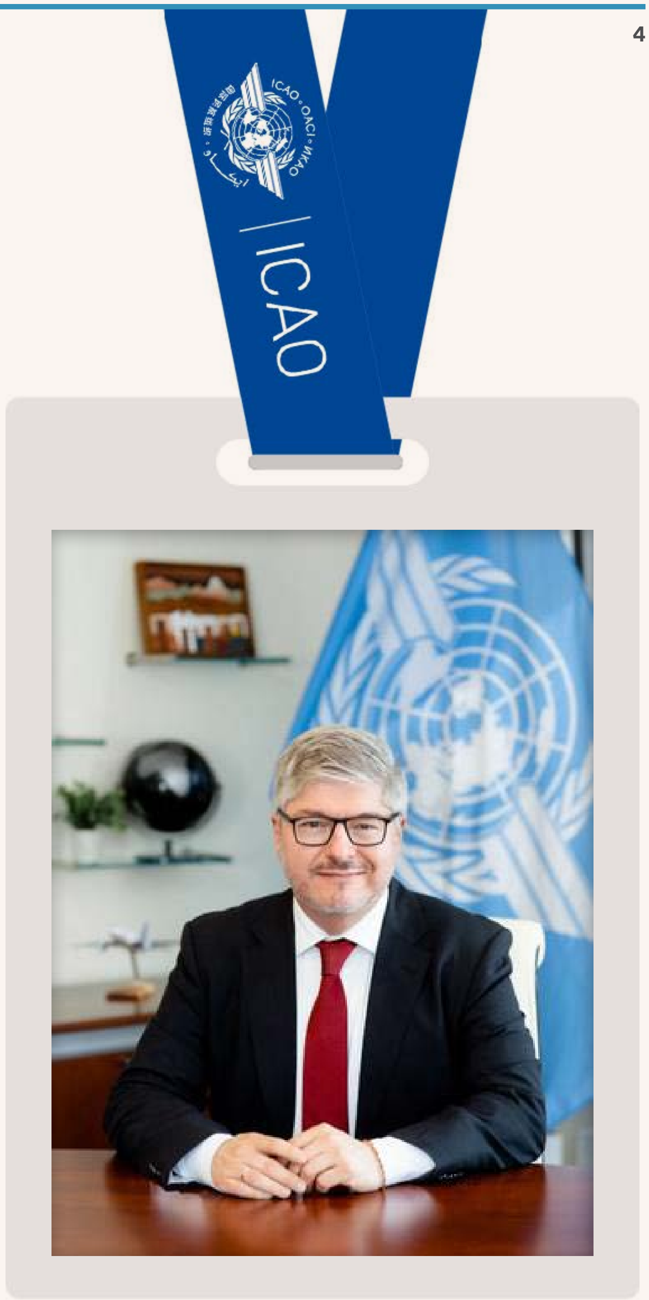
As we approach the Assembly, our collective focus must remain on facilitating the development and bringing to the market innovative aircraft technologies, continuously optimizing operational efficiencies, accelerating the scale-up in the development and deployment of cleaner energy sources for aviation, while ensuring that implementation support and access to finance is available to enable this transformation in particular aviation's cleaner energy transition for all States. ICAO is fostering enhanced collaboration with development banks, financial institutions, and emerging technology and cleaner fuel providers through the operationalization of the Finvest Hub project to ensure that sustainability solutions are not only innovative, but also economically viable and widely accessible.

International aviation is at a defining moment. The commitments made today will shape the future of air transport for decades to come. At the Assembly, ICAO, together with its Member States and partners, will have an important opportunity to establish meaningful ICAO policies to continue to drive the environmental transformation of the sector, while ensuring it remains an enabler of global connectivity and socio-economic benefits. But we will need policies that not only enable but that accelerate the path to Net Zero.

By embracing a collective vision for innovation, investment, and policy support, we can accelerate the realization of a truly sustainable and resilient global aviation system.

SALVATORE SCIACCHITANO
President of the ICAO Council.

Insights from the Secretary General of ICAO



How has ICAO responded to the increasing urgency of climate action, and what progress has been made over the last triennium?

The last triennium has been a period of dynamic transformation for the International Civil Aviation Organization (ICAO) and international aviation, marked by accelerated progress in sustainability efforts. The latest assessments from the Intergovernmental Panel on Climate Change (IPCC) have made it unequivocally clear that human activities — particularly greenhouse gas emissions — have caused global warming. Emissions remain alarmingly high, putting the 1.5°C limit at immediate risk without deep, rapid, and sustained reductions across all sectors.

These findings reinforce the urgency for bold and coordinated action across all sectors, including aviation. ICAO, under the mandate of its 193 Member States, has embraced this responsibility with renewed determination, working closely with governments, industry, and other stakeholders over the past three years to deliver meaningful progress in advancing aviation's transition towards cleaner energies.

A major milestone during this period was the historic adoption of the Long-Term Global Aspirational Goal (LTAG) for international aviation at the 41st Session of the ICAO Assembly. The LTAG of net-zero carbon emissions by 2050 now stands as a central driver of environmental work in the ICAO Strategic Plan 2026 - 2050, providing a clear long-term vision and anchoring the Organization's efforts to support a sustainable future for international civil aviation.

Could you expand more regarding the tangible progress ICAO has achieved since the adoption of the LTAG?

Since the adoption of the LTAG at the 2022 Assembly, significant progress has been made across multiple areas. By adopting the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, ICAO and its Member States agreed to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 percent by 2030, through the use of aviation cleaner energies. The Global Framework is underpinned by four Building Blocks — Policy and Planning, Regulatory

Framework, Implementation Support, and Financing — guiding ICAO's collaborative work with the aerospace sector to ensure that our shared vision for aviation decarbonization becomes reality.

ICAO has been advancing with the full-scale implementation of the Roadmap for achieving the LTAG and Global Framework, providing structured, inclusive, and progressive pathways for emissions reductions through the deployment of such cleaner energies worldwide. Notably, the ACT-SAF Programme has been instrumental in supporting the global scale-up of SAF, LCAF and other cleaner energies with a strong emphasis on capacity-building for developing countries. Simultaneously, the launch of the ICAO Finvest Hub is poised to mobilize critical financing for aviation decarbonization projects. Progress has also continued through the development of the monitoring and reporting methodology to support the LTAG tracking, and the continued robust implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

At a more technical level, ICAO's environmental work streams have also achieved notable results during this period. These include the refinement of life-cycle assessment methodologies for SAF, and the development of integrated noise-CO_2 stringency standards for aeroplanes. Parallel initiatives have advanced ICAO's work on non-CO_2 climate effects, airport and operation-related environmental measures, and climate adaptation strategies, further reinforcing the sector's collective progress toward achieving wider environmental objectives.

How does ICAO promote innovation in aviation environmental protection, and how are outreach activities helping to accelerate progress?

Innovation continues to be at the core of ICAO's environmental strategy. Through the annual ICAO LTAG Stocktaking events and dedicated innovation seminars, ICAO has provided vital platforms for States and stakeholders to exchange knowledge, showcase technological advances, and foster collaboration on cutting-edge solutions. These outreach activities also reinforce the strong spirit of partnership that drives ICAO's initiatives. By creating inclusive spaces for dialogue and information-sharing, ICAO helps ensure that innovations are not only developed but also widely disseminated across all regions and actors of aviation.

Building on these efforts, ICAO held its first-ever Non-CO_2 Emissions Symposium in 2024, and brought together experts from industry, academia, governments, and international organizations to explore scientific developments, measurement techniques, and mitigation strategies related to non-CO_2 climate effects from aviation. The Symposium underscored the importance of enhancing scientific understanding and integrating new knowledge into ICAO's work on environmental protection, recognizing the broader climate impacts of aviation and supporting a more holistic and evidence-based approach to sustainability.

Innovation and aviation's cleaner energy transition requires significant financial investment. How is ICAO helping to bridge the gap to facilitate access to financing opportunities?

Financing aviation decarbonization is a global challenge that requires global solutions. The Organization recognizes that many States, particularly developing countries, face specific hurdles in mobilizing the resources needed to scale up cleaner energy deployment and innovative technologies. ICAO's leadership in this area is firmly rooted in its commitment to inclusivity, transparency, and building practical pathways for States and stakeholders to participate fully in aviation's cleaner energy transition.

To help bridge the critical gap between innovation and financing, ICAO launched the Finvest Hub initiative to facilitate access to funding, by matchmaking aviation decarbonization projects with potential public and private funds and investors. The Finvest Hub will feature a knowledge platform of financing sources, project opportunities, and matchmaking mechanisms. ICAO is intensifying advocacy and outreach efforts to expand the Finvest Hub's reach, engaging with multilateral development banks, private financing institutions, and international organizations.

The signing of a landmark Memorandum of Cooperation between ICAO and the International Renewable Energy Agency (IRENA) in October 2024 exemplifies this approach, leveraging synergies to enhance access to climate finance through innovative platforms such as IRENA's Energy Transition Accelerator Financing (ETAF) platform. Through these collective efforts, ICAO is not only advancing its Global Framework for Cleaner Energies but also ensuring that the momentum behind aviation cleaner energy transition is matched by real, tangible opportunities for financing the sector's sustainable transformation.

As ICAO continues to advance aviation's environmental goals, what is the pathway forward, and what will be essential to ensure the continued success?

The achievements of the 2023–2025 triennium reflect the collective determination of the international aviation community to address the challenges of climate change, local air quality, and noise with practical and forward-looking solutions. However, the journey ahead requires even deeper cooperation, greater investment, and stronger partnerships among States, industry, and all stakeholders.

Aviation connects the world — and it must do so in a sustainable manner. ICAO calls upon the global community to continue working together with resolve and ambition, to ensure that international aviation remains a driver of economic growth, peace and cultural exchange, and sustainable development for generations to come.

JUAN CARLOS SALAZAR
Secretary General, ICAO

Insights from the Director of the Air Transport Bureau (DATB), ICAO

How does ICAO support States and Regions on environment, particularly in light of the Long Term Aspirational Goal (LTAG)?

We are witnessing a pivotal transformation in the aviation sector—driven by an extraordinary pace of innovation and an urgent imperative for environmental sustainability. To ensure ICAO's leadership in the area, as the ICAO Secretariat, it is incumbent upon us not to merely respond to this momentum, but to continuously guide and shape it. The scope and velocity of recent developments are evidenced by the landmark decisions of this triennium: the adoption of the Net-Zero 2050 goal at the 41st Assembly in 2022, followed by the endorsement of the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other aviation cleaner energies, in 2023.

These milestones demand meaningful and inclusive action. As custodians of these commitments, we must ensure they are operationalized through comprehensive and equitable implementation strategies that reflect the diverse capacities and circumstances of all Member States. This entails fostering robust partnerships, mobilizing resources, and advancing technical assistance and capacitybuilding efforts, particularly for developing countries and small island developing States and other vulnerable regions that face unique challenges in achieving these goals. Therefore, a one-size-fits-all approach will not suffice. It is essential that we tailor our strategies to meet the diverse needs of all Member States, considering their specific developmental stages, resources, and local contexts. The emphasis on inclusivity means prioritizing the needs of those who require the most support.

By focusing on innovation and collaboration, we can bridge these gaps and accelerate the transition toward a sustainable aviation future. This requires a forward-thinking approach, integrating cutting-edge technologies such as SAF, electric propulsion, and new operational efficiencies. Moreover, it is crucial to engage stakeholders from across the aviation ecosystem, including governments, industry players, and civil society, to align efforts and ensure that the benefits of these advancements are shared equitably.

In this context, ICAO Secretariat plays a pivotal role in facilitating knowledge exchange, fostering partnerships, and coordinating global efforts to ensure that all Member States, regardless of size or development level, have the support they need to achieve their environmental commitments. Together, we can transform the aviation sector while remaining inclusive, equitable, and sustainable for the long term.

Moreover, as aviation continues to evolve—through the integration of cleaner energy sources, new technologies, and innovative operational practices—the Secretariat must play a proactive role in setting global standards, facilitating knowledge exchange, and aligning efforts across stakeholders. By doing so, we not only uphold the principles of the Chicago Convention but also reinforce ICAO's leadership in steering the sector toward a resilient, inclusive, and sustainable future.

One of the Air Transport Bureau's key efforts has been on the enhancement of the ICAO State Action Plans (SAP) initiative[1]. Today, 150 States, representing over 99% of global Revenue Tonne Kilometers (RTK), have voluntarily submitted and updated their State Action Plans, including the expected results from the implementation of their selected measures to reduce aviation CO_2 emissions. States are encouraged to incorporate the latest innovations in aviation technologies and cleaner energies, outlining respective policies, actions and roadmaps in their SAPs, which will also be the essential means for ICAO to monitor progress in implementing all elements of the basket of measures toward achieving the LTAG.

In addition, ICAO continues to support States through seminars, workshops, tailored guidance, and tools that support the implementation of aviation decarbonization measures, including for the implementation of the LTAG and Global Framework.

Specifically, what role does ICAO play in accelerating the development and deployment of SAF, LCAF and other aviation cleaner energies?

To accelerate the development and deployment of cleaner energies in aviation, several actions are already underway and must continue to advance. The ICAO Roadmap for the implementation of the LTAG and Global Framework with its four Building Blocks: policy and planning, regulatory framework, implementation support, and financing serves as a key driver to step up this acceleration. Among the Building Blocks, a high and immediate focus should be given to the need to accelerate the level of capacity-building and implementation support, financing, and other critical enabling and monitoring elements, to foster swift production and deployment of aviation cleaner energies in all regions.

In that regard, ICAO is making important progress on the Assistance, Capacity-building and Training for SAF (ACT-SAF) programme, and the operationalization of ICAO Finvest Hub.

Guidance materials are also supporting States on their journey toward cleaner energy use. A key element in this transition is the advancement of policies that enable the adoption and commercialization of aviation cleaner energies, and ICAO, through its Committee on Aviation Environmental Protection (CAEP), developed the Guidance on Policy Measures for SAF Development and Deployment, outlining key policy options and approaches to support SAF deployment while also helping policymakers estimate costs and evaluate the effectiveness of various policy options.

Beyond aviation cleaner energy sources, what operational and collaborative strategies is ICAO prioritizing to drive environmental progress?

Operational improvements remain a vital component of ICAO's environmental strategy. The Air Transport Bureau and Air Navigation Bureau of the ICAO Secretariat are cooperating closely to advance the initiatives that optimize air traffic management (ATM), improve efficiency in airport operations, and implement new technologies that reduce fuel burn and emissions.

1 https://www.icao.int/environmental-protection/pages/climatechange_actionplan.aspx

A crucial strength of the ICAO CAEP's technical work in this area is its ability to bring together key stakeholders: Air Navigation Service Providers (ANSPs), airlines, airport operators, and industry leaders to discuss not only the implementation but also the methods for monitoring effectiveness, since a consistent and harmonized monitoring is vital for measuring progress. Harmonizing methodologies ensures that improvements can be tracked and integrated into ICAO's Global Air Navigation Plan, supporting the goal of decarbonizing aviation, through operational improvements.

Ensuring sustainable and resilient airport operations are also essential to aviation's cleaner energy transition. By adopting cleaner energy sources, circular economy practices, and climate adaptation strategies, airports can significantly reduce their environmental footprint, while supporting the deployment of SAF, LCAF and other aviation cleaner energies. The ICAO Green Airports Seminar, hosted in Athens, Greece in April 2024, also served as an important platform to share information and best practices.

Looking ahead, how will the Air Transport Bureau continue to support international aviation's cleaner energy transition?

ICAO remains steadfast in fostering multilateral collaboration, ensuring that *No Country is Left Behind* in this transition. Continued engagement with regulators, industry leaders, and research institutions is enabling ICAO to shape policies that are both ambitious and achievable. In close collaboration with other Bureaus of the Secretariat, we will further strengthen the implementation support, enhancing financing mechanisms, and promoting the widespread adoption of innovative technologies which will define aviation's decarbonization pathway.

The challenges ahead are significant, but through strategic action and collective commitment, international aviation can achieve its long-term Strategic Goal. ICAO will continue to provide the leadership and coordination needed to ensure that aviation remains an engine of global connectivity while aligning with climate imperatives.

MOHAMED KHALIFA RAHMA
Director, Air Transport Bureau, ICAO

A Historic Milestone in Aviation Environmental Progress

JANE HUPE
Deputy Director, Environment, ICAO

In my decades of service within ICAO's environmental programme, I have never witnessed such a remarkable convergence of commitment, innovation, and progress across the aviation sector as in this triennium. It is a moment of deep professional pride—and a profound sense of responsibility. Compiling the 2025 ICAO Environmental Report has been an immensely rewarding experience. When viewed in its entirety, the report makes clear that momentum is accelerating: international aviation is not just recovering, but advancing—smarter, greener, and more united than ever.

ICAO's environmental journey began in the 1960s, initially addressing noise and local air quality. Since then, the scope and ambition of our work have expanded significantly, particularly in recent years, with global agreements supporting meaningful climate action. From the six chapters of the inaugural 2007 ICAO Environmental Report, we now present a comprehensive 16-chapter edition in 2025—reflecting the depth and breadth of global progress. New areas such as the Long-Term Aspirational Goal (LTAG), aviation cleaner energies, and climate financing are now central to our efforts.

This report serves not only as a snapshot of where we stand today, but as a chronicle of our journey and a guidepost for the path ahead. It captures a pivotal moment—one that future generations may look to as the point when aviation met the climate challenge with resolve and unity. The path to net-zero aviation by 2050 is ambitious—but absolutely achievable if we act boldly, together, and without delay.

CHAPTER BY CHAPTER: CHARTING THE SKYWARD ASCENT IN CLIMATE ACTION

Each chapter explores key dimensions of aviation's environmental strategy—highlighting priorities, accomplishments, and ongoing challenges:

- **Chapter 1** provides an overarching Aviation & Environment Outlook, outlining global trends, scientific updates, and developments in policy and technology. It also addresses emerging topics, such as non-CO_2 and NO_X emissions, and emphasizes the importance of nurturing the next generation of aviation professionals.

- **Chapter 2** focuses on Climate Change Mitigation, detailing progress in implementing the LTAG since its 2022 adoption. It provides updates on the development of the methodology for LTAG monitoring and reporting, and showcases collaborative contributions from States, industry, academia, and civil society toward achieving the LTAG.
- **Chapter 3** showcases the potential of Aircraft Technologies to support the achievement of LTAG. Ongoing studies and deliberations related to the Integrated Dual Stringency analyses for CO_2 and noise, along with breakthroughs in hydrogen and hybrid-electric powered propulsion, offer promising pathways toward a more sustainable aviation future. Many of these innovations, developed or assessed through CAEP's Working Groups, would bring us closer to realizing the LTAG.
- **Chapter 4** brings attention to Operational Improvements, an important component of the basket of measures to address aviation emissions. Air operations rely on a complex, collaborative network system—involving regulators, air navigation service providers, airlines, aircraft manufacturers, and airports. This chapter highlights innovative approaches in air traffic management to mitigate emissions and addresses topics such as contrail formation avoidance, drawing on perspectives from key operational stakeholders.
- **Chapter 5** is dedicated to Aviation Cleaner Energies, identified as the most promising avenue for reducing CO_2 emissions. It details progress under ICAO's Global Framework on SAF, Lower Carbon Aviation Fuels (LCAF), and other Aviation Cleaner Energies, adopted in 2023, across its four Building Blocks: Policy and Planning, Regulatory Framework, Implementation Support, and Financing—towards the achievement of the collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 percent by 2030 through the use of these aviation cleaner energies.
- **Chapter 6** updates on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the world's first global market-based measure for a sector. It presents updates on the CORSIA implementation elements, including State pairs, the CO_2 Estimation and Reporting Tool (CERT), CORSIA Eligible Fuels, CORSIA Eligible Emissions Units, and the CORSIA Central Registry (CCR). It also features contributions from stakeholders—such as States, industry, and other UN bodies—highlighting their roles in supporting CORSIA implementation.
- **Chapter 7** covers the State Action Plans to Reduce Aviation Emissions (SAPs) initiative, which covers over 99% of international traffic. It reflects the widespread efforts of States and stakeholders in developing long-term decarbonization strategies and measures to implement them, highlighting their commitment to aviation sustainability.
- **Chapter 8** focuses on Capacity Building and Implementation Support, highlighting ICAO's commitment to "No Country Left Behind." It showcases achievements under the ACT-CORSIA and ACT-SAF programmes, and shares lessons from States advancing their climate action with ICAO support.
- **Chapter 9** explores Climate Financing as a critical enabler of LTAG implementation. It introduces the newly launched ICAO Finvest Hub, currently under operationalization, and outlines ICAO's engagement with the broader financing ecosystem to unlock sustainable aviation investment.
- **Chapters 10 and 11** delve into Noise and Local Air Quality, addressing current standards and anticipating future challenges, especially with the rise of new propulsion technologies and SAF. These chapters bring together the latest science, regulatory efforts, and stakeholder perspectives.
- **Chapter 12** spotlights Green Airports, showcasing their role in decarbonization—from energy supply to ground operations. It includes best practices and guidance to support sustainability across airport functions.
- **Chapter 13** introduces Climate Adaptation and Resilience, a growing priority. It reviews how aviation stakeholders—particularly airports—are addressing climate risks and enhancing resilience, including cooperation with other international bodies on extreme weather adaptation.
- **Chapter 14** examines Circular Economy principles within aviation. From design to waste management, the sector is increasingly embracing circularity to help tackle climate change, pollution, and biodiversity loss.

- **Chapter 15** is dedicated to Biodiversity. It highlights ICAO's contributions to avoid biodiversity loss through its regulatory framework related to CORSIA Eligible Fuels and CORSIA Eligible Emissions Units, and aviation contributions to forest firefighting efforts. It also emphasizes airport action to contribute to biodiversity preservation and the commitment of the aviation sector towards the Kunming-Montreal Global Biodiversity Framework.
- **Chapter 16** underscores Multistakeholder Cooperation as essential to achieving aviation's environmental goals. It highlights joint initiatives with UN agencies, international organizations, and the private sector to foster a more integrated and effective response to climate change.

THE ROAD AHEAD: FROM COMMITMENTS TO ACTION

This report is not just a catalogue of achievements—it is a call to action. The progress made over the past three years is significant, but it is only the beginning. Translating commitments into lasting change will require even greater coordination, innovation, and resolve.

As we look ahead to the 42nd ICAO Assembly, we must accelerate our collective efforts. The environmental transformation of international aviation is no longer an aspiration—it is underway. It is real. It is measurable. And it must endure.

May this report stand as a legacy of progress —a testament to a sector that chose to lead, to act, and to rise to the climate challenge.

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CHAPTER ONE

Aviation & Environmental Outlook

Turning Ambition into Action: From the LTAG and Global Framework to International Cooperation

By ICAO Secretariat

As the world moves steadily beyond the challenges of the early 2020s, international aviation is not just bouncing back, it's evolving. At the heart of this transformation lies a shared commitment: to ensure that the growth of global air transport goes hand in hand with strong environmental protection and responsibility. ICAO's adoption of the Long-Term Global Aspirational Goal (LTAG) in 2022—aiming for net-zero carbon emissions from international aviation by 2050—was a major milestone in that journey.

Over the past three years, ICAO has worked with Member States and stakeholders to build the necessary frameworks, partnerships and capacities to turn ambition into action. ICAO has made significant progress, drawing on science, policy, and cooperation to guide the way forward.

Key milestones have shaped this trajectory. ICAO has been a strong advocate for the use of Sustainable Aviation Fuels (SAF), defined as renewable or waste-derived aviation fuels that meets sustainability criteria, as a key pathway to aviation decarbonization. Notably, the technical analysis we have carried out (LTAG Report) shows that SAF has the greatest potential to reduce CO_2 emissions from international aviation.

In 2023, ICAO further adopted a comprehensive ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, which included a Vision for reducing CO_2 emissions in international aviation by 5 per cent by 2030 through SAF and cleaner energies.

To support use of SAF and other aviation cleaner energies, ICAO has been implementing a comprehensive set of initiatives under the four building blocks of the ICAO Global Framework:

1. Policy and Planning
2. Regulatory Framework
3. Implementation Support
4. Financing

The ICAO roadmap adopted by the Council in 2024 provided a clear and structured path forward, grounded in those four interconnected building blocks.

Concrete progress has been made on all fronts, ranging from the operationalization of the ICAO Finvest Hub to enhanced ACT-SAF Programme deliverables such as the training Series and the rollout of SAF Feasibility Studies in multiple States. All these ICAO achievements will be detailed throughout their corresponding chapters in this Report.

A key ICAO activity is to showcase progress on climate and environmental action, including the latest developments across all environmental topics. Since 2019, this has been achieved through a series of annual LTAG Stocktaking events.

In 2023, the Organization held its first in-person LTAG Stocktaking event since the pandemic—an important step in reconnecting the global community around aviation decarbonization. The 2024 edition marked the largest LTAG Stocktaking gathering to date, showcasing real-world progress and innovations across technologies, fuels, and operations and beyond with discussions on ensuring a just cleaner energy transition within the aviation sector. That same year, ICAO also hosted its first-ever Symposium on Non-CO_2 Aviation Emissions, opening a new chapter in the international conversation on short-lived climate pollutants and their role in aviation's climate impact. The event marked an important step in global understanding and cooperation around topics such as contrail formation, nitrogen oxides and particulate matter, striving to understand and enhance the climate science, potential mitigation measures and policy options.

At the same time, ICAO has continued to foster meaningful dialogue and engagement among States and stakeholders. ICAO has also delivered an ambitious series of environmental seminars across all regions, supporting States in the implementation of the ICAO Global Framework for SAF, LCAF and other aviation cleaner energies.

In parallel to its core decarbonization workstreams, ICAO has significantly expanded its environmental agenda through outreach, engagement, and collaboration with other UN bodies and international organizations. A major example is the ICAO participation at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties or COP, in which all States that are Parties to the Convention review its implementation and any other legal instruments that the COP adopts and take decisions necessary to promote the effective implementation of the Convention. ICAO's contributions to recent COP meetings (COP27[1], COP28[2] and COP29[3]) are available at ICAO website and are further detailed in "Chapter 16 – Multistakeholder Cooperation" of this Report under the ICAO Secretariat article.

At the 2024 UNFCCC COP29[3] in Baku, Azerbaijan, ICAO actively contributed to discussions on international carbon markets and climate finance, ensuring aviation's voice was heard during negotiations on Article 6 of the Paris Agreement. With the adoption of new rules to ensure transparency and integrity in global carbon markets, ICAO is now encouraging the issuance of Letters of Authorization from host States to facilitate access to eligible emissions units under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). ICAO also reiterated the sector's concern over proposals to use international aviation as a source of climate finance for unrelated sectors, reaffirming the importance of protecting the integrity and equity of aviation's decarbonization path.

Looking ahead, ICAO is preparing for its 2025 Climate Week, scheduled for 2–4 June 2025, which will integrate the LTAG Stocktaking event and address a broader range of topics such as adaptation, infrastructure resilience, electrification and hydrogen, and green airports. The initiative aims to bring all stakeholders to a common level of understanding in advance of the 42nd ICAO Assembly and UNFCCC COP30 both in 2025. With sessions dedicated to technology, operations, finance, and implementation support, Climate Week is envisioned as a platform to showcase cross-cutting progress and facilitate knowledge-sharing on the full spectrum of environmental workstreams under ICAO's remit.

UNITED NATIONS CLIMATE CHANGE CONFERENCE
COP30
AMAZÔNIA
CUIDAR DO PLANETA PARA O FUTURO DA HUMANIDADE
BELÉM • BRASIL • 2025

1 https://www.icao.int/environmental-protection/Pages/COP27.aspx.
2 https://www.icao.int/environmental-protection/Pages/COP28.aspx.
3 https://www.icao.int/environmental-protection/Pages/COP29.aspx.

In support of this comprehensive approach, ICAO continues to strengthen cooperation with organizations such as IRENA, UNDP, the World Bank, and UNEP. These partnerships aim to mobilize financial resources, accelerate sustainable infrastructure development, and address emerging challenges including plastic pollution and wildfire risk management.

ICAO is also scaling up its outreach activities in preparation for COP30, to be held in Belém, Brazil, immediately following the Assembly. The Organization is committed to ensuring that the environmental progress achieved within international aviation is fully recognized on the global climate stage, while safeguarding the sector's ability to decarbonize effectively and equitably.

A key driver of ICAO's progress is the work of the Committee on Aviation Environmental Protection (CAEP), which continues to serve as the Organization's technical powerhouse for environmental standards and technical analysis. As ICAO continues to support Member States in delivering on the collective vision for net-zero carbon emissions by 2050, the technical expertise and consensus-building facilitated by CAEP remain fundamental. Throughout its 13th cycle (CAEP/13), the Committee has provided critical assessments and recommendations across the full spectrum of environmental priorities in aviation—ranging from CO_2 and non-CO_2 emissions, to noise, local air quality, and cleaner energies sustainability certification. Its work also supported the development of robust methodologies to monitor LTAG implementation and guided the evolution of ICAO's regulatory and analytical tools.

CAEP/13's outputs have underpinned much of ICAO's recent progress and will inform decisions by the Council and the 42nd Session of the ICAO Assembly in 2025. A comprehensive overview of the CAEP/13 cycle, including its main deliverables and technical contributions, is presented in the next article: *Overview of the Thirteenth Cycle of the Committee of Aviation Environmental Protection (CAEP/13): ICAO's technical progress towards achieving net zero carbon emissions by 2050 and environmental protection.*

Following the CAEP overview and environmental trends assessment, this Chapter includes global climate context from the World Meteorological Organization (WMO) and forward-looking insights from ICAO's Independent Experts. Acknowledging the critical role of human capacity in driving this transformation, this chapter also highlights the importance of building a sustainable aviation workforce—featuring perspectives on diversity, youth engagement, and the growing role of academic institutions in shaping the next generation of aviation professionals and researchers.

Non-CO_2 emissions articles

Recognizing the growing importance of non-CO_2 effects in aviation's overall climate impact, ICAO has expanded its technical and policy focus to include discussions on short-lived climate pollutants such as nitrogen oxides (NO_X), water vapour, soot, and the formation of contrails and cirrus clouds. These effects, while more complex to measure and mitigate than CO_2 alone, are increasingly acknowledged for their significant contribution to aviation's total radiative forcing.

In 2024, ICAO hosted its first-ever **Symposium on Non-CO_2 Aviation Emissions[4],** a milestone event that brought together scientific, regulatory, and operational experts to foster international understanding and explore pathways for mitigation. This Symposium laid the foundation for future work, including ongoing discussions on how to integrate non-CO_2 effects into ICAO's environmental assessment tools, regulatory frameworks, and guidance materials.

Reflecting the centrality of this topic, several chapters in this Report feature dedicated articles on Non-CO_2 emissions, each offering unique perspectives—from scientific research to operational strategies and institutional cooperation. These contributions include:

- **Chapter 1 – Aviation & Environmental Outlook:**
  - *ICAO's work on NO_x emissions regulation (Federal Office of Civil Aviation (FOCA), Switzerland)*
  - Aviation Non-CO_2 Experts Network (ANCEN) (EASA)
  - In-Service Aircraft for a Global Observing System (IAGOS)

4 https://www.icao.int/Meetings/SymposiumNonCO2AviationEmissions2024/Pages/default.aspx

- **Chapter 2 – Climate Change Mitigation: Overview:**
  - Exploring the Contribution of SLCPs Mitigation to ICAO's LTAG (ICCT)
  - How to Integrate Non-CO_2 Effects in Monitoring, Reporting and Verification Mechanisms (DLR German Aerospace Center)

- **Chapter 3 - Climate Change Mitigation: Aircraft Technologies:**
  - Addressing Non-CO_2 Emissions – The Way Towards Clean and Competitive Aviation (DLR, NRC, and ONERA)

- **Chapter 4:**
  - Operational Opportunities to Reduce Climate Effects of Contrails (CANSO and IFALPA)
  - Operational Opportunities and Challenges for Addressing Air Transport's Non-CO_2 Environmental Impacts (IATA)
  - Leveraging environment footprint reduction in operations, including Non-CO_2 (Airbus)

- **Chapter 11:**
  - Local Air Quality and Sustainable Aviation Fuels (SAF) (Swiss Federal Office of Civil Aviation and Aerodyne Research)
  - Jointly regulating jet fuel aromatic and sulfur content: A near-term strategy for public health and climate benefits (Environmental Defense Fund – EDF & ICSA)

Together, these articles underline ICAO's commitment to a science-based, multidimensional approach to climate action—one that addresses both CO_2 and non-CO_2 emissions to ensure aviation's full alignment with global climate objectives.

Overview of the Thirteenth Cycle of the Committee on Aviation Environmental Protection (CAEP/13)

ICAO's technical progress towards achieving net zero carbon emissions by 2050 and environmental protection

By Michael Lunter[1] (Netherlands) and Neil Dickson (ICAO CAEP Secretary)

Introduction

The Committee on Aviation Environmental Protection (CAEP), stands as a technical body of the ICAO Council. It provides the technical information for ICAO to address climate impact and other environmental challenges within the global civil aviation industry and adopts the necessary Standards, guidance and other decisions related to climate change and environmental protection. As concerns related to aircraft noise, local air quality, and the climate impact of greenhouse gas emissions intensify, the work of CAEP becomes ever more significant and fundamental for a sustainable future for international aviation.

CAEP's work includes studies on noise reduction, local air quality (LAQ), and measures to lower CO_2 emissions, such as advancements in aircraft technology, operational improvements, sustainable aviation fuels, and market-based measures like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), helping to inform policy decisions targeted at tackling climate change. The Council reviews CAEP's recommendations, informing and supporting the decisions of the Assembly.

This article offers an overview of the work accomplished by the Committee during the CAEP/13 cycle (2022-2025), which is currently under evaluation by the ICAO Council for final approval.

A Brief History

ICAO has been working on environmental issues since 1960, with a more concentrated focus on aircraft noise and engine emissions. On December 5th, 1983, CAEP was established by the ICAO Council as a successor to the Committee on Aircraft Noise (CAN) and the Committee on Aircraft Engine Emissions (CAEE). Its creation marked an important step towards consolidating ICAO's environmental oversight into a single technically focused body responsible for advising the Council on environmental matters related to international civil aviation.

1 Michael Lunter was Chairperson of the ICAO Council's Committee on Aviation Environmental Protection (CAEP) during its thirteenth cycle (2023-2025). Francis Mwangi from Kenya and Maryam Al Balooshi from the United Arab Emirates were Vice-Chairpersons.

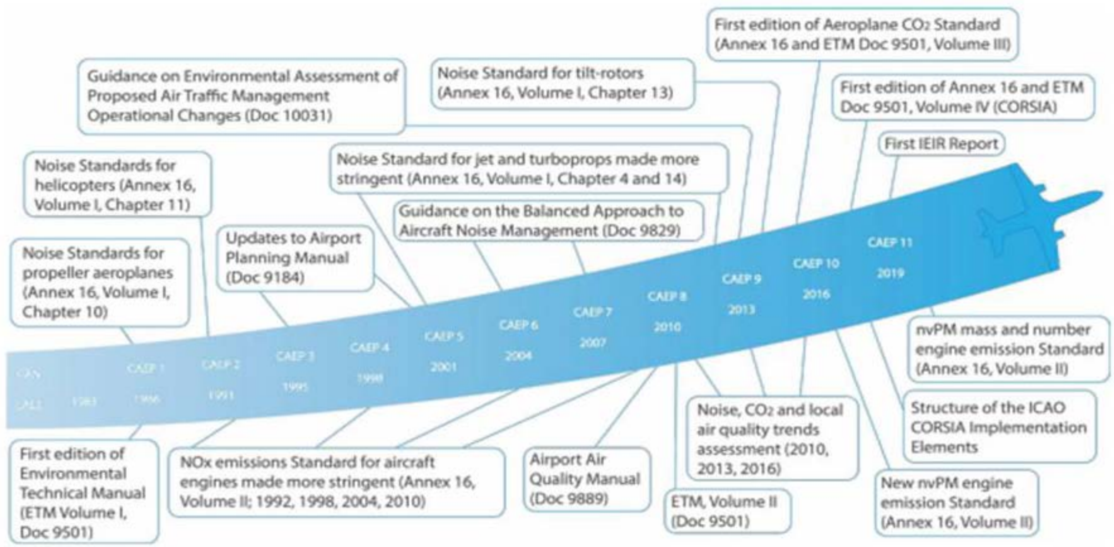

FIGURE 1: Deliverables of CAEP since CAEP/1.

Since it was established, CAEP has been a cornerstone in the development of international Standards and Recommended Practices (SARPs) addressing aircraft noise, local air quality emissions, and global climate impacts. The first SARPs were formalized in 1971 in Annex 16 to the Convention on International Civil Aviation and have evolved to include:

- Volume I: Aircraft Noise
- Volume II: Aircraft Engine Emissions
- Volume III: Aeroplane CO_2 Emissions
- Volume IV: Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

As of 2025, CAEP has completed 13 cycles, during which it has guided the aviation sector through technical advancements and policy developments. These include the creation of the Airport Air Quality Manual in 2010, the adoption of the first global CO_2 emissions standard for aeroplanes and new standards for non-volatile particulate matter (nvPM) in 2016, and comprehensive analyses supporting the rollout of CORSIA, ICAO's carbon offsetting scheme in 2017.

CAEP Process & Contributors

The success of the Committee lies in its expert-oriented and collaborative approach to developing aviation environmental standards. CAEP brings together 33 ICAO Member States covering all geographic regions. There are also 22 Observers (10 states and 12 organisations) who participate in CAEP's activities but are not be part of the final decision-making process of the members. Overall, more than 1200 globally recognized experts contribute to CAEP's activities. Nominated by CAEP's Members and Observers, they offer technical guidance in specialized areas of CAEP working groups, assisting in the delivery of CAEP work programme. CAEP's experts represent a variety of stakeholders, including government agencies, industry organizations, other UN agencies, civil society, NGOs, and research groups. This diversity of contributors ensures that CAEP's work is inclusive of a wide range of perspectives to inform the decisions of ICAO Member States

- CAEP is led by a Chairperson and two Vice-Chairpersons. Each are elected by the Committee from its Members at the beginning of every new cycle. Meanwhile, the CAEP Secretary is appointed by the President of the ICAO Council and supports the Chairperson in conducting the work undertaken by the Committee. As a Committee of the Council, CAEP operates under a confidentiality agreement, with its discussions remaining private until the ICAO Council approves the results and decides on publication.

CAEP holds formal meetings once every three years to deliver its work programme and decide on the future work programme for the upcoming cycle. Additionally, annual Steering Group meetings are held every year to

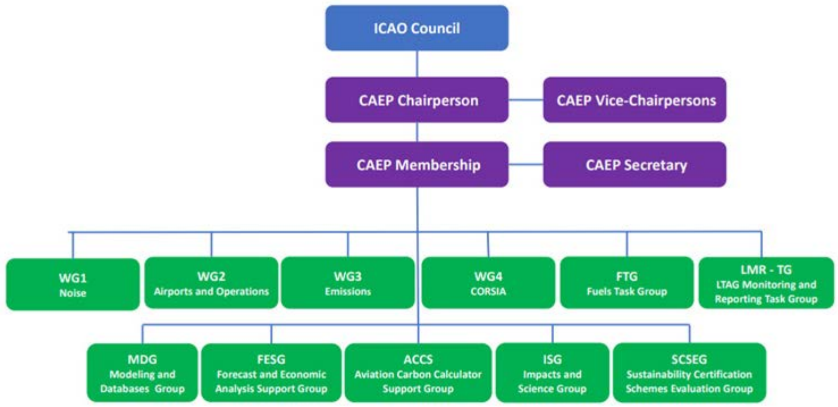

FIGURE 2: CAEP Structure during CAEP/13 cycle.

steer and guide the work undertaken by the Working Groups. The Working Groups, established under CAEP, work on various technical items concerning the nexus of aviation and environment. The scope of CAEP's work is continuously expanding and 11 Working Groups have been established to develop the CAEP/13 work program. Figure 2 highlights the CAEP/13 structure, with details of its Working Groups.

Key achievements of CAEP/13 cycle

The Thirteenth meeting of CAEP, hosted at the ICAO headquarters in Montréal, took place from 17 to 28 February 2025. The meeting gathered over 286 participants to conclude the CAEP/13 cycle, culminating three years of activity by the CAEP Working Groups. A total of 31 recommendations were agreed by the Committee which established a methodology on monitoring and reporting CO_2 emissions reductions against the ICAO long term global aspirational goal, proposed more stringent aircraft noise and CO_2 emissions standards, and made progress on non-CO_2 emissions, climate adaptation, airports, operations, fuels and CORSIA. Together these advancements respond to the requests of the 41st Session of the ICAO Assembly and the Council and will lay the technical foundation needed to continue to transform the sector's environmental commitments into concrete actions.

Environmental Trends

One key deliverable of the Committee during the CAEP/13 cycle was assessing environmental trends in aircraft noise and emissions. CAEP updated global environmental trends on aircraft noise, Greenhouse Gases (GHG), and Local Air Quality (LAQ) emissions, as requested by the 41st Session of the ICAO Assembly.

LTAG Monitoring and Reporting (LMR) Methodology

CAEP also advanced in work related to the Long-Term Aspirational Goal (LTAG) Monitoring and Reporting (LMR). In response to Assembly Resolution A41-21, paragraph 9, as well as the Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other aviation cleaner energies adopted by the Third Conference on Aviation and Alternative Fuels (CAAF/3), CAEP developed and agreed to start the implementation of a robust and comprehensive LMR methodology to track progress towards the LTAG. This methodology combines a backward-looking assessment to track actual performance of international aviation, with a forward-looking assessment towards 2050. These assessments will consider the contributions from various drivers and measures, such as traffic, technological innovations, Sustainable Aviation Fuels (SAF), and their effect on CO_2 emissions reductions, as well as cost and impacts on the sector's development. CAEP also developed a tiered approach to the LMR methodology to enable a phased implementation of the LMR methodology during future CAEP cycles.

Moreover, CAEP agreed on future CAEP work on residual CO_2 emissions mitigation measures for aviation to be carried out during the CAEP/14 cycle.

Aviation Fuels

Regarding aviation fuels, CAEP continued its technical work related to Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other aviation cleaner energies to accelerate the certification of new fuel pathways, a critical technical work for achieving the sector's vision of 5% CO_2 emissions reduction through cleaner energies by 2030, agreed at the Third Conference on Aviation and Alternative Fuels (CAAF/3) in 2023. CAEP agreed to recommend amendments to three ICAO documents referenced in Annex 16, Volume IV tied to CORSIA Eligible Fuels (CEF), regarding criteria for the evaluation from sustainability certification schemes (SCS), new provisions for electricity sourcing used in CEF production, updates to Life Cycle Assessment values and methodologies, refining methodologies for co-processing in refinery units certified for LCAF production.

CORSIA

To strengthen the implementation of CORSIA, CAEP agreed to recommend amendments to Annex 16, Volume IV, as well as to the associated Environmental Technical Manual. These proposed changes include technical recommendations on how fuel monitoring methods are used by aeroplane operators, along with improved guidance related to reporting and verification procedures. CAEP is actively supporting the preparation for the 2025 periodic review of CORSIA, providing a range of technical inputs on CORSIA analyses to inform the Council and the Assembly.

Noise CO_2 Dual Stringency Standards

Substantial progress was also made on Noise and CO_2 Dual Stringency Standards, representing the first time both standards have been made more stringent simultaneously for aviation. CAEP conducted a detailed combined assessment of more stringent standards for aircraft noise and CO_2 emissions, using 32 modeling scenarios to evaluate their technical feasibility, economic reasonableness and environmental benefits. After reviewing the stringency options, CAEP recommended a new Chapter 16 noise Standard for new subsonic aircraft, making the standard more stringent by 6dB for large aircraft and 2dB for small ones, to take effect on 1 January 2029. It also proposed making the CO_2 standard 10% more stringent for large aircraft and 3% for small ones. The applicability date for new aeroplane types is 31 December 2031, and on 1 January 2035 for in-production models. These dual standards intend to shape the next generation of aircraft designs by moving manufacturers toward solutions reducing environmental impacts.

Supersonic Aeroplanes

CAEP recommended a new Chapter 15 Landing and Take-Off (LTO) noise certification standard for supersonic aeroplane types, to be included in Annex 16, Volume I and applicable as of January 1, 2029. The committee also agreed to continue its work developing an en route noise certification Standard for supersonic aeroplanes and an LTO emissions certification Standard for supersonic aeroplane engines.

Airports and Operations

During the CAEP 13 Cycle, the Committee developed several reports regarding airports and operations, including Community engagement practices, an updated Climate Adaptation Synthesis Report, good practices of noise monitoring systems, a Report on Operational Opportunities to Reduce Climate Effects of Contrails and Non-CO_2 Emissions, as well as a new publication on *Cleaner Energy at Airports* added to the Eco-Airport Toolkit e-collection, all of which will be published to the ICAO website.

CAEP also considered the ICAO Global Air Navigation Plan (GANP), focused on operational improvements.

CAEP also proposed technical amendments to Annex 16, Volume II and ETM Volume II regarding Local Air Quality emissions and amendments to the ICAO Airport Air Quality Manual.

Impacts and Science

CAEP Impacts and Science Group (ISG) produced three reports related to aviation climate impact and non-CO_2 aviation emissions science to be published, on *Air Quality and Climate Impacts Interdependencies and Trade-Offs*, *Supersonic Climate, Air Quality and Noise Impacts* as well as a report of the CAEP ISG workshop on contrail impacts.

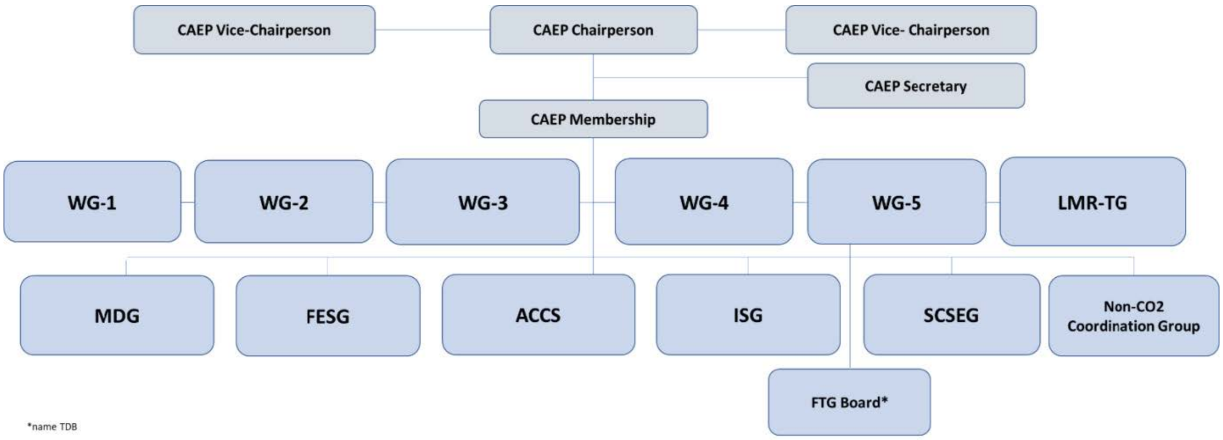

FIGURE 3: the new structure for CAEP/14 cycle.

Future Work for the CAEP/14 Cycle

Additionally, CAEP decided on its future work programme for the CAEP/14 Cycle (2025-2028), during the meeting. CAEP will continue its work on environmental trends, noise, airports and operations, emissions, CORSIA, fuels, LTAG Monitoring and Reporting, Impacts and Science.

CAEP plans to provide technical contributions in support of the ICAO Roadmap for the implementation of the CAAF/3 outcomes and the LTAG, for example with the implementation of LMR methodology, the development of a study on fuel accounting systems for international aviation, and the assessment of Life Cycle Assessment values for new fuel sources and pathways.

Conclusion

CAEP's achievements during the last triennium reflect the invaluable dedication of its Members, Observers, and technical experts in supporting ICAO's environmental goals. As CAEP enters its new cycle, it will remain committed to monitoring emerging issues and developments in environmental aviation, ensuring that relevant, and well-researched recommendations continue to guide the ICAO Council and the Assembly toward a more sustainable future for international aviation.

Environmental Trends in Aviation to 2070

By Gregg G. Fleming (USA DOT Volpe), Darren Rhodes (UK CAA), Roger Schaufele (USA FAA), Catherine Marthe (Switzerland FOCA), and David Pace (USA DOT Volpe)[1]

Background

At the end of each three-year work cycle, the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) assesses the future environmental trends in aviation that include:

- Full flight fuel burn and emissions.
- Aircraft noise.
- Aircraft engine emissions that affect Local Air Quality (LAQ).

The environmental trends discussed in this chapter are based on data from the latest CAEP/13 air travel mid demand forecast. The forecast utilized the base year of 2018 and forecast years of 2019, 2020, 2024, 2030, 2040, 2050, and 2070. The passenger and cargo forecasts were derived from ICAO's Long-Term Traffic Forecast (LTF), while the business jet forecast was developed from a new International Business Aviation Council (IBAC) aircraft delivery forecast. The traditional forecast development process was adjusted to account for the continued effect of COVID-19 on economic activity and traffic demand. Uncertainty around the effect of the pandemic on traffic demand is acknowledged through a series of forecast scenarios.

Data presented for years earlier than 2018 are reproduced from prior CAEP trends assessments. Trends results presented for fuel burn and emissions represent international aviation only, while noise results include both domestic and international operations. In 2018, approximately 65% of global aviation fuel consumption was from international aviation. According to the CAEP/13 traffic demand forecast, this proportion is expected to remain relatively stable out to 2070.

The trends presented here were developed in the context of a longer-term view, assuming no airport infrastructure or airspace operational constraints. However, these trends may be substantially impacted by a wide range of factors, including fluctuations in fuel prices, uptake of alternative jet fuels (AJF), and global economic conditions, including any residual effects of recovery from the COVID-19 pandemic.

Three environmental models contributed results to the full flight fuel burn and emissions trends assessment: FAA's Aviation Environmental Design Tool (AEDT); EUROCONTROL's Integrated Aircraft Noise and Fuel Burn & Emissions Modelling Platform (IMPACT); and Manchester Metropolitan University's Future Civil Aviation Scenario Software Tool (FAST). In addition, the US EPA's fuel burn and emissions tool, which is not a CAEP approved model, also provided limited results for comparisons.

Two distinct fleet evolution models were used: FAA's Fleet Builder (FB) and the EC/EASA/EUROCONTROL Aircraft Assignment Tool (AAT). The AEDT, FAST and US EPA results were based on the FB operations, while the IMPACT results were based on the AAT operations. Key databases utilized in this assessment include CAEP's Global Operations, Fleet, and Airports Databases.

During the CAEP/12 work cycle, a comprehensive introduction to the forecasting and environmental trends

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1 Gregg G. Fleming and Darren Rhodes are co-Rapporteurs of the Modelling and Databases Group (MDG) of the ICAO Council's Committee on Aviation Environmental Protection (CAEP). Catherine Marthe and David Pace are co-Rapporteurs of the Forecasting and Economic Analysis Support Group (FESG).

assessment process was developed and is available for reference at ICAO's public website.

Traffic Demand Forecasts and COVID-19

The CAEP/13 environmental trends traffic demand forecast has a 2018 base year and 32-year forecast horizon through 2050 (with an additional forecast extension going out to 2070). It represents an update of the CAEP/12 forecast (which had the same 2018 base year), reflecting changes in global economic activity, including revised near-term traffic demand that was still being influenced by the recovery from the effects of the COVID-19 pandemic.

The traditional forecast development process was adjusted to account for the continued effect of COVID-19 on economic activity and traffic demand. Uncertainty around the effect of the pandemic on traffic demand is acknowledged through a series of forecast scenarios.

To account for the effect of COVID-19, a set of assumptions were developed and used to guide how the aviation industry was anticipated to continue to transition out of the pandemic driven downturn. These included expectations on the short-run path for when each market—passenger, cargo and business jet—would return to 2019 pre-COVID-19 levels under different scenarios (e.g., a delay in business travel recovery in the passenger market). Based on historical data it was determined that while the passenger market remained below 2019 levels, the cargo and business jet markets were largely back to pre-pandemic levels of activity at the time the CAEP/13 forecast was being developed.

The CAEP/13 forecast used updated macroeconomic forecast information incorporating the short- and long-run economic outlook as the world's economies moved out of the pandemic. Available historical data allowed for capturing the decline in demand beginning in 2020 and continuing through 2022. These data, and the guiding assumptions, allowed for identifying the point at which each market (i.e., passenger, cargo and business jet) is expected to return to their 2019 levels of activity, after which the long-term trends were used to guide the outlook.

Passenger market traffic demand shows a sharp decline in 2020 due to the pandemic (global revenue passenger kilometres (RPKs) declined by 67%) (Figure 1). The near-term recovery trajectories have global traffic demand returning to 2019 levels in 2024 for the high and mid scenarios, and 2025 for the low scenario. Over the 32-year forecast period, the CAEP/13 mid forecast has revenue passenger kilometres growing at an annual average rate of 3.4% for global and 3.5% for international demand (compared with 3.6% for global and international RPKs from the CAEP/12 COVID-19 LTF mid outlook).

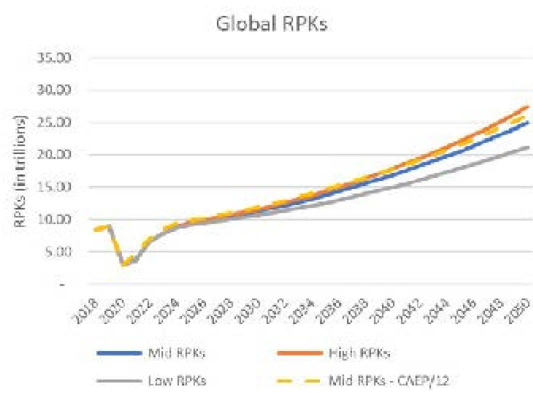

FIGURE 1: COVID-19 Global Passenger Forecast Scenarios.

The cargo market CAEP/13 forecast shows a decline in global demand of 15% in 2020 with a return to 2019 levels by 2021 for all scenarios (Figure 2). Over the course of the mid 32-year forecast, global freight tonne kilometres (FTKs) are expected to grow by 3.1% per annum (down from 3.5% in the CAEP/12 COVID-19 outlook), with international FTKs increasing by 3.0% per annum (compared with 3.4% in the CAEP/12 COVID-19 outlook).

Based on updated historical information, Business Jet operations saw a continued increase in operations during the height of the pandemic, counter to the CAEP/12 forecast that estimated a decline in operations (See Figure 3). For the CAEP/13 forecast, under the mid outlook operations are expected to increase on an average annual basis of 2.7% for the entire 32-year forecast period (unchanged from CAEP/12 outlook).

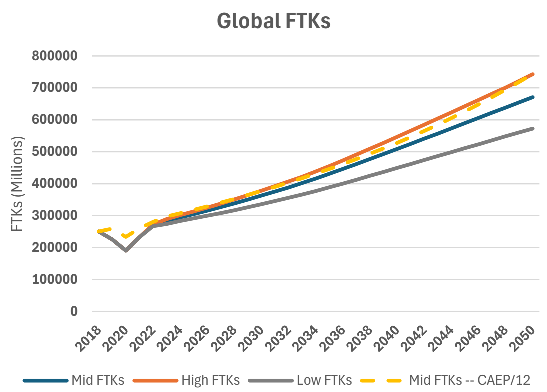

FIGURE 2: COVID-19 Global Cargo Forecast Scenarios.

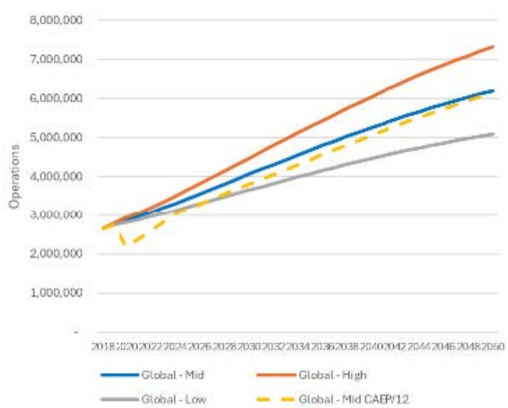

FIGURE 3: COVID-19 Global Business Jet Forecast Scenarios

A 20-year extension was added to the CAEP/13 traffic demand forecast, taking the forecast to 2070. The extension was developed using the methodology from CAEP/12, which leveraged information contained within the CAEP/13 forecast models.

Over the 52-year forecast period to 2070, passenger RPKs grow at an annual average rate of 3.3%, compared with 3.4% for the period from 2018 to 2050. International RPKs increase by an average of 3.3% per annum from 2018 to 2070, compared with 3.5% through 2050. Cargo FTKs are expected to increase at an average rate of 2.9% from 2018 through 2070, compared with 3.1% for the 32-years through 2050. International FTKs are expected to grow by an average of 2.8% per annum through 2070, compared with 3.0% growth through 2050. For the business jet market, operations are expected to grow at an average annual rate of 1.9% in the 52-year forecast period to 2070, compared with 2.7% growth between 2018 and 2050.

2 Independent Expert Integrated Review (IEIR)

Full Flight Fuel Burn and Emissions Trends

Table 1 below summarizes the aircraft technology and operational scenarios developed for the assessment of trends for full flight fuel burn and aircraft emissions. The CAEP/13 trends assessment included full flight fuel burn, carbon dioxide (CO_2), nitrogen oxides (NO_X), and non-volatile particulate matter (nvPM).

Trends in Full-Flight Fuel Burn and Emissions

Figure 4 below shows the results for full flight (i.e., from departure gate to arrival gate) fuel burn for international aviation from 2005 to 2070. The analysis considered the impact of aircraft technology, improved air traffic management, and infrastructure use (i.e., operational improvements) on fuel consumption. The dashed line in the figure illustrates fuel burn that would be expected if ICAO's 2% annual fuel efficiency goal were to be achieved.

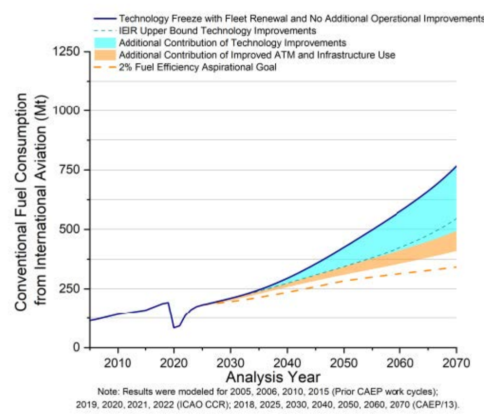

FIGURE 4: Fuel Burn from International Aviation, 2005 to 2070.

For 2070 Fuel Scenario 3 (IEIR[2] upper bound) aircraft technology accounts for a reduction of 220 Mt and operations accounts for an additional 85 Mt for a total reduction of 305 Mt as compared with Fuel Scenario 1. For Fuel Scenario 3 (IEIR lower bound) aircraft technology accounts for a reduction of 271 Mt and operations accounts for an additional 85 Mt for a total reduction of 356 Mt as compared with Fuel Scenario 1. Overall, Fuel Scenario 3 results in 27% and 46% reduction in fuel burn as compared with Fuel Scenario 1 in 2050 and 2070, respectively.

Considering Fuel Scenario 3 (IEIR lower bound), an average fuel efficiency of 1.5% would be observed by 2050, increasing to about 1.6% by 2070. This would represent lower improvements compared to the ICAO 2% fuel efficiency aspirational goal for international aviation.

Figure 5 depicts the uncertainties associated with the forecasted demand, which is the largest contributor to uncertainty in fuel burn. The uncertainty in forecasted demand is roughly twice the size of the range in technology and operational improvements combined. Despite the range of uncertainties, the CAEP/13 forecast traffic trends are generally consistent with other published aviation forecasts. The CAEP/13 commercial market forecast for revenue passenger kilometres (RPK), shows a 20-year (2018 to 2038) compound average annual growth rate (CAGR) of 3.1%. By way of comparison, Boeing and Airbus RPK forecasts released in 2022 have CAGRs of 3.8%, and 3.6%, respectively for the period from 2019 to 2041.

Figure 6 presents full-flight CO_2 emissions for international aviation from 2005 to 2070; CO_2 emissions are based solely on the combustion of jet fuel, assuming that 1 kg of jet fuel burned generates 3.16 kg of CO_2. As with the previous fuel burn analysis, this CO_2 analysis considers the contribution of aircraft technology, improved air traffic management, and infrastructure use (operational improvements).

The delta between the CAEP/12 and CAEP/13 CO_2 trends baselines in 2040 is approximately 13%. Most of this variation can be attributed to differences between the central demand forecasts. Specifically, the CAEP/12 (2018) forecast was produced based on initial views of what the recovery from COVID-19 would look like. Those views were revised accordingly as part of preparing the CAEP/13 forecast, which was also based on a 2018 baseline.

Considering the range of fuel consumption scenarios (Table 1), the difference between the highest anticipated fuel consumption in 2019 (Fuel Scenario 1) and the lowest anticipated fuel consumption in 2050 (Fuel Scenario 4) results in a minimum CO_2 emission gap of 422 Mt in 2050 compared to 2019 emissions.

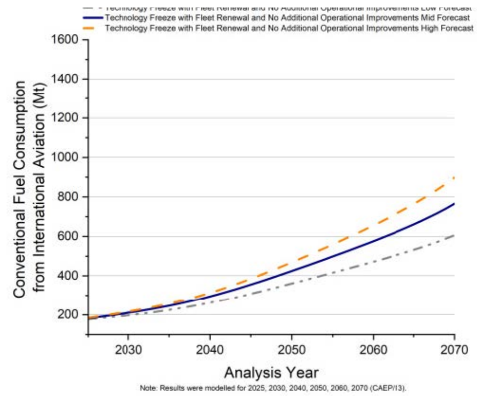

FIGURE 5: Range of Uncertainties Associated with Demand Forecast, 2024 to 2070.

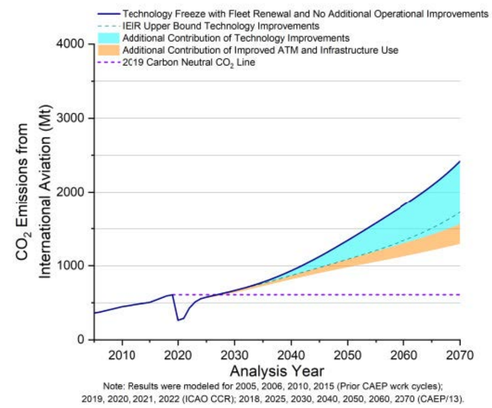

FIGURE 6: CO_2 Emissions from International Aviation, 2005 to 2070.

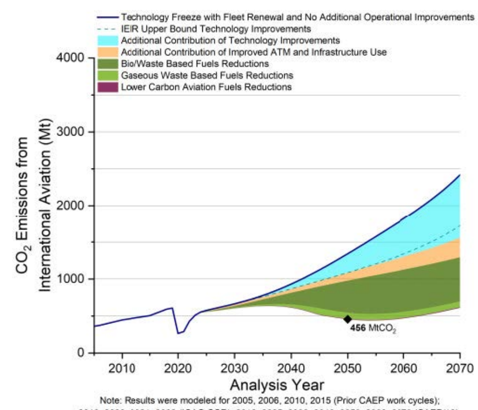

FIGURE 7: Combustion CO_2 Emissions from International Aviation, 2005 to 2070, Including Alternative Jet Fuels Life Cycle Emissions Reductions (Based on 3.16 kg of CO_2 per 1 kg of fuel burn).

Contribution of Alternative Fuels to Fuel Burn and CO_2 Trends

As shown in Figure 7 for international aviation, for the year 2050 and 2070, with alternative fuels replacement, there is a 53% reduction in residual CO_2 emissions in addition to the reduction from technology and operations improvements.

CAEP monitors long-term developments in CORSIA eligible fuels (CEFs) production and updates the fuels scenarios as needed for the ICAO Environmental Trends assessment. This includes projections for drop-in aviation fuels from renewable or waste resources, i.e., sustainable aviation fuels (SAF) and lower carbon aviation fuel (LCAF). Coordination of the various CEF activities within CAEP helps ensure consistency across analyses.

SAF production values were a blend of two distinct scenarios. To meet ICAO's 2030 goal, a blend of two scenarios were used for the years 2025 to 2030, and then the analysis switched back to the single scenario out to 2070. The SAF values beyond 2030 were based on assumptions about feedstock and technology success and could vary widely. The SAF scenario chosen is a gap analysis from previous work and is not supported by current production announcements.

Trends in Aircraft Full Flight NO_X and NVPM Emissions

Figure 8 shows the full flight NO_X emissions from international aviation. In 2018, NO_X emissions were calculated as 2.97 Mt. In 2070, NO_X emissions range from 10.46 Mt under Scenario 3 to 15.12 Mt under Scenario 1, representing up to a 4.66 Mt (7.18 Mt for global aviation) reduction with technology and operational improvements.

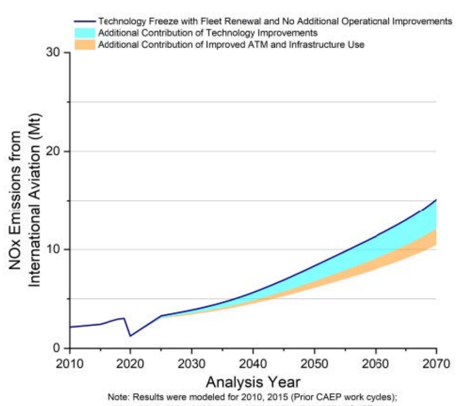

FIGURE 8: Full Flight NO_X Emissions from International Aviation, 2010 to 2070.

Figure 9 shows the full flight nvPM emissions trend from international aviation. In 2018, nvPM emissions were calculated as 6.99 kt. In 2070, nvPM emissions range from 12.92 kt under Scenario 3 to 24.75 kt under Scenario 1, representing up to a 11.83 kt (15.28 kt for global aviation) reduction with technology and operational improvements.

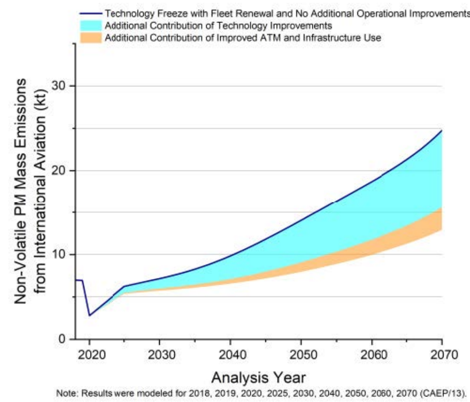

FIGURE 9: Full Flight nvPM Emissions from International Aviation, 2018 to 2070.

Trends in Aircraft Noise

Four scenarios were developed for the noise trends assessment, resulting in the total contour area and population inside the yearly average day-night level (DNL) contours of 55, 60, and 65 dB for 320 global airports, representing approximately 80% of global population exposure to aircraft noise. Population counts for airports in the US, Europe and Brazil used the latest available local census data. For all other airports, the NASA Gridded Population of the World version 4 was used.

Scenario 1 (CAEP/13 Baseline) assumes no further aircraft technology or operational improvements after 2018. Scenario 2 includes noise technology improvements of 0.1 EPNdB per annum for all aircraft entering the fleet from 2019 to 2070. Scenario 3 was meant to capture the COVID-19 delay with no noise technology improvement from aircraft entering the fleet from 2019 to 2023, and technology improvement of 0.2 EPNdB per annum for all aircraft entering the fleet from 2024 to 2070. Scenario 4 includes noise technology improvement of 0.2 EPNdB per annum for all aircraft entering the fleet from 2019 to 2070. For Scenarios 2, 3 and 4, an additional moderate operational improvement of 2% is applied for population

Scenario	Aircraft Technology: Per annum fuel burn improvement for fleet entering after 2018	Aircraft Technology: Emissions improvements against CAEP/7 IE NO_x Goal	Operational Improvements
Fuel 1 - Tech Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
Fuel 2 - Moderate Aircraft Technology and Low Operational Improvements	0.96 percent 2018 to 2050; for 2051 to 2070, no additional improvements (Case 1) and continued 0.96 percent to 2070 (Case 2)	NA	Fleet wide CAEP/12 LTAG low operational improvement by route group
Fuel 3 – Independent Expert Integrated Review (IEIR) Technology and Medium Operational Improvements	IEIR by aircraft type improvement 2018 to 2050; for 2051 to 2070, no additional improvements (Case 1) and continued IEIR by aircraft type improvement (Case 2)	NA	Fleet wide CAEP/12 LTAG medium operational improvement by route group
Fuel 4 – LTAG, Advanced Tube and Wing (ATW) Medium Technology and Medium Operational Improvements	LTAG ATW medium technology improvement by aircraft type 2018 to 2050; for 2051 to 2070, no additional improvements (Case 1) and continued LTAG ATW medium technology improvement by aircraft type (Case 2)	NA	Fleet wide CAEP/12 LTAG medium operational improvement by route group
NO_x 1 - Technology Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
NO_x 2 - CAEP/12 LTAG Low Operational, and 50% CAEP/7 IE Emissions Improvements	NA	50 percent of CAEP/7 IE NO_x Goal met by 2036 with no further improvement thereafter	Fleet-wide CAEP/12 LTAG low operational improvements by route group
NO_x 3 – CAEP/12 LTAG High Operational, and 100% CAEP/7 IE Emissions Improvements	NA	100 percent of CAEP/7 IE NO_x Goal met by 2036 with no further improvement thereafter	Fleet-wide CAEP/12 WG2 high operational improvements by route group
nvPM 1 - Technology Freeze with No Operational Improvements	NA: use only base year (2018) in-production aircraft	NA	NA: maintain current operational efficiency levels
nvPM 2 – CAEP/12 LTAG Low Operational, and CAEP/13 Moderate Technology Improvement	**CAEP/13 Moderate Technology Improvement**	NA	Fleet-wide CAEP/12 LTAG Low Operational Improvements by route group

TABLE 1: Fuel Burn and Emissions – Technology and Operational Improvement Scenarios

inside the 55, 60 and 65 dB contours.[3] Four modelling scenarios were included, and modelled for each of the future years, as follows: 2019, 2020, 2025 (scenario 1 only); and 2030, 2040, 2050, 2060, and 2070 (all 4 scenarios).

Figure 10 provides results for the total global 55 DNL[4] contour area (i.e., for 320 airports) for 2018 (base year), 2019, 2020, 2025 (scenario 1 only) and 2030, 2040, 2050, 2060 and 2070 for the four scenarios. Historical data modelled in the CAEP/11 work cycle is also shown for 2015. The 2018 contour area is 16,657 square km. This value decreases to 10,306 square km in 2020 due to COVID-19 pandemic and increases to 14,164 square km by 2025. In 2070 the technology freeze (Scenario 1) total

3 In order to show the COVID-19 pandemic related downturn and the recovery, 2019, 2020 and 2025 years were modelled for Scenario 1 (Technology Freeze with no Operational Improvement).

4 DNL 55 covers all the noise above 55 dB including 60 dB and 65 dB and DNL 60 covers all the noise above 60 dB including 65 dB.

global contour area is 32,887 square km and decreases to 22,240 square km with low technology improvements (scenario 2), to 15,723 square km with moderate technology improvements (scenario 3), and to 11,363 square km with the advanced technology improvements (scenario 4). The total population inside the 55 DNL contours was estimated to be 36 million in 2018 and could range from 78 million under Scenario 1 to 27 million under Scenario 4 in 2070; this is under the assumption that population density around airports does not vary in time.

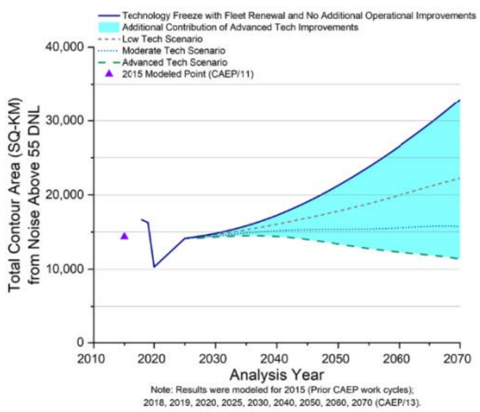

FIGURE 10: Total Global Aircraft Contour Area Above 55 dB DNL, for 320 Airports (km²), 2015-2070.

Trends in Landing and Takeoff (LTO) Emissions

A range of scenarios was also developed for evaluation of aircraft emissions that occur below 3,000 feet above ground level; namely NO_X and total (volatile and non-volatile) particulate matter (PM). The NO_X and PM scenarios for LTO are equivalent to the those used in the full-flight trends assessment (Table 1).

NO_X emissions below 3000 feet from international aviation are shown in Figure 11. In 2050, technology and operational improvements could provide reductions of up to 0.14 Mt (36%) and 0.30 (36%) Mt in NO_X emissions for international and global aviation, respectively. By 2070, technology and operational improvements could provide reductions of up to 0.30 Mt (45%) and 0.66 Mt (45%) in NO_X emissions for international and global aviation, respectively.

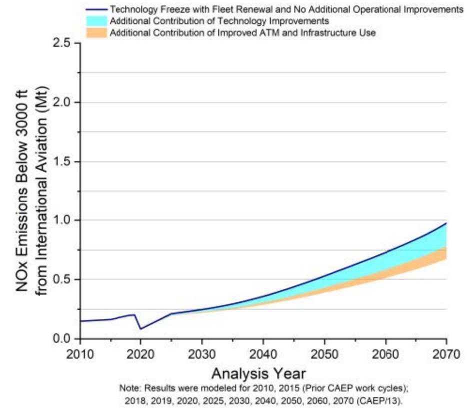

FIGURE 11: NO_X Emissions below 3000 ft from International Aviation, 2010 to 2070.

Non-volatile PM (nvPM) emissions below 3000 feet from international aviation are shown in Figure 12. In 2050, technology and operational improvements could provide reductions of up to 0.26 Kt (42%) and 0.54 (42%) Kt in nvPM emissions for international and global aviation, respectively. By 2070, technology and operational improvements could provide reductions of up to 0.50 Kt (48%) and 1.05 Kt (48%) in nvPM emissions for international and global aviation, respectively.

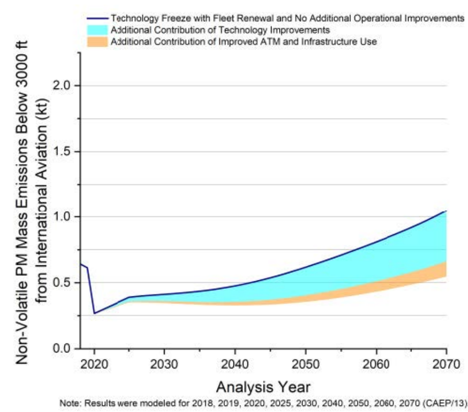

FIGURE 12: nvPM Emissions below 3000 ft from International Aviation, 2018 to 2070.

Conclusions

Full-flight and LTO emissions from international aviation are expected to increase through 2070 by 2 to 5 times 2018 levels, depending on the pollutant (CO_2, NO_x, nvPM, or PM) and the analysis scenario. Specifically for the full flight technology freeze scenario (Fuel Scenario 1), CO_2, NO_x, and nvPM are expected to increase by a factor of 4, 5 and 3.6, respectively. For LTO emissions (Fuel Scenario 1), NO_x and nvPM are expected to increase by a factor of 4.9 and 1.6, respectively. These factors are generally consistent for both international and global aviation. The total DNL 55 dB noise contour area at the 320 airports in the analysis could stabilize after 2025 under an advanced technology improvements scenario.

In 2018[5], international aviation consumed approximately 188 Mt of fuel, resulting in 593 Mt of CO_2 emissions. By 2070, fuel consumption is projected to increase 3 to 4.1 times the 2018 value, while revenue tonne kilometres (RTK) are expected to increase 5 times under the most recent forecasts (the 52-year [2018 to 2070] compound annual growth rate for RTKs is 3.2%). Assuming the most optimistic fuel technology improvements (Fuel Scenario 4), international fuel efficiency (volume of fuel per RTK) is expected to improve at an average rate of 1.5% per annum (2015 to 2050), increasing slightly to 1.6% by 2070. This indicates that ICAO's aspirational goal of 2% per annum fuel efficiency improvement is unlikely to be met by 2050. Aircraft technology, ATM and AJF combined have the potential to curb the growth in net CO_2 emissions from aviation in the longer-term (beginning in 2035), but this will likely necessitate significant investments. Furthermore, uncertainties associated with future aviation demand remain high.

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1. ICAO. 2022 Environmental Report. https://www.icao.int/environmental-protection/pages/envrep2019.aspx.
2. Environmental Trends in Aviation to 2050. pp 24-31.
3. ICAO Environmental Trends: https://www.icao.int/environmental-protection/Pages/Environmental-Trends.aspx .

5 The CAEP/14 Environmental Trends is expected to have a 2024 base year.

The State of Global Climate and Hazards posed by Sand and Dust Storms and Wildfires

By Greg Brock, Stéphanie Wigniolle and Chris Hewitt (WMO)

The State of Global Climate

By Greg Brock, Stéphanie Wigniolle and Chris Hewitt (WMO)

The State of Global Climate Report 2024[1], published by the World Meteorological Organization (WMO) in March 2025, highlights that 2024 was the warmest year in the 175year observational record, with the annually averaged global mean nearsurface temperature of 1.55 °C ± 0.13 °C above the 1850-1900 average used to represent preindustrial conditions. (Figure 1 below.) This beats the previous record set in 2023. While a single year above 1.5 °C warming does not indicate that the long-term temperature goals of the Paris Agreement are out of reach, it is though a wake-up call. Each of the past ten years (20152024) were individually the ten warmest years on record. (Note, the analysis is based on a synthesis of six global temperature datasets.)

In respect of atmospheric concentrations of the three main greenhouse gases – namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – real-time data

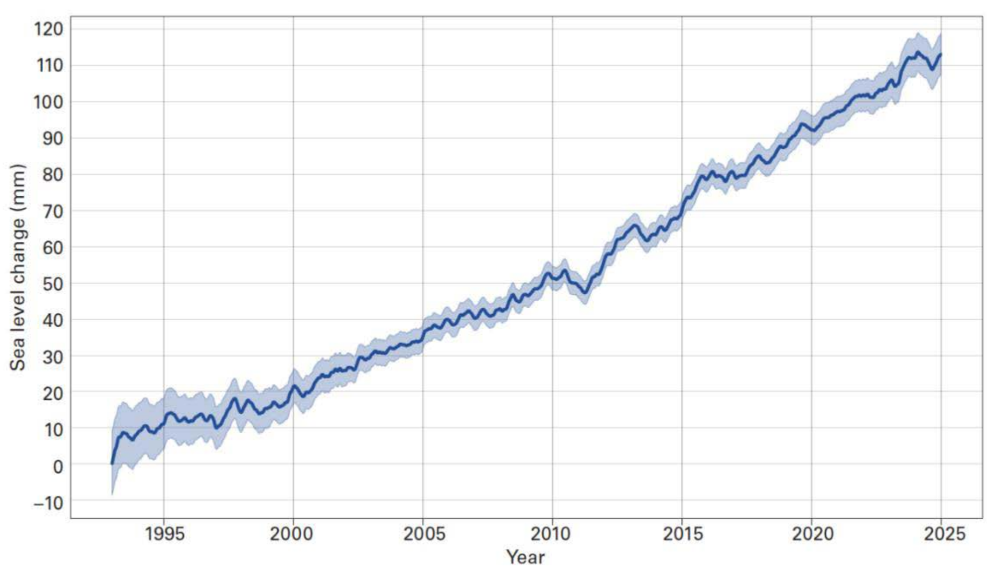

FIGURE 1: Annual global mean temperature anomalies relative to a pre-industrial (1850–1900) baseline shown from 1850 to 2024. Source: Data are from the six datasets indicated in the legend.

1 https://library.wmo.int/records/item/69455-state-of-the-global-climate-2024

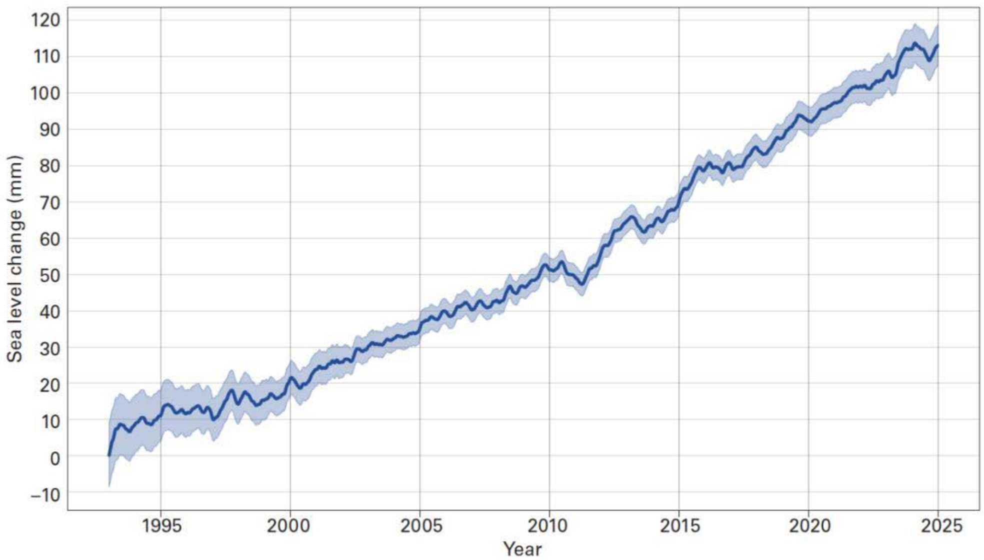

FIGURE 2: Seasonal global mean sea level change from 1993 shown for 1993–2024. The seasonal cycle has been removed from the data. The shaded area indicates the uncertainty. Source: Data from AVISO CNES.

from specific locations show that levels continued to increase in 2024. Moreover, in 2023 (the most recent year for which consolidated global annual figures are available), atmospheric concentrations of CO_2, CH_4 and N_2O were at their highest levels in the last 800,000 years. In calendar year 2023, for example, the concentration of CO_2 increased by 2.8 parts per million (ppm), representing the fourth largest within-year change since modern CO_2 measurements started in the 1950s. (Note, the rate of growth is typically higher during El Niño conditions due to an overall increase from fire emissions and reduced net terrestrial carbon sinks.) And concentration of CH_4 reached 1 934 ± 2 parts per billion (ppb), which is 265% of pre-industrial levels, while N_2O reached 336.9 ± 0.1 ppb, which is 125% of pre-industrial levels.

In respect of other climate change indicators of interest to aviation:

- The global mean sea level reached a record high in the satellite record (1993 to present). (Figure 2 above.) The rate of global mean sea-level rise in the past 10 years (20142025) was more than twice that recorded in the first decade of the satellite recorded (19932002), increasing from 2.1 mm per year between 1993 and 2002 to 4.7 mm per year between 2015 and 2024. In an aviation context, if the sea-level rise trend continues and without any adaptation or mitigation to build resilience, coastal and low-lying airports will be particularly vulnerable to an increased risk of flooding and storm surges.

- Most land areas in 2024 were warmer than the 30-year long-term average (19912020), with limited areas of below-average temperatures around Iceland, parts of Antarctica and the southern tip of South America. Record or near-record high annual mean temperatures were observed across large areas of the tropics from South and Central America east to the western Pacific. Other land areas outside of the tropics also experienced exceptionally high annual temperatures, including eastern North America, North Africa and Europe, and southern and eastern Asia. In an aviation context, warmer near-surface temperatures and extreme heat can negatively affect aircraft take-off performance and fuel efficiency, airport runway conditions and throughput, and may result in the imposing of more stringent weight restrictions.

- Unusually dry or unusually wet conditions were experienced across continents in 2024. In Africa, for example, drier than average (1991–2020) conditions were observed over much of Southern Africa, some locations in coastal West Africa and along the North

African coast, while parts of the Sahel region and parts of Central and southern East Africa were wetter than normal. Meanwhile, in South America, the Amazon lowlands and northern Andes to the Pantanal wetlands were drier than normal. And, in large parts of North-east, East and Central Asia and to a smaller extent also in South-east, South and South-west Asia, higher than normal precipitation totals were observed. Variance in the distribution of precipitation, i.e. lower than normal and higher than normal, was experienced elsewhere across the globe too. In an aviation context, unusually dry conditions can create an environment favourable to sand and dust storms, which may cause disturbances, including safety concerns, to air and ground operations.

In terms of impacts, extreme weather events in 2024 led to the highest number of new displacements recorded in a year since 2008. New, onward and protracted displacements affected significant numbers of people in fragile, and conflict affected contexts. Alongside the destruction of homes, critical infrastructure, forests, farmland and biodiversity, such extreme weather events can undermine resilience and pose significant risks to people on the move and those already living in displacement.

Tropical cyclones were responsible for many of the highest-impact events of 2024. Other high-impact events included abnormal cold and snowfall, extreme rainfall, severe flooding including flash flooding, an abnormally active monsoon season, exceptionally dry or severe drought conditions, and heatwaves.

Aviation was not immune to the impacts of extreme or high-impact weather events in 2024. In April 2024, the United Arab Emirates was affected by an extreme rainfall event, which led to flash flooding at Dubai international airport and the reported cancellation of several hundreds of flights and delays to the travel plans of thousands of passengers. A few months later, in July 2024, Houston international airport in the United States of America was affected by Hurricane Beryl, reportedly resulting in the cancellation of nearly a thousand flights. These are just a couple of examples, among many, of how aviation can be impacted by extreme or high-impact weather events. While caution should be exercised to link such events to climate change, changes in the frequency and/or intensity of weather events, and where they occur, requires aviation to be proactive in its preparedness and response, through the building climate adaptation, mitigation and resilience and the appropriate use of meteorological and climatological information from authoritative sources, including national meteorological and hydrological services of WMO Members.

Hazards posed by sand and dust storms and wildfires

By Sara Basart (WMO

Atmospheric composition-related hazards — such as sand and dust storms (SDS) and smoke from vegetation fires — pose increasing safety and operational risks to international civil aviation. These hazards can cause severely reduced visibility, strong gusty winds, turbulence and wind shear, all of which have contributed to aviation incidents and accidents. Dust-induced icing has also been linked to fatal occurrences (Scherllin-Pirscher et al, 2025)[2]. In addition to immediate flight safety concerns, prolonged exposure to airborne dust and smoke accelerates corrosion, causes surface abrasion, and leads to molten particle ingestion in engine hot-section components — compromising aircraft airworthiness, heightening maintenance needs, and increasing lifecycle ownership costs.

The frequency and severity of SDS and wildfires are expected to rise in many regions due to the impacts of climate change (WMO State of the Global Climate, 2024)[3]. These changes contribute to both the expansion of arid regions and the growing vulnerability of ecosystems to fire, amplifying the scale and frequency of dust and smoke events that may affect aviation.

To address these evolving risks, the World Meteorological Organization (WMO), continues to support the integration of specialized hazard monitoring systems into national meteorological and hydrological services, including those that provide service for aviation. The WMO Sand and Dust Storm Warning Advisory and Assessment System

2 https://journals.ametsoc.org/view/journals/bams/106/1/BAMS-D-23-0311.1.xml
3 https://library.wmo.int/records/item/69455-state-of-the-global-climate-2024

(SDS-WAS)[4] and the Vegetation Fires and Smoke Pollution Warning Advisory and Assessment System (VFSP-WAS)[5], for example, provide essential regional and global forecasting, advisory and observational products to support flight planning and hazard avoidance. Nevertheless, gaps remain in data resolution, coverage and real-time availability, particularly in data-sparse regions.

Enhanced collaboration among ICAO, WMO, national meteorological and hydrological services and the scientific community is critical to improving aviation resilience to atmospheric composition hazards, consistent with the needs of ICAO Annex 3 – *Meteorological Service for International Air Navigation* and the broader global climate adaptation efforts.

4 https://community.wmo.int/en/activity-areas/gaw/science-for-services/sds-was
5 https://community.wmo.int/en/activity-areas/gaw/science/modelling-applications/vfsp-was

Bridging the Upper-Air Data Gap

WMO's Aircraft Observations for Enhanced Forecasting and Greener Aviation

By Nicolás Rivaben (WMO)

Since the late 1990s, the World Meteorological Organization (WMO) Aircraft-based Observations Programme (ABOP)[1] has concentrated on enhancing aircraft-based meteorological observations (ABO) to improve numerical weather prediction (NWP) and severe weather forecasting. There has been a particular emphasis on expanding coverage in data-sparse upper-air regions, such as Latin America, Africa and parts of Asia. By leveraging existing aircraft infrastructure, WMO's Aircraft Meteorological Data Relay (AMDAR)[2] observing system collects real-time in-situ data from commercial aircraft and relays to NWP centres, complementing existing radiosonde network. A key innovation involves retrofitting aircraft with high-accuracy water vapour sensors to fill critical data gaps, particularly in regions with limited observational capacity. Additionally, accurate water vapour monitoring at flight cruise levels is critical for ice-crystal icing, contrail avoidance studies and mitigation as well as climate science.

ABO contributions from national meteorological and hydrological services (Figure 1) worldwide for global NWP are instrumental in reducing the aviation sector's environmental impact. The optimisation of flight routes and fuel efficiency, enabled by the provision of more accurate weather forecasts for flight dispatch, can be facilitated by the enhancement of NWP products such as those within ICAO's world area forecast system (WAFS), and the delivery of essential products to end-users in the meteorological field. The enhancement of NWP capabilities enables airlines to minimise weather-related delays, reduce excess fuel consumption, and decrease CO_2 emissions, while also facilitating the implementation of contrail avoidance programmes. Consequently, these efforts are in alignment with global climate mitigation objectives.

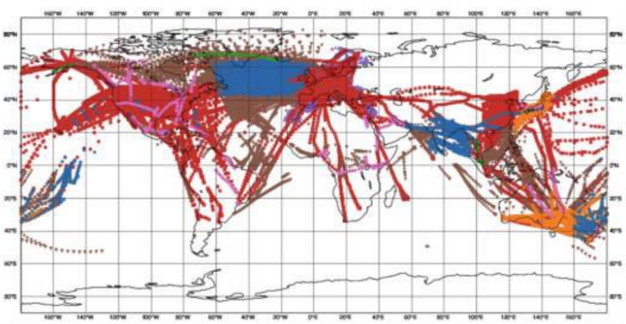

FIGURE 1: Coverage for all ABO-related sources - ingested by ECMWF Operational NWP between 03:00 and 06:00UTC - 09 January 2025. Each colour represents type of ABO -in-situ data: red and orange shows "AMDAR" coverage; brown for "Wx ADS-C"; blue for "AIREP"; pink for "AFIRS"; purple for "SSR Mode S"; and green for "FLYHT TAMDAR". Source: Data assimilation monitoring of ECMWF[3].

WMO ABOP delivers measurable benefits, including a projected 10-25% increase in weather prediction accuracy in data-sparse regions using data from targeted airlines. This can translate into millions of dollars in annual savings for the aviation industry through optimized operations and reduced carbon footprints, as well as lower fuel consumption in those regions. Qualitatively, it strengthens the social contribution of the aviation industry and enhances

1 https://community.wmo.int/en/activity-areas/aircraft-based-observations
2 https://community.wmo.int/en/activity-areas/aircraft-based-observations/amdar
3 https://www.ecmwf.int/

climate resilience through providing observations for early warning systems for extreme weather for civilian communities such as the United Nations Early Warnings for All (EW4All) Initiative[4] among others.

Despite these benefits, ABO programmes have been reduced in their contribution since the aviation industry was impacted by the consequences of the COVID-19 pandemic (Figure 2).

Over the next three years, WMO plans to expand AMDAR coverage by partnering with aviation stakeholders to recover the 2019 levels by 2027. Long-term goals include achieving a sustainable and resilient increase in global water vapour aircraft-based observations by 2030, fostering airline participation, green climate funds and regulation-related entities supporting the reduction of the sector's carbon footprint through precision meteorology for operations and improved support for future contrail avoidance systems. By bridging ABO data gaps with targeted airlines participation and through WMO and its Members supporting ICAO green aviation policies, this initiative positions itself as a catalyst for both aviation operational efficiency and environmental stewardship in the coming decade.

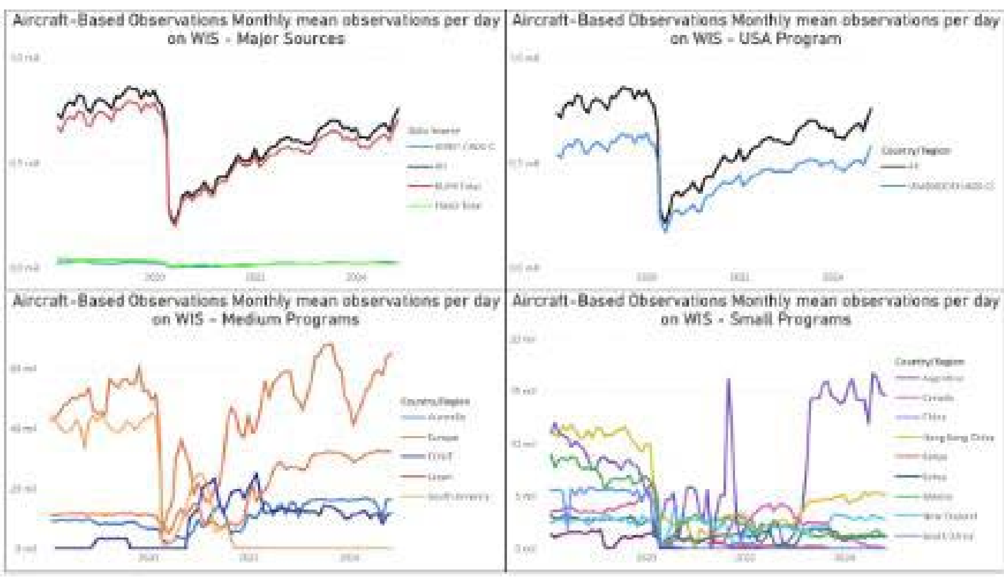

FIGURE 2: Evolution of daily Aircraft-based Observations data provided by national meteorological and hydrological services (NMHS) into the WMO Information Systems for the period January 2018 to October 2024. Source: WMO ABO Monitoring site[5] with data provided by Environment and Climate Change Canada[6].

4 https://earlywarningsforall.org/site/early-warnings-all
5 WMO ABO Monitoring site
6 https://www.canada.ca/en/environment-climate-change.html

In-Service Aircraft for a Global Observing System

By Hannah Clark (IAGOS)

Global climate change and air quality represent one of the most serious environmental challenges facing humanity today. Climate and air quality issues require (i) a good knowledge of the state of the atmosphere and (ii) a long-term monitoring strategy for addressing the changes and their causes. Reliable predictions of the future climate and air quality using climate or chemistry-transport models are central and fundamental requirements for determining future mitigation strategies. For several decades, networks of measurements have been deployed from the surface, mostly over the continental areas of the northern hemisphere. In the 1980s, satellites began providing a global view for few variables, mostly integrative data (i.e.,columns), but they lack the vertical sensitivity which is required for certain regions of the atmosphere.

Thirty years ago, a collaboration was initiated by the scientific research community, aircraft manufacturers and commercial airlines to respond to concerns about the impact of aviation on the climate and particularly on ozone chemistry and on the emissions of water vapour at cruise altitude from a continually growing number of aircraft. The project 'MOZAIC' (measurement of ozone and water vapor by Airbus in-service aircraft) was set-up to measure water vapour and ozone using commercial aircraft as a platform. Its aims were to build a database of measurements for studying chemical and physical processes in the atmosphere rather than to focus solely on the direct effects of aircraft emissions on the budget of ozone which was a key issue in the years following the Montreal Protocol.

MOZAIC has evolved into 'IAGOS' (In-service Aircraft for a Global Observing System) which is a European Research Infrastructure using commercial aircraft to carry scientific instruments for automatic and routine measurements of atmospheric composition including reactive gases (ozone, carbon monoxide, nitrogen oxides, volatile organic compounds), greenhouse gases (water vapour, carbon dioxide, methane), aerosols, and cloud particles along with essential meteorological parameters. The core IAGOS instrumentation consists of two packages, Package1(P1) and Package 2(P2).

- P1 is installed on every equipped aircraft and is the basic instrument containing ozone and carbon monoxide analyzers and the data acquisition system for the IAGOS Humidity Sensor (ICH) and the Backscatter Cloud Probe (BCP). It also records the position of the aircraft and provides data transmission for all IAGOS instruments via the mobile phone network. P1 consists of the instrument unit and the pump box, which contains membrane pumps that compress the sample air from ambient pressure to cabin pressure. The ambient air is sampled via a pitot tube on the IAGOS inlet plate (Figure 1).

FIGURE 1: The inlet plate used on IAGOS-CORE aircraft.

- P2 is available as five different options: nitrogen oxides (P2a and P2b), aerosols (P2c), greenhouse gases (P2d), and the so-called "air quality package" (or P2e) for NO_2 aerosol extinction. Before and after each deployment period (3–6 months), the instruments are shipped to the different European laboratories for detailed quality assurance. Details of operating procedures, data analysis, and quality assurance are described in the Standard Operating procedures (SOP) available from the website[1].

The IAGOS system is currently certified for A340 and A330 aircraft, with the A350 planned in the near future. The measurements are taken throughout the flight, providing data along flight routes at cruise altitude and as quasi-vertical profiles during landing at take-off at worldwide airports (Figure 2). Through cooperation with airline partners, IAGOS is able to build-up a good geographical coverage of data for the benefits of the scientific community and for the operational services in charge of air quality and climate change issues. Currently 10 aircraft are equipped, contributing about 500 flights per aircraft per year.

Commercial long-range aircraft such as A330s spend on average 80% of their time at cruise altitude in a region of the atmosphere known as the upper-troposphere and lower stratosphere (UTLS). Small changes to atmospheric composition from the gases and particles emitted there, have relatively larger impacts on the radiative forcing of climate.

Through various chemical interactions, the emissions of NO_X, CO_2 and H_2O perturb the concentrations of the radiatively active gases CO_2, O_3, and methane and they may also trigger the formation of contrails and contrail induced cirrus. Other gases and particles emitted by aircraft such as SO_X, hydrocarbons and soot interact through microphysical processes leading to increased cloudiness or modify the composition of aerosols with further effects on climate. Lee et al. (2021), estimated that aviation represented about 3.5% of the net anthropogenic effective radiative forcing in 2018 with non-CO_2 emissions comprising about two-thirds. However, of the radiative forcing components due to aviation, contrails and aircraft induced cloudiness are one of the more uncertain (Lee et al., 2021).

Key to the study of contrails, predicting where they will form and avoiding their formation, is an accurate knowledge of upper tropospheric humidity and regions of ice supersaturation (Ice-Supersaturated Regions - ISSR), and an accurate prediction of these regions in meteorological models. The IAGOS Capacitive Hygrometer (ICH) is one of 3 types of instruments used for aircraft-based humidity measurements. It consists of a capacitive sensor and a platinum resistance sensor to measure the temperature. The IAGOS humidity sensor ICH is the only sensor able to provide these measurements with sufficient accuracy in the upper troposphere to detect ISSRs reliably. IAGOS is working with partners within the project CICONIA, a SESAR project funded by the EU which aims to offer strategies for contrail avoidance working through the chain from the prediction of the ISSR to the proposal of the new routing with air traffic management and finally the execution of the flight by the pilots. The avoidance strategy is extremely sensitive to the prediction of ISSRs as an unnecessary avoidance manoeuvre results in more emissions of CO_2.

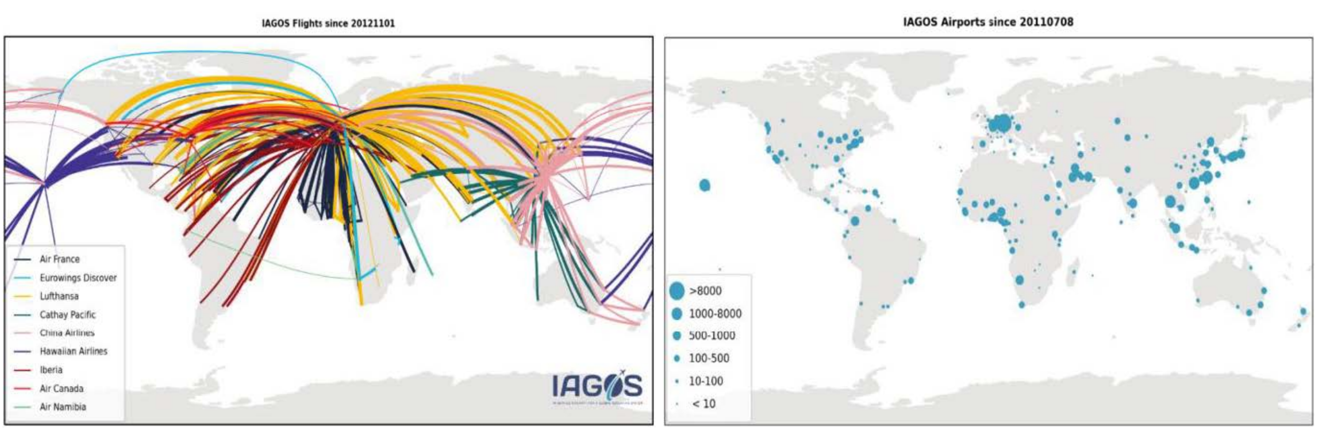

FIGURE 2: (Left) Current flight coverage by the airlines carrying IAGOS equipment. (right) Distribution of airports visited by IAGOS aircraft.

1 www.iagos.org

The continuity of data over the long-term is an important feature of IAGOS. Having been running for 30 years, the time-series is now recognised as a 'climate' dataset by the World Meteorological Organisation. Time-series of ozone in the free troposphere from IAGOS are essential for analysis of trends used in the Tropospheric Ozone Assessment Report (TOAR) which in turn show the impact of mitigation policies. 30 years of water vapour measurements give us the longest time series of upper tropospheric water vapour and ISSRs which serves as a reference dataset with which to compare satellites and models and allows us to understand the vertical distribution and seasonality (Gierens et al. 1999, Petzold et al. 2020). The 30-year time-series is important for detecting any trends or changes in the abundance of upper tropospheric water vapour, which is the most important greenhouse gas, and has a positive feedback role in climate change.

Data collected by IAGOS aircraft are freely available and accessible via the data centre after registration. Also provided are additional products that aid the scientific interpretation of the data. These range from important parameters such as the tropopause height, which is essential to place the aircraft in the upper troposphere or in the lower stratosphere where atmospheric characteristics are very different or information on the source of the pollution through an application that gives a source-receptor link for the observed anomalies in CO. These so-called added-value products enable more thorough analysis and diagnostics that can be used for evaluating the behavior of atmospheric models. Humidity data from the ICH is available in near-real-time (NRT - defined as within 3 days) to the Copernicus Atmosphere Monitoring Service and to partners in the CICONIA project for the purposes of validating global and regional forecasts of humidity and ISSRs.

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ICAO's work on NO_x emissions regulation

By Theo Rindlisbacher and Urs Ziegler (Federal Office of Civil Aviation (FOCA), Switzerland)

ICAO's work on NO_x regulation

The climate impact of aviation today generally stems from emissions of carbon dioxide (CO_2) and cloud formations like contrail-cirrus, while air quality impacts are mainly due to emissions of oxides of nitrogen (NO_x) and particulate matter (PM). NO_x regulations have been in place for decades and NO_x emissions continue to be a major engine design parameter. In summary, NO_x environmental impacts are as follows:

NO_x and climate: The net present-day radiative effect of aircraft NO_x emissions is estimated to be positive (i.e. a warming effect). However, this estimate does not account for the (highly uncertain) cooling from NO_x attributable to aerosols. Because of these indirect forcings and potential changes in background concentrations of ozone precursors, future net NO_x radiative forcing could vary from positive to negative. Since NO_x radiative forcing is currently estimated to be positive and the effects are relatively short-lived, stabilization of aircraft NO_x emissions may be a reasonable target with respect to climate effects.

NO_x and local air quality: Aviation emissions contribute to the degradation of air quality via increases in ground level concentrations of harmful pollutants like NO_2. Recent research has strengthened the understanding that aviation air quality impacts include both local-to-regional scale impacts due to near-surface (near airport) emissions as well as global scale impacts resulting from emissions during cruise. Some modelling studies[1] find that global aviation air quality impacts are principally due to cruise-altitude emissions of NO_x. Aircraft emissions during the LTO phase also have been shown to cause health impacts due to exposure to ultrafine particles (UFP), PM2.5, O_3 and NO_2 concentrations. In many countries, local air quality regulatory limits for NO_2 are therefore in force and tend to become more stringent over time. From a local air quality perspective, increasing aviation NO_x emissions around airports are of concern.

While more modern engines tend to emit less pollutants thanks to reduced fuel consumption and improved combustion technology, this is not generally the case for NO_x. Already during the CAEP/12 cycle, the CAEP Impacts and Science Group (ISG) and the Emissions Technical Working Group (WG3) identified increasing NO_x emissions for modern aircraft-engine combinations replacing older aircraft-engine combinations of similar capacity. Some inventories showed an increase in absolute NO_x emissions from aviation, which was even higher than the increase of absolute CO_2-emissions caused by growth of aviation. How was this possible?

The existing Landing and Take-off cycle (LTO) NO_x metric in ICAO environmental standards for engine certification has been originally designed to incorporate relevant physical parameters related to NO_x emissions, namely the fuel flow and a correlation to the overall pressure ratio (OPR) of the engine. The higher the OPR of an engine, the higher the thermodynamic efficiency, but the higher the combustion temperatures and the harder it gets to control NO_x. This is because, at these conditions, Nitrogen and Oxygen (the primary constituents of air) start to react with each other. In order to account for the physical dependence on OPR, NO_x regulatory limits have a positive slope as a function of OPR. The higher the OPR of an engine, the higher is the regulatory limit. As higher OPR is linked to higher combustion efficiency, there is an inherent trade-off between fuel burn and NO_x emissions. Therefore, the

1 Barrett et al. 2010; Eastham et al. 2024; Eastham and Barrett 2016; Lee et al. 2013; Quadros, Snellen, and Dedoussi 2020, Grobler et al. 2019 (details in References)

development of more fuel-efficient engines was leading to higher OPR, which in turn tended to produce higher NO_x emissions. There are exceptions, as engine manufacturers have been working very hard to optimize or even develop dedicated complex combustion systems to better control NO_x. In terms of changes in fleet composition, also a tendency towards using larger aircraft has been observed. With the exception of the most modern combustion technology, larger engines also tend to produce higher NO_x per unit of thrust.

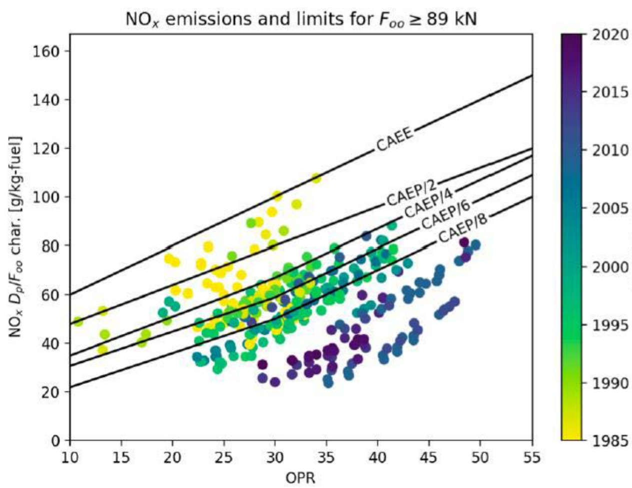

FIGURE 1: LTO NO_x metric values (mass of NO_x emitted during the LTO cycle over the engine rated thrust (Dp/Foo[2]), colored dots) in function of engine OPR. The black lines correspond to the regulatory limit lines for engines with rated thrust > 89 kN, with the original highest limit "CAEE" and the latest limit "CAEP/8" agreed in 2010. The color scale indicates the year of the emission certification test of the engines. (Source: ICAO Engine Emissions Databank[3])

The ICAO LTO NO_x Standard has not been updated since 2010 (CAEP/8). Taking the history and advancements in certified combustion system designs for latest generation engines into account, it became obvious that the standard needs an update. During the last three years, a number of alternative metrics and stringency approaches have been considered by WG3 with a view to correct for the observed trend of increasing NO_x emissions. For future work on NO_x regulation, it was determined in the CAEP/13 cycle that the current NO_x metric system (LTO NO_x normalized by rated thrust vs OPR) still has the best possibility for controlling NO_x and be backward compatible with existing regulations. WG3 found that the regulatory problem identified can be addressed by keeping the metric but updating the design and shape of the regulatory limit line. In February 2025, the CAEP/13 meeting recommended to start a NO_x LTO Stringency Standard Setting Process, pending Council approval, following three possible approaches or a combination of them:

a) Shift the CAEP/8 line (right or down) to achieve NO_x neutral improvement,
b) Change (decrease) the slope of the LTO NO_x per rated thrust (Dp/Foo) vs OPR line, and
c) Place a "cap" on the maximum Dp/Foo value (either a flat "cap" or a "cap curve" asymptoting to a maximum value)

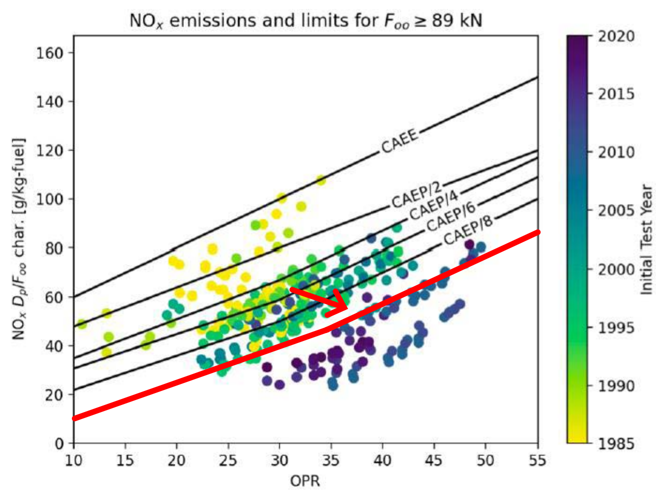

FIGURE 2: Illustration of the option for shifting the CAEP/8 line to the right, based on expected future increase in engine OPR, with a view to stabilize NO_x emissions in balance with high fuel efficiency.

Subject to Council approval, CAEP will undertake the analysis and develop proposals for an updated, more stringent LTO NO_x regulation. An updated standard will have to follow the CAEP principles, balancing environmental benefit with technological feasibility, economic viability, and the interdependency between environmental factors. Completion of an updated LTO NO_x stringency in ICAO Annex 16, Volume II is targeted for CAEP/14 (2028).

2 The mass, in grams (Dp), of any pollutant emitted during the reference landing and take-off (LTO) cycle, divided by the rated output (Foo) of the engine.

3 ICAO Aircraft Engine Emissions Databank: https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

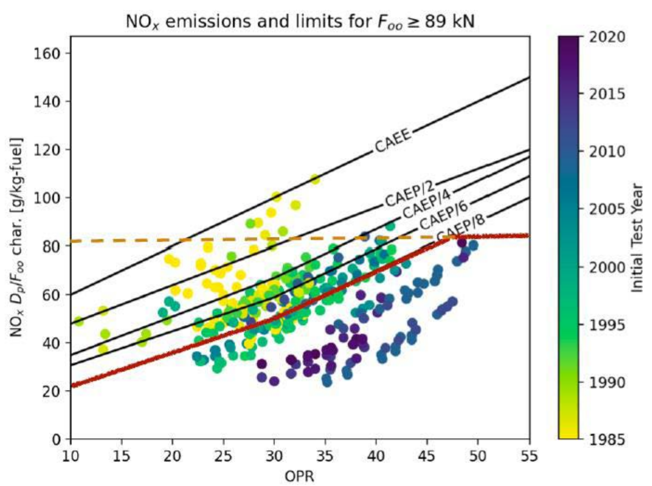

FIGURE 3: Example of putting a cap (red horizontal line) for a maximum NO_X Dp/Foo. The colored points correspond to certified values in the ICAO engine emissions database, with the color code indicating the year of the emission certification test.

Due to climate issues, cruise NO_X increased in importance. The traditional LTO NO_X metric has been designed with a view to control airport-related NO_X emissions and consequently to satisfy local air quality standards. This includes the choice of four reporting points, which are linked to taxi operations (7% Foo) on ground, full rated thrust take-off roll (100% Foo), a climb (85% Foo) and an approach mode (30% Foo), see Figure 4. With increasing scientific knowledge and awareness of impacts from cruise NO_X emissions, the question of how well the LTO regulation is able to control cruise emissions was coming more and more into focus. The cruise NO_X performance of an engine cannot be measured at ground conditions. In terms of combustor inlet temperature in cruise, a ground level thrust setting with the same inlet temperature will usually be somewhere in the middle between 30 and 85% thrust. But since engine combustion pressures, ambient temperature and the lack of forward movement of the engine in the static test do not correspond to cruise conditions, a ground level measurement does not relate to the emissions during cruise in a straightforward way and conversion calculations to altitude conditions are necessary.

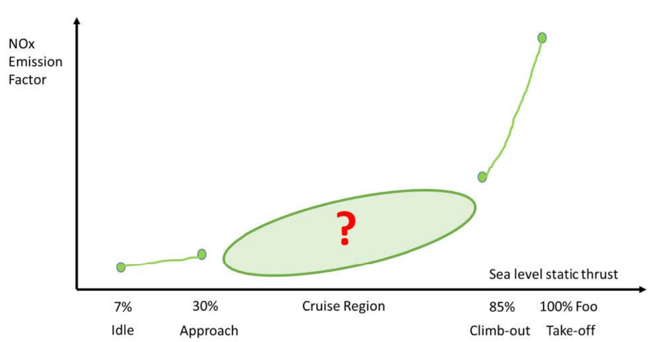

FIGURE 4: Illustration of certification NO_X emission factors measured at 7, 30, 85 and 100% sea level static thrust. The green circle depicts an area of cruise NO_X emission factors, which are currently interpolated between 30 and 85% points and corrected for altitude cruise flight conditions for NO_X emission inventories.

Historically, it has been accepted that controlling LTO NO_X would control cruise/climb NO_X to a high degree. The main reason for this is the heavy weighting of the 85% thrust point in the LTO metric. If this point is at a relatively low value, the slope of the interpolation between 30 and 85% will be lower. However, it was unclear whether interpolation assumptions would be good enough for most modern and future engine designs. In the CAEP/13 cycle, analysis was done considering new technology combustors (i.e. advanced rich burn and lean burn as currently certified), the several stages of the cruise phase (fuel flow and power varies between early, middle, and late cruise) as well as considering all phases of full flight except leaving out the LTO components. The analysis showed that the cruise/climb emissions can depend differently on the engine power points compared to the LTO emissions. As an example, two most modern engines could have similar values in the LTO NO_X metric, while they might have very different cruise NO_X performance.

In February 2025, the CAEP/13 meeting therefore decided, pending Council approval, that WG3 should continue to develop an additional engine-level cruise NO_X metric to complement the LTO NO_X metric and assess its ability to better control cruise NO_X emissions.

As mentioned above, the LTO metric lacks reporting of emission factors between 30 and 85% sea-level static thrust (Foo). However, this range is relevant for cruise NO_X estimations, as can be seen in Figure 4. The CAEP/13 meeting therefore agreed to investigate (pending Council approval) the feasibility and added value of a potential reporting point for EI NO_X at 57.5% Foo (the mid-point between 30 and 85%). The goal is to better characterize cruise emissions in the future while recognizing that the ground-based 57.5% Foo point does not correspond directly to cruise emissions. WG3 will collect and analyse emission indices NO_x data of modern gas turbine engines for combustor inlet temperature ranges relevant for cruise flight conditions. Depending on the outcome of such analysis, it will propose amendments to implement a respective reporting requirement into Annex 16, Volume II. This activity is strongly related to actions on aviation Non-CO_2 emissions and on nvPM reporting.

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Global cooperation to advance the understanding of Non-CO_2 effects in aviation

The Aviation Non-CO_2 Experts Network (ANCEN) experience

By Stephen Arrowsmith (EASA)

Introduction

Global environmental challenges require global cooperation to achieve agreed future goals. This cooperation is critical when the optimum measures to address these challenges are not completely clear. One such current issue in the aviation sector is the need to address its total climate impact considering both CO_2 and non-CO_2 emissions.

Main Challenges

In 2023, the WMO State of the Global Climate Report[1] and the European State of the Climate Report[2] both highlighted that records were once again broken for greenhouse gas levels, surface temperatures, ocean heat and acidification, sea level rise, Antarctic Sea ice cover loss and glacier retreat. A recent acceleration in the increase of atmospheric CO_2 concentrations in 2024 was also reported resulting in the highest ever level over the last 800 000 years of 427 parts per million. 2023 was confirmed as the warmest year on record with the global average near-surface temperature at 1.45°C above the pre-industrial baseline, culminating in the warmest ten-year period on record. Extreme weather events have impacted millions of lives and inflicted billions of euros in economic losses.

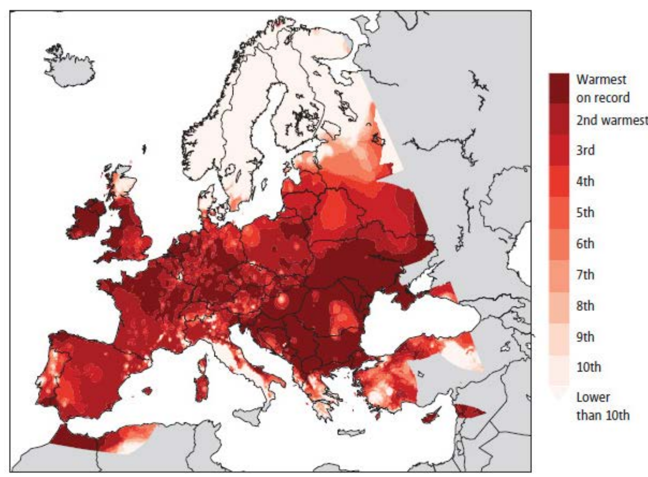


FIGURE 1: Ranking of annual average surface air temperature in 2023 (Copernicus Climate Change Service).

As with all other economic sectors, aviation is therefore under pressure to reduce its emissions in order to contribute to international climate objectives, including the Paris Agreement and ICAO's goal for international aviation of net-zero carbon emissions by 2050.

The climate impact from aviation emissions is a combination of both its CO_2 and non-CO_2 emissions that include Nitrogen Oxides (NO_X), Particulate Matter (soot), Sulphur Oxides (SO_X) and water vapour, as well as the subsequent effects

1 https://library.wmo.int/records/item/68835-state-of-the-global-climate-2023
2 https://climate.copernicus.eu/esotc/2023

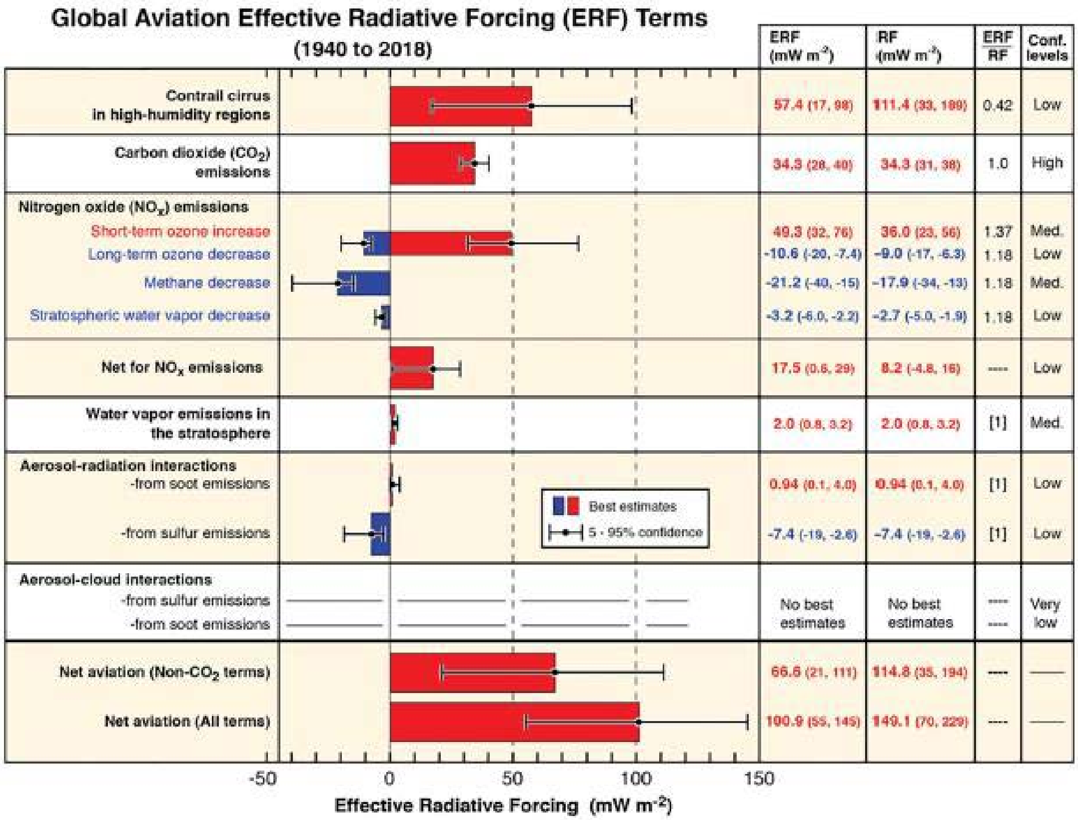


FIGURE 2: Latest best estimates for climate forcing terms of historic global aviation emissions from 1940 to 2018 (Lee et al., 2021).[3]

from the formation of persistent contrail-cirrus clouds and aerosol-cloud interactions. To inform a robust decision-making process and ensure that mitigation measure has the intended effect, the gaps in our understanding of the science of and impacts from non-CO_2 emissions need to be addressed.

Key gaps include accurate modelling of non-CO_2 emissions from different fuels and engine technology as well as the subsequent direct and indirect climate effects. These challenges are further compounded by potential trade-offs between CO_2 and non-CO_2 emissions, which can vary depending on how the CO_2 equivalent emissions are calculated and the associated time horizon.

ANCEN

In order to bring greater cohesion to the various European research initiatives in this area, the European Commission and EASA established the "Aviation Non-CO_2 Experts Network (ANCEN[4])" in 2024. The primary goal of the Network, which compromises of approximately 50 experts, is to facilitate a holistic approach to addressing non-CO_2 emissions through coordination across all relevant stakeholders (e.g. airlines, manufacturers, air navigation service providers, fuel producers, met services, intergovernmental organisations, research programmes, academia, policymakers and non-governmental organisations). The Network aims to reach a common

ANCEN
AVIATION NON-CO_2 EXPERT NETWORK

This project is funded from the European Union's Horizon Europe Programme

3 https://pubmed.ncbi.nlm.nih.gov/32895604/
4 https://www.easa.europa.eu/en/research-projects/ancen-nonco2

FIGURE 3: ANCEN Members Plenary Meeting, June 2024.

understanding on this complex topic that can act as a basis for objective, timely and credible technical advice. This would feed into discussions on the development, agreement and implementation of effective policy and operational actions within Europe and internationally, to mitigate the overall climate impacts caused by aviation CO_2 and non-CO_2 emissions.

Mitigation Measures

It is important to recognise that there are existing mitigation measures to reduce aircraft non-CO_2 emissions, such as the ICAO Annex 16 Volume II aircraft engine emissions certification standards, and the uptake of cleaner energies (e.g. Sustainable Aviation Fuels).

Since the EASA report[5] that was published in 2020, which provided an updated analysis of the non-CO_2 climate impacts of aviation and potential policy measures, there has been a significant increase in European research projects[6] looking to enhance our understanding on this issue and potential additional mitigation measures.

Key areas of research where there is a high level of uncertainty include methodologies to estimate aircraft emissions inventories with different fuels and the climate impact of induced changes in cloudiness from changes in operational initiatives. There is also a separate EU project to explore the feasibility of optimising fuel composition in order to reduce the environmental and climate impacts from non-CO_2 emissions without negatively impacting safety (e.g. lower aromatics, sulphur).

Work Programme

The current ANCEN Work Programme includes the following tasks:

1. Establish key common **terminology** to support discussions and assessment, drawing on Intergovernmental Panel on Climate Change (IPCC) language.

2. Develop a **framework to communicate the level of uncertainty** as a confidence level and likelihood for risk assessment and monitor how this evolves over time, including an example of how to implement the framework, drawing on IPCC approach.

3. Identify elements of a process on data / measurements / model development that are needed to ultimately support **robust decision-making** and implementation / monitoring / review of measures.

5 https://www.easa.europa.eu/en/document-library/research-reports/report-commission-european-parliament-and-council
6 https://www.easa.europa.eu/downloads/140090/en

4. Perform a research **gap and prioritisation analysis**, and maintain over time, to optimize future aviation related research in critical areas and avoid duplication.

5. Summarise current **best practices** on modelling aircraft emissions inventories.

6. Compile an overview of **historic and on-going work** linked to the effects of aviation non-CO_2 emissions on climate change.

7. Consider how to clearly **communicate** on climate impacts of short-term and long-term climate forcer emissions in different future scenarios to place non-CO_2 impacts in context with those from CO_2. Develop Fact Sheets / Briefing Notes / FAQs on topics linked to non-CO_2 emissions climate impacts

8. Perform outreach to relevant **international partners** working on the topic of climate impacts from aviation non-CO_2 emissions.

9. Provide **technical support** to policymakers, as requested, and input into the European Aviation Environmental Report[7].

There is a growing urgency for the aviation sector to turn sustainability goals into action, and thereby secure the future of the industry. This can only be done through a more ambitious, comprehensive and holistic approach involving all stakeholders. There is no single solution and the entire basket of measures (e.g. new technology, efficient operations, sustainable aviation fuels, market-based measures) needs to be applied.

Photo credit : Airbus SAS

7 https://www.easa.europa.eu/en/domains/environment/eaer

Encouraging diversity in the aviation sector

By Maria Vittoria Corazza (Sapienza University of Rome) and Jane Hupe (ICAO)

General Questions

1. **Can you share your journey in aviation and what initially inspired you to pursue a career in this field?**

Maria Vittoria Corazza: My journey is relatively short as I started teaching Air Transport at Sapienza University of Rome only in 2017. To be honest, this was not my first choice as a researcher in transportation studies, but I was soon attracted by the complexity of aviation, a multifaceted world, encompassing physics and mathematics; technological, regulatory, economic, and geopolitical dimensions, operational dynamics and, last but not least, environmental challenges.

Jane Hupe: My journey into aviation was not linear, but it has been deeply fulfilling. I started my career rooted in a passion for environmental protection. Early on, I realized that if we are to make meaningful progress on global sustainability, we must engage with sectors that are both essential and environmentally intensive—aviation being one of them. During my university years, I became increasingly aware of how the aviation sector was evolving—both technologically and geopolitically—and how critical it was for environmental voices to be part of that transformation. I was drawn to the opportunity to bring sustainability into a field traditionally driven by speed, efficiency, and connectivity. Over the years, I have been privileged to work at ICAO, where I could help shape international standards and support States in developing policies that address aviation's environmental impacts. This global perspective—working across cultures, regions, and technical disciplines—has kept me inspired and grounded in purpose.

2. **From your perspective, how can diversity—across gender, backgrounds, and experiences—shape the future of aviation, particularly in advancing environmental sustainability?**

Maria Vittoria Corazza: The fifth goal outlined in the United Nations' "Agenda for Sustainable Development by 2030" underscores the pivotal role of gender equality and the OECD (Organization for Economic Co-operation and Development) emphatically asserts that nations grappling with the segregation and discrimination of women struggle to fulfill sustainability criteria. **Focusing on aviation, diversity across gender plays a pivotal role in advancing aviation's environmental sustainability by fostering innovation, enhancing problem-solving, and driving systemic cultural shifts.** This also aligns with broader societal goals of fairness and inclusion.

Take as examples the ICAO's gender equality resolution (Resolution A41-26 refers) and EUROCAE's standards for sustainable aviation systems, both showing how women in leadership roles prioritize long-term environmental goals. Moreover, broadening talent pools helps address labor shortages in critical roles (e.g., pilots, engineers) while integrating underrepresented groups into green aviation projects. I think that visions like the ECAC's Diversity Network, advocating for policies that link social equity to sustainability goals, such as the EU Green Deal's climate targets, can really enhance environmental decision-making process, or that training programs that emphasize diversity and sustainability, such as ENAC's gender-focused curricula, prepare the next generation to lead green transitions.

Jane Hupe: Diversity is not just a value—it is a strategic imperative, especially in a sector like aviation that operates on a global scale and faces complex sustainability challenges. Different life experiences, cultural insights, and professional backgrounds bring unique lenses to problem-solving. In my work at ICAO, I have seen firsthand how inclusive teams produce more robust environmental policy—whether it is crafting ambitious climate goals or developing new frameworks for sustainable fuels and cleaner technologies. Diversity helps question entrenched assumptions and encourages more holistic thinking. This is particularly important in environmental matters, where solutions often require interdisciplinary and cross-cultural collaboration. Greater gender balance and broader representation in technical and decision-making roles can also strengthen aviation's alignment with the UN Sustainable Development Goals, particularly SDG 5 and SDG 13. A diverse aviation sector is better equipped to innovate, adapt, and lead in addressing the climate crisis.

3. **What challenges have you encountered in your career, and how have you navigated them?**

Maria Vittoria Corazza: A female academic in aviation or related study fields may face typical, systemic gender-based challenges rooted in cultural norms, institutional structures, and societal opportunities. Male-dominated environments often marginalize women's contributions, particularly in decision-making processes and career opportunities. For example, few women in senior academic positions result in sparse mentorship networks, underrepresentation in conferences, publications, and leadership roles perpetuates a cycle of exclusion, the work-life imbalance represented by rigid academic schedules can disproportionately affect women, particularly in fieldwork-heavy disciplines like aviation and more in general transportation studies. **The strategy is to build research's support network by collaborating with interdisciplinary teams to amplify visibility and share resources**, and, in my case, to highlight how gender intersects with sustainability in aviation. Examples like those by the International Aviation Women's Association (IAWA) to seek sponsors (not just mentors) and/or any initiative of public engagement (write op-eds, host podcasts and the likes), are additional, excellent strategies. More strategies belong to the institutional advocacy field, like policy reforms on parental leave extensions (e.g. on tenure-clock pauses) or remove unconscious bias in hiring and promotions.

Jane Hupe: Advocating for environmental change in aviation has not always been easy. For many years, sustainability was seen as a secondary concern—something that could be addressed once the core priorities of safety and efficiency were met. Navigating that mindset required persistence, diplomacy, and a clear vision. I often found myself in rooms where the environmental agenda needed stronger champions, and I learned to present data-driven arguments, build coalitions, and engage in constructive dialogue with States and industry. Another challenge has been ensuring that developing countries are not left behind in the transition to sustainable aviation. This meant emphasizing capacity-building and support mechanisms, which I have worked on extensively through ICAO's ACT initiatives. Ultimately, I believe that change is possible when you combine technical knowledge, strategic patience, and inclusive partnerships

Environment & Sustainability Focus

5. **In what ways do you see diversity driving innovation and progress in aviation's environmental sustainability efforts?**

Maria Vittoria Corazza: I think that by fostering inclusive cultures, leveraging diverse perspectives, and expanding talent pools, the industry can accelerate innovation to achieve net-zero goals while ensuring long-term viability.

Jane Hupe: Innovation thrives in environments where different perspectives are encouraged and respected. In the environmental field, this is particularly crucial. Solutions to climate-related challenges require us to think differently—to imagine new systems, technologies, and behavioral patterns. Diversity, whether gender-based, cultural, regional, or disciplinary, injects creativity into this process. At ICAO, I have seen how diverse expert groups—comprising engineers, scientists, policymakers, and academics from all over the world—have collaboratively advanced solutions like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and long-term aspirational goals. When we embrace different viewpoints, we are better equipped to innovate responsibly and inclusively.

6. **Are there any sustainability initiatives or projects in aviation that particularly inspire you or that you've been involved in?**

Maria Vittoria Corazza: If we consider the equation "**more gender parity=improved inclusion=increased**

sustainability" I think the first highly inspirational cases that come to my mind are the United Airlines' Aviate Academy to have least half of the pilot trainees women, the Jazz Airline's policy to support diversity and inclusion, leading to a multi-faith space at one of the company location, the IATA's 25by2025 initiative to increase female representation in senior roles by 25%. There are many more, of course, and they are never enough, but it tells a lot on the march that has started and that is not stopping. As an academician, I also see of the utmost importance all the initiatives supporting women in STEM disciplines and study programs and I am involved in a research proposal at my university on this very topic.

Jane Hupe: One initiative that has inspired me is the development of Sustainable Aviation Fuels (SAF). I have been fortunate enough to be involved in projects that explore the potential of SAF to significantly reduce aviation's carbon footprint. Additionally, I have found great inspiration in the work being done to integrate environmental goals into long-term planning within ICAO and by Member States. For instance, the collective commitment to achieve net-zero carbon emissions by 2050, supported by initiatives like the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF) programme, is a major step forward. These kinds of multilateral efforts, grounded in both technological innovation and international cooperation, give me hope for the future of sustainable aviation.

7. **What steps can the industry take to foster more inclusive leadership in environmental and technical fields?**

Maria Vittoria Corazza: I agree with Milena Bowman, at EUROCONTROL, when she says that sustainable aviation relies on three Ps – people, planet and profit. Thus, **having women in leading roles** managing staff, operations, environmental policies as consolidate positions in the aviation corporate culture is certainly a necessary step in this path.

Jane Hupe: Building inclusive leadership starts with creating pathways—educational, professional, and institutional—for underrepresented groups to enter and thrive in aviation. The industry can strengthen mentorship programs, invest in gender-responsive leadership training, and embed diversity goals in recruitment and promotion strategies. Technical fields in particular need to be demystified and made more accessible, especially for young women and professionals from regions with fewer opportunities. From an institutional point of view, decision-making bodies need to be intentional about whose voices are heard. Inclusion should not be an afterthought; it must be embedded in how we define excellence, how we reward performance, and how we lead teams. Creating inclusive cultures in environmental and technical areas can unlock both talent and trust.

Looking Ahead

8. **What advice would you give to young professionals interested in aviation and sustainability?**

Maria Vittoria Corazza: There can be many advices. The aviation industry needs not just brilliant engineers or passionate environmentalists, but both. So my first advice would be to **embrace both technology and environment with the same passion**: be a skilled aviation professional but also an innovator reshaping aviation's future through the environmentally conscious lens, from electric flight to sustainable fuel, greener airport operations, and circular supply chains. This introduces the second advice: **Seek interdisciplinary strength**. As emerging women leaders in aviation and sustainability, cultivating interdisciplinary expertise is essential; meaningful innovation often arises where technical proficiency intersects with policy insight, data literacy, environmental issues and systems thinking. So, do not just focus on engineering or environmental science in isolation, since the real breakthroughs happen where disciplines collide. To achieve this, study and read widely (everything, from academic journals, industry white papers, climate policy briefs, to tech blogs). But stay critical too, because often some voices are missing from the mainstream narrative.

Jane Hupe: I would encourage young professionals to embrace the duality of ambition and patience. The aviation sector is undergoing a profound transformation, but systemic change takes time. Be bold in your vision, but also patient in the process. Stay informed, stay connected, and never stop learning—especially across disciplines. Sustainability in aviation touches everything from engineering to economics to ethics, so interdisciplinary curiosity is your best ally. Also, seek out mentors and networks that challenge and support you. Finally, remember that your voice matters. The next generation of aviation professionals will define what kind of industry we become—greener, more equitable, and more resilient.

9. **How can organizations like ICAO create more opportunities for diverse voices in environmental policymaking and research?**

Maria Vittoria Corazza: First, **by creating more constant, inclusive research funding mechanisms**. This can be done by regularly launching targeted grants or fellowships for specific researchers (young professionals, and women in STEM, especially those directly affected by the lack of environmental policies) and areas (underrepresented regions, indigenous or marginalized communities, small island states to study the environmental impacts of aviation and propose localized solutions). This can be complemented by supporting interdisciplinary, community-engaged research that includes voices not typically present in technical discourse (e.g., climate justice advocates or youth climate groups).

This can also include **mentored policy fellowships for women, youth, and professionals from diverse backgrounds** to work within ICAO's environmental units. Indeed, mentorship is certainly one more avenue to explore: women who are pushing boundaries in sustainable aviation, climate tech, aerospace policy, or corporate culture can be part of structured mentorship programs that matches early-career women professionals with mid-career or senior women mentors in aviation and sustainability fields. This should be global and inclusive, with attention to gender balance, cultural context, and regional representation.

One more opportunity could be to expand the on-going ICAO initiatives (for example the Next Generation of Aviation Professionals, NGAP) to include specific tracks on environmental policy, climate resilience, and sustainable aviation technologies.

For what strictly concerns policymaking, one opportunity could be to liaise with regional aviation bodies, universities, and NGOs that work closely with underrepresented groups to co-create dedicated policy recommendations.

Jane Hupe: ICAO can continue to lead by example in broadening participation in its environmental work. This means not only expanding technical assistance and training for underrepresented States but also ensuring diverse representation in expert panels, working groups, and leadership positions. One powerful step is investing in youth engagement and capacity-building through initiatives like NGAP and ACT-SAF, but with a more targeted inclusion strategy—bringing in young women, professionals from small island developing States, and voices from indigenous and marginalized communities. There is also room to support academic partnerships and research fellowships that prioritize inclusive and regionally relevant environmental topics. Diversity in policymaking is not just about fairness—it improves the quality and reach of the outcomes we deliver.

10. **What is your vision for a more inclusive and sustainable aviation industry over the next decade?**

Maria Vittoria Corazza: Good question! Over the next ten years, the vision for a more inclusive and sustainable aviation industry centers on transformative change, **where environmental responsibility, social equity, and innovation are not just parallel goals, but deeply interconnected priorities**. Thus, aviation's future will be defined not just by how it flies, but by whom it serves. On the one hand, this means that, specifically for the industry, innovations in the field of net-zero emissions through sustainable fuels, electrification, and cleaner infrastructure, embedding sustainability into core business models, shall consolidate and become regular operations. On the other hand, the challenge will be in creating full inclusive environments, and this can happen only by advancing women and underrepresented professionals in technical and executive roles, fostering diverse innovation.

I would love to see in the next decade aircraft where women and diverse voices take the cockpit, so inclusion and equity take flight!

Jane Hupe: My vision for the next decade is one where aviation is not only environmentally sustainable but also a sector that provides equal opportunities for all. I see a future where the industry leads in green technologies and has a diverse workforce in leadership roles, shaping the future of aviation. By making sustainability and diversity central to the industry's goals, we can ensure that aviation continues to grow responsibly and inclusively.

Advancing Sustainable Aviation: developments in aviation sustainability from the academic perspective

By Suzanne Kearns (Waterloo Institute for Sustainable Aeronautics, University of Waterloo, Canada), David Zingg (Centre for Research in Sustainable Aviation, University of Toronto) and Tim Ryley (Griffith Aviation, School of Engineering & Built Environment)

Inspiring Tomorrow's Aviation Leaders: Strategies for Environmental Education

Introduction

The aviation sector faces tremendous sustainability challenges. While technological innovations — sustainable aviation fuels, zero-emission aircraft, and advanced operational efficiencies — are critical, these solutions alone are not sufficient. Achieving the Long-Term Global Aspirational Goal (LTAG) of net-zero by 2050 will also depend on a well-prepared, environmentally literate workforce that can design, implement, and lead the industry through its decarbonization.

Youth engagement is central to this transformation. ICAO's Next Generation of Aviation Professionals (NGAP) and Assistance, Capacity-Building, and Training for Sustainable Aviation Fuels (ACT-SAF) initiatives emphasize **the need to empower new talent with interdisciplinary skills and environmental awareness.** Academic institutions play a crucial role in equipping young professionals with the knowledge and tools to understand and address aviation's complex sustainability challenges.

The Waterloo Institute for Sustainable Aeronautics (WISA) at the University of Waterloo in Canada offers strategies on how universities can support these goals through education, research, and collaboration. This article outlines several strategies employed at WISA — ranging from accessible e-learning to student-led research that can be adapted and scaled by other institutions around the world to foster a future-ready aviation workforce.

Expanding Access Through Asynchronous e-Learning

For many working aviation professionals, environmental studies were not part of the aviation curriculum when they completed their education. Equipping the global aviation community with climate literacy begins with foundational education. Recognizing that professionals and students around the world often face geographic, financial, and time-related barriers to in-person learning, a suite of asynchronous e-learning courses focused on sustainable aviation were developed within WISA (Figure 1 refers).

The Aviation Sustainability course introduces learners to the core concepts of environmental responsibility within the aviation sector, aligning with the United Nations Sustainable Development Goals (SDGs). It frames sustainability as a comprehensive, industry-wide framework for responsible decision-making, relevant to all aviation careers, from airport operations to flight dispatch and aircraft maintenance.

FIGURE 1: WISA e-Learning Course Banners.

FIGURE 2: WISA e-Learning Course examples.

Learners examine practical strategies such as fuel-efficiency initiatives, waste reduction, and stakeholder engagement, while also reflecting on how these efforts support broader global objectives like climate action (SDG 13), responsible consumption and production (SDG 12), and industry innovation and infrastructure (SDG 9). Through this lens, the course allows participants to integrate sustainability into their professional practices.

The Aviation and Climate Change course provides sector-specific climate literacy, covering how aviation contributes to climate change through carbon dioxide, non-CO_2 effects such as contrails and nitrogen oxides, and what mitigation and adaptation strategies are available. The course also explores emerging technologies and market-based measures, offering a systems-level understanding of climate solutions (Figures 1 and 2 refer).

In 2025, UWaterloo and ICAO will launch a new co-developed program called Fundamentals of International Aviation. This initiative supports ICAO's capacity-building efforts by offering foundational knowledge in an accessible format for global learners, particularly in regions where aviation training infrastructure may be limited.

These courses use instructional design strategies that enhance engagement, such as short video segments, interactive assessments, and scenario-based learning. This structure ensures that learners consume the information and can apply it, cultivating the critical thinking needed to navigate complex environmental, economic, and operational trade-offs.

Asynchronous digital education can make sustainability training available at scale, removing traditional barriers and supporting ICAO's objective to upskill current and future aviation professionals worldwide.

Student-Driven Research in Electric Aviation

In addition to online learning, hands-on research opportunities provide students with direct experience tackling environmental challenges in aviation. WISA's electric aircraft research project allows student pilots to work as part of the research team to test and analyze the performance of the Pipistrel Velis Electro, an electric training aircraft (Figures 3 and 4 refer).

This initiative examines how electric aircraft can be integrated into pilot training programs while reducing emissions and operating costs. Since electric aircraft have no combustion emissions during operation and are significantly quieter than conventional piston aircraft, they offer promising environmental and community benefits, especially in training environments with frequent takeoffs and landings.

FIGURE 3: Pipistrel Velis Electro E-Plane.

FIGURE 4: Electric Plane Research Assistants Zach and Caitlin.

Over the past two years at WISA, student-pilots have worked alongside professors and graduate students to complete a series of flights in the electric aircraft, collecting operational data including battery performance, climb rates, and system health under various seasonal conditions. Students are trained in flight operations and data analysis, contributing to publications and informing regulatory conversations with Transport Canada.

One student remarked that uploading data after each flight was ‘one step closer to a more sustainable future in aviation’, highlighting the dual benefit of experiential education and real-world contributions. The project has demonstrated that electric aircraft can operate safely and reliably even in colder Canadian climates—an important data point for expanding electric flight globally.

Beyond the environmental impact, the integration of students as research collaborators builds technical capacity and fosters early-career engagement in sustainability-focused innovation. This model of involving students in applied, solution-oriented research can be adapted in other contexts, using available technologies to offer experiential learning opportunities that prepare youth for leadership roles in sustainable aviation.

Building Interdisciplinary Expertise in Graduate Education

Meeting global decarbonization goals requires the development of highly qualified, interdisciplinary talent capable of designing and implementing multifaceted solutions. WISA has prioritized graduate education to build this capacity, drawing on the University of Waterloo's strengths across science, engineering, environment, health, math, and the social sciences.

Graduate students affiliated with WISA are contributing to a range of sustainability initiatives, including:

- Sustainable aviation fuels (SAF) development, where chemistry and engineering students investigate feedstocks, lifecycle emissions, and fuel performance.
- Flight operations optimization, where data science and aerospace researchers collaborate to improve routing, reduce fuel burn, and integrate predictive analytics.
- AI training technologies, where psychology, health, and computer science researchers co-develop adaptive simulation and eye-tracking systems to enhance pilot training efficiency and safety.

This interdisciplinary model reflects the reality that no single field can address aviation's environmental challenges in isolation. By integrating diverse perspectives, students develop systems-thinking capabilities that align with ICAO's long-term sustainability priorities.

In many cases, these graduate students work on projects co-supervised by academic and industry partners, ensuring relevance and applicability. Their contributions feed directly into technological innovation, policy analysis, and capacity-building, whether through peer-reviewed research or industry-facing deliverables.

This emphasis on interdisciplinary talent development supports ICAO's NGAP vision and provides a replicable model for other academic institutions. Universities around the world can foster similar collaboration by creating cross-departmental research clusters, sustainability-focused student funding, and experiential learning partnerships with aviation stakeholders.

Linking Academia with Industry: The Collaborative Aeronautics Program

To further strengthen ties between education and industry, WISA launched the Collaborative Aeronautics Program (CAP), an interdisciplinary graduate training initiative that allows students from graduate programs across the university to pursue an aviation specialization alongside their primary degree.

Students in the CAP complete a shared set of aviation-focused courses and engage in team-based consulting projects with industry or government partners (Figure 5 refers). These projects are real-world design or policy challenges that range from prototyping decarbonization strategies to enhancing safety management systems or testing new training tools.

This model reflects a growing need for graduates who are not only technically proficient, but also able to work across disciplines, communicate with stakeholders, and translate academic research into actionable outcomes. For employers, it offers access to emerging talent and novel research insights; for students, it develops relevant experience and professional networks.

This approach also responds directly to ICAO's calls for academic–industry partnerships as a foundation for aviation innovation and sustainability. The CAP model demonstrates how universities can serve as both knowledge producers and implementation partners, by supporting industry needs while educating the next generation of aviation professionals.

The success of CAP has been driven by interdisciplinary collaboration across the University of Waterloo, illustrating that sustainable aviation is not the domain of engineers or climate scientists alone, but a collective responsibility requiring cross-sector cooperation.

FIGURE 5: Allison Lynch, CAP PhD Student.

Conclusion

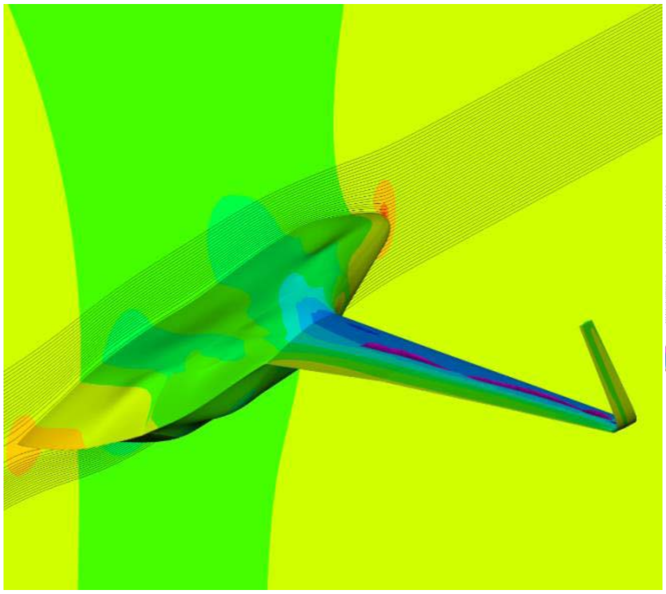
Aviation's pathway to sustainability is as much about people as it is about technology. The global community's ability to achieve net-zero aviation emissions will depend on how effectively it can mobilize, educate, and empower the next generation of aviation professionals. The strategies implemented at WISA provide one example of how academic institutions can respond to this call.

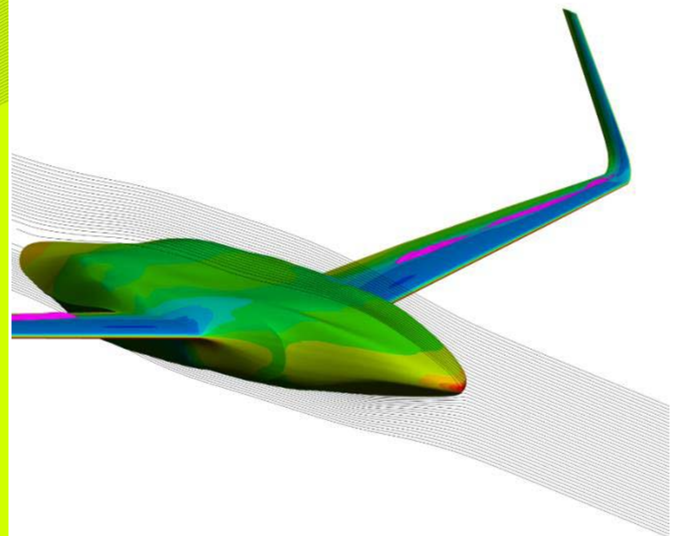
By combining accessible digital learning, hands-on research, interdisciplinary collaboration, and industry engagement, WISA's approach helps ensure that students not only understand the environmental challenges facing aviation—but are also prepared to lead in solving them. As ICAO continues to promote environmental education and innovation through its strategic initiatives, institutions around the world are encouraged to collaborate in order to foster youth leadership and build long-term capacity for sustainable aviation.

Research and Education in Sustainable Aviation at the University of Toronto Institute for Aerospace Studies (UTIAS)

The University of Toronto Institute for Aerospace Studies (UTIAS) is home to the Centre for Research in Sustainable Education (CRSA). The CRSA conducts research to reduce the environmental impact of aviation and contributes to the education of the next generation of students who will have the technical and leadership skills needed by the aeronautics sector as it faces the daunting challenge to improve the sustainability of aviation. A few updates on the CRSA's activities are provided in this article.

The popular course Sustainable Aviation will be offered again in 2025. This course offers a comprehensive treatment of sustainable aviation, taught by UTIAS faculty and guest lecturers from other universities, industry, and government. Topics range from engineering (technologies for improving energy efficiency of aircraft, alternative fuels, lifecycle analysis) to science (atmospheric chemistry) to regulatory aspects. Graduate students who take this course, as well as several others from a list of relevant courses, receive a





Certificate of Emphasis in Sustainable Aviation, which has proven to be popular with students and employers alike.

With respect to research, UTIAS faculty members collaborate extensively with Canadian industry on projects related to sustainable aviation. Extensive research to reduce noise from high-lift devices and landing gear is ongoing in collaboration with Bombardier. A major project with Pratt & Whitney Canada concentrates on contrails, an important contributor to aviation's climate change impact. UTIAS is also contributing to Bombardier's next generation of aircraft through its research on blended wing-body configuration and natural laminar flow.

The CRSA hosts the highly regarded UTIAS International Workshop on Aviation and Climate Change every two years. This invitation-only event brings together many of the world's leading experts on technological and scientific aspects related to reducing aviation's impact on climate change from academia, industry, and government. This provides leading researchers with an opportunity to exchange ideas, establish research priorities, and identify opportunities for collaboration. Moreover, UTIAS students are provided with a comprehensive overview of current challenges and opportunities related to technological aspects of aviation and climate change.

Overall, the workshops, graduate courses, and research related to sustainable aviation at UTIAS provide the students with the expertise, skills, and knowledge needed for future careers in the aeronautical sector. Graduates from UTIAS are well-prepared to contribute to the development the next generation of aircraft, engines, and fuels that will enable aviation to become sustainable.

Experiences from Griffith Aviation, School of Engineering & Built Environment

Griffith University has been providing qualifications to the aviation industry for over 25 years and is known worldwide for its innovative and student focused teaching. The aviation discipline, Griffith Aviation, based within the School of Engineering & Built Environment, has over 500 students across undergraduate and graduate programs. It is one of the largest aviation units in an Australian university. The programs cover flight-training and aviation management, as well as double degree options with either engineering or information technology. Study can either be at the Nathan campus in South Brisbane or fully online.

With aviation sustainability being a global challenge, there is a need for universities to lead internationally on delivering the skills and expertise in this area. While aviation remains economically and socially vital, there are pressing concerns about its environmental impacts. Griffith Aviation is fully aware of the environmental implications of aviation and is planning accordingly in our teaching and program development. We currently have sustainable aviation, and associated topics such as the relationship between aviation and climate change, as well as sustainable aviation fuels, in courses within the aviation management program. There is an optional elective to aviation students on an introduction to environmental sustainability, delivered by the university School of Environment & Science.

In the second Trimester , beginning in mid-July of 2025, there will be a new dedicated third-year Aviation and the Environment undergraduate university course. It will be a core course for Bachelor of Aviation Management students and optional for other students across the aviation discipline, School of Engineering & Built Environment and the wider university. The Aviation and the Environment course explores the highly-specific environmental issues associated with the aviation industry. It will introduce students to environmental principles, such as Sustainable Development Goals (SDGs), climate change concepts and sustainable aviation fuels, and applies these concepts to the aviation industry. The material could be further developed as a short course for industry professionals. The aviation industry certainly needs upskilling in environmental sustainability.

Griffith University has been holding for now five years the annual Aviation Reimagined seminar series featuring industry leaders, policymakers and researchers sharing their insights about a transition to a low-carbon and climate ready future for the aviation sector. Over 500 individuals registered for Aviation Reimagined in October 2024 (see Aviation Reimagined 2024)[1] which covered three sessions:

- Decarbonizing aviation context – the economic and regulation issues;
- Managing future environmental impacts – in the air and on the ground; and
- Social licence to fly – maximising the benefits of a low-carbon transition.

There is a need for universities to respond responsibly in the matter of environmental sustainability for aviation, particularly when many of them, such as Griffith University, have sustainability as a core value. In 2022, Griffith University has agreed to reduce university aviation emissions by 25% in time for 2030. There was an associated implementation plan to work through the implications and practicalities. Much of the focus was on reducing staff air travel, but there were other elements incorporated in terms of underpinning research, engagement with stakeholders, and innovations in data and processes.

Our aviation industry partners are currently engaging in environmental issues and solutions. There is some turbulence though, with some in the industry questioning the 2050 aviation net zero commitment, whilst others advocate for more urgent action with increasing climate change concerns. **There is certainly plenty for the university sector to review, research and respond to in aviation sustainability now and in the coming years.**

1 https://www.griffith.edu.au/research/business/institute-tourism/our-research/aviation-reimagined-2024

CHAPTER TWO

Climate Change Mitigation – Overview

Advancing Global Aviation Climate Mitigation: Setting the Scene for LTAG Implementation

By ICAO Secretariat

The ICAO CAEP LTAG Report: foundation for Net-Zero CO_2 emissions scenarios

The ICAO Committee on Aviation Environmental Protection (CAEP) through technical analysis and scenario modelling, over the course of three years and with the support of more than 300 experts, prepared the CAEP Long-Term Aspirational Goal (LTAG) Feasibility Study Report, published in 2022. This report served as the scientific and analytical foundation for the Assembly's adoption of the LTAG which aims for net-zero carbon emissions from international aviation by 2050. It evaluates potential climate mitigation pathways, drawing on projections for traffic demand, energy use, and emissions trajectories.

The report outlines the critical role of SAF and other cleaner energy sources, projected to deliver the majority of mitigation needed to meet the LTAG. It also assesses the contribution of aircraft technology improvements and operational efficiencies, including advancements in air traffic management and airport procedures.

From LTAG adoption to ICAO Global Framework

Since 2022, ICAO and its Member States have advanced critical work on mitigating the effect that international aviation has on climate change. These efforts are focused on achieving the LTAG, adopted by the 41st ICAO Assembly. This goal anchors ICAO's climate mitigation framework and sets the direction for coordinated global action.

To support the LTAG implementation, ICAO has mobilized a growing suite of tools, guidance, and collaborative platforms aimed at tracking the latest progress and innovations on climate mitigation, enabling States and industry to effectively contribute to aviation decarbonization, and enhancing transparency on the progress.

As part of its efforts to achieve the LTAG and drive climate change mitigation, ICAO has placed particular emphasis on enabling the global transition to cleaner aviation energies sources, such as Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other cleaner energy sources such as hydrogen. Recognizing that these cleaner energy sources are essential to achieving net-zero carbon emissions by 2050, ICAO and its Member States have agreed to a Global Framework to achieve, in support of the achievement of the LTAG, a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030, compared to zero cleaner energy use. This Global Framework has four building blocks—policy and planning, regulatory and implementation, financing, and innovation and adaptation—to support the global transition to cleaner aviation energy.

To showcase and support these efforts, ICAO published a Special Environment Report[1] in 2023 focused on the international aviation cleaner energy transition. This Report provides an essential historical perspective on ICAO's work related to SAF, tracing its evolution from initial discussions in the 2000s through to the Third ICAO Conference on Aviation Alternative Fuels (CAAF/3) held in 2023, which culminated in the adoption of the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies. It also outlines the institutional milestones, technical advancements, and policy consensus-building that have enabled SAF and other cleaner energy sources to take center stage in ICAO's mitigation strategy.

These developments are integral to the implementation of LTAG and are explored in greater detail throughout this Chapter.

In June 2024, the ICAO Council approved the ICAO Roadmap for the implementation of the ICAO Global Framework, including the planned actions, roles and responsibilities, timeframe, required resources, and its relationship with LTAG implementation. The Roadmap is a "living document", regularly updated to reflect progress and elaborate on further actions, and is now a recurring item in Council sessions. Its implementation advances through four interdependent building blocks mentioned above, including progress on ICAO State Action Plans, the ACT-SAF Programme, and the operationalization of ICAO Finvest Hub.

An Inclusive Process towards mitigating aviation's climate impact

From the outset, ICAO has anchored its LTAG process in multilateral engagement. The LTAG Consultative Process includes technical working groups, regional dialogues, and global Stocktaking events that bring together governments, industry, and civil society. These platforms promote collaboration, share experiences, and identify emerging challenges and opportunities.

The reintroduction of in-person LTAG Stocktaking events in 2023, followed by the largest edition of the event held in 2024, has reinforced transparency and accountability in LTAG implementation. These events showcase real-world actions—from SAF production projects to new aircraft configurations, financing and energy-efficient airport systems. They also provide a space to align global and regional mitigation efforts and ensure coherence with broader sustainability frameworks.

Tracking progress towards the LTAG: Data Collection and Information Sharing

Achieving the LTAG requires robust systems to track progress and guide future planning. The LTAG Monitoring and Reporting task group (LMR-TG) in CAEP has developed a methodology to track the actual performance of the sector (traffic, CO_2 emissions, alternative fuels used) and compare it against previously developed trends (backward-looking assessment). Similarly, the LMR-TG will produce new forward-looking assessments of how the sector may evolve from now until 2050, in the context of the present situation. In response to the request from Assembly Resolution A41-21, the group will also evaluate the past and future costs of decarbonization for international aviation, and the subsequent impact on the development of the sector, particularly on developing States.

In complement, ICAO has significantly enhanced its environmental data capabilities, enabling real-time monitoring of fuel efficiency, CO_2 reductions, and the uptake of low-emissions technologies. States are increasingly encouraged to strengthen their monitoring and reporting efforts in line with ICAO Doc 9988[2] (*Guidance on the Development of States' Action Plan on CO_2 Emissions*

1 https://www.icao.int/environmental-protection/Documents/ICAO%20Special%20Environment%20Report%20on%20International%20Aviation%20Cleaner%20Energy%20Transition%20.pdf
2 https://store.icao.int/en/guidance-on-the-development-of-states-action-plan-on-co2-emissions-reduction-activities-doc-9988

Reduction Activities), using harmonized methodologies to ensure comparability and data integrity.

Digital platforms, AI-powered tools, and dynamic dashboards are being adopted by the industry to evaluate mitigation performance, optimize operations, and share best practices. In parallel, ICAO has developed a set of LTAG Tracker Tools[3], which provide a global view of progress in cleaner energies deployment, the main tracker tool, and also on technology development[4], operational mitigation measures and net zero initiatives. These trackers foster transparency, facilitate peer learning, and support evidence-based policy interventions.

Mitigation Support for All: Focus on Inclusion and Implementation

ICAO recognizes that achieving the LTAG is a global effort that must include all regions and levels of development. A priority moving forward is to enhance access to climate finance, build institutional capacity, and facilitate technology transfer. ICAO's Assistance, Capacity-building and Training programs, including ACT-SAF and ACT-CORSIA, are central to this mission. They support States in developing national SAF roadmaps, enabling policies, CORSIA engagement and CO_2 data submission and pilot projects aligned with LTAG.

State Action Plans are also evolving to reflect LTAG ambitions. These plans help mainstream aviation mitigation into national climate strategies and unlock financing opportunities through coherence with National Determined Contributions (NDCs).

Looking ahead: scaling up action

As we move beyond 2025, the focus will increasingly shift from planning to implementation at scale. While significant progress has been made, much remains to be done to deliver the levels of emissions mitigation needed. Future action will require:

- Accelerating cleaner energy transitions, particularly SAF scale-up through policy certainty and investment incentives;
- Expanding inclusive support mechanisms for least developed and small island developing States;
- Harnessing innovation in aircraft design, airspace operations, and infrastructure to maximize emissions reductions.

Conclusion

ICAO's efforts on implementing the basket of measures to achieve the LTAG, mark a new phase of global climate change mitigation action in the aviation sector. The path to net-zero will be long and complex, but the foundations are in place. Through shared tools, common frameworks, and an inclusive consultative process, ICAO continues to foster alignment and momentum. The articles in this chapter showcase the diverse actions and perspectives shaping this transition—from technological innovation to integrated planning, and from global frameworks to local implementation.

The aviation sector's climate future depends on our collective capacity to turn ambition into sustained mitigation. ICAO remains committed to enabling that transformation, and the efforts are reflected throughout this Chapter, which features a diverse set of contributions: from the LTAG Monitoring and Reporting (LMR) Methodology, to scenario-based insights on net-zero pathways, mitigation of short-lived climate forcers, and approaches to minimizing residual CO_2 emissions. The Chapter also includes perspectives from industry leaders and highlights the importance of research and training institutions in advancing long-term mitigation strategies. Collectively, these contributions underscore the multifaceted and inclusive approach that ICAO is fostering to support the achievement of its global climate goals.

3 https://www.icao.int/environmental-protection/Pages/SAF.aspx
4 https://www.icao.int/environmental-protection/SAC/Pages/GCSA%20main%20page.aspx

Introduction to the LTAG Monitoring and Reporting (LMR) Methodology

By Marcela Anselmi (Brazil)[1] and Michael Lunter (Netherlands)[1]

INTRODUCTION

The 41st ICAO Assembly, in its Resolution A41-21, adopted, in 2022, the long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050, in support of the Paris Agreement's temperature goal, while also recognizing that each State's special circumstances and respective capabilities will inform the ability of each State to contribute to the LTAG within its own national timeframe. In order to allow for the monitoring of the progress towards the achievement of LTAG, Resolution A41-21, paragraph 9, also requested the ICAO Council to consider the necessary methodologies for the regular monitoring of progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG[2].

In response to Resolution A41-21, paragraph 9, and a further request by the Council, as well as the Global Framework adopted by CAAF/3, the Committee on Aviation Environmental Protection (CAEP) developed a comprehensive and robust LTAG Monitoring and Reporting (LMR) Methodology to provide a standardized global approach to track aviation's progress on decarbonization, enabling transparent and informed decision-making across the international aviation sector. The LMR methodology, delivered by CAEP/13, will be considered by the Council at its 235th Session (April - July 2025), to inform global policy decisions at the upcoming 42nd ICAO Assembly in September/October 2025.

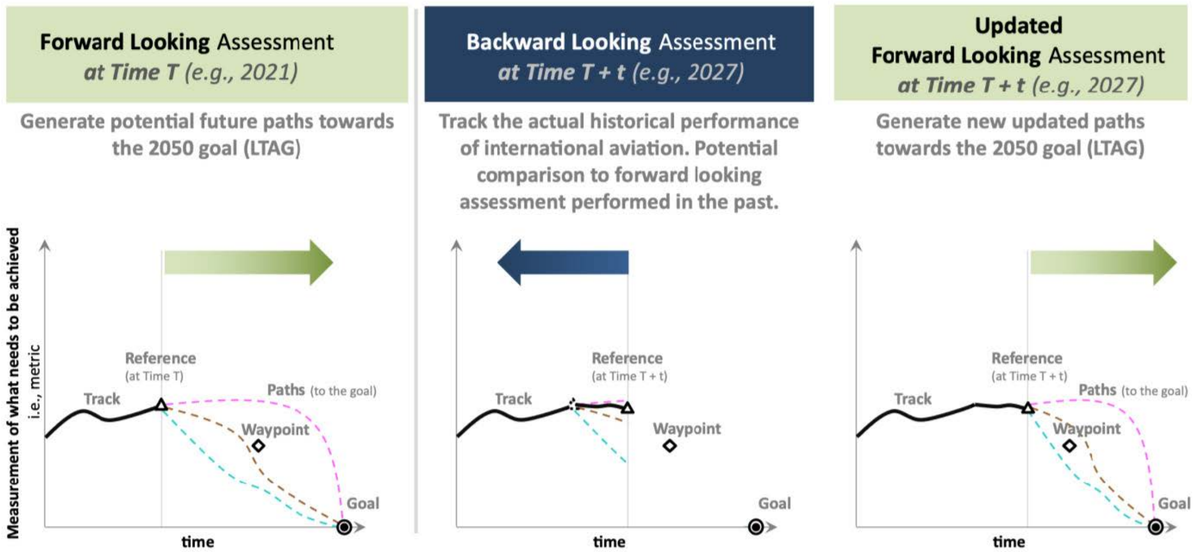
The LMR methodology aims to assess progress on the implementation of CO_2 emissions reduction measures towards the achievement of the LTAG, including the past and future CO_2 emissions reductions, the cost impacts of efforts to achieve the LTAG, the impact on the development of the sector, as well as the cost impacts of a changing climate on international aviation.

In addition to this methodology, ICAO also monitors progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG, through the ICAO environment Stocktaking process, the review of the ICAO Vision for SAF, monitoring of information from State Action Plans for international aviation CO_2 emissions reduction and means of implementation.

The LMR methodology follows key objectives and principles: 1) address the request from Assembly resolution A41-21 (paragraph 9 refers) insofar as it is within CAEP's remit to do so; 2) allow for the review of historical performance of the international aviation sector and updated outlooks; 3) leverage existing relevant data, methods, tools and analyses from ICAO; and 4) evolve and be enhanced over time to address existing gaps in data or methods.

1 Marcela Anselmi and Michael Lunther are Co-Rapporteurs of LMR-TG of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

2 ICAO Assembly Resolution A41-21: https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A41-21_Climate_change.pdf



Note: Paths (to the goal) are meant to be generic/illustrative and do not represent the ICAO LTAG -TG Integrated Scenarios 1, 2 a nd/or 3.

FIGURE 1: Description of the Backward- and Forward-Looking Assessments of the LMR Methodology

OVERVIEW OF THE LMR METHODOLOGY

1. LMR Methodology: Backward- and Forward-Looking Assessments

Against the above principles and working from the Assembly Resolution A41-21 requirements to monitor progress towards the achievement of the LTAG, the proposed LMR methodology combines two key components described in Figure 1:

1- **Backward-looking assessments** to track actual historical performance of the international aviation sector in context of previous forward-looking assessments, along with

2- **Forward-looking assessments** that comprise updated/refreshed forecasts and projections towards 2050.

Forward-looking assessments include the regular CAEP Trends assessment and updated analyses and projections described in the 2022 LTAG Report, such as assessments of the costs of the impacts to achieve the LTAG[3].

While some of the elements of the LMR methodology would leverage historical and recurring work by CAEP (e.g., CAEP Trends), some elements are new(er) such as the backward-looking assessments that aim to put recent actual historical data, in context of previous forward-looking assessments. This will allow identifying the progress against the LTAG integrated scenarios, CAEP Trends and against any updated forward-looking assessments.

Therefore, the proposed high-level approach, including backward- and forward-looking assessments, will allow ICAO to make the following assessments, as described in Figure 2:

b) to track the actual performance (e.g., residual CO_2 emissions) of the international aviation sector;
c) to place the actual performance in context of the previously projected trends;
d) to provide description and/or explanation of the contribution from individual drivers and measures (e.g., traffic, technology, operations, and/or SAF) and their effects on the actual performance of the sector; and
e) to update the forward-looking assessments to generate new/updated paths towards the 2050 goal based on the latest available historical data at the time.

3 2022 ICAO LTAG Report: https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

Themes & Metrics:	Backward Looking Approach	Forward Looking Approach
CO_2 Emissions	Assessment of contribution from traffic and capacity to actual CO_2 emissions levels	(Enhanced) CAEP Trends
including: Aviation Activity	Assessment of contribution from Technology and Operations Improvements	
	Assessment of contribution from SAF and LCAF	
	Comparison of actual CO_2 emissions with Net-Zero 2050 Goal	
Costs impacts of efforts to achieve LTAG	Comparison of Costs and Investments (actual vs. planned)	Estimated Future Costs (and Investments) of efforts to achieve the LTAG
Impacts on Development	Assessment of Recent Impact on Development	Methodology for Assessing Impacts on Development

FIGURE 2: Description of the outcomes of the LMR Methodology

2. LMR Methodology: A Tiered Approach for a Phased Implementation

Along with the backward- and forward-looking assessments, the LMR methodology is further characterized by a tiered approach, consisting of a core methodology (i.e., Tier 1), an extension of Tier 1 that would provide additional insights (i.e., Tier 2) and a more advanced methodology (i.e., Tier 3).

Tier 1 captures elements of the LMR methodology that meet the minimum requirements from Resolution A41-21 (paragraph 9 refers), with confidence of successful implementation in the near-term. This Tier allows for a descriptive approach, comparison to previous forward-looking assessments (e.g., CAEP Trends, LTAG Report), relevant milestones (e.g., CAAF/3 global aspirational Vision), and existing data sources and methodologies.

In developing the methodology, the data, methods, and tools already available in ICAO will be leveraged, instead of creating new data or new reporting requirements.

With additional resources and further data and modelling capabilities, additional elements from Tiers 2 and 3 could contribute to enhancing the LMR methodology in the future. As the methodology moves towards Tiers 2 and 3, an additional level of understanding and granularity of the underlying drivers and factors influencing the observed trends can be provided. Tiers 2 and 3 seek also to explain these trends by gathering, analyzing and reporting additional data and, as such, this would require additional resources and further data and modelling.

Some limitations to the data available to ICAO have been identified and further work will enable ways to be proposed to address them.

The assessments of the **"cost impacts of the efforts to achieve the LTAG"** would update estimated costs as well as track actual costs of efforts to achieve the LTAG focusing on fuel savings from aircraft technology improvements and cost premiums from SAF and LCAF as part of Tier 1, and expanding to other types of costs (e.g., aircraft technology non-recurring costs, operational costs) in Tier 2 and costs of hydrogen and electricity for alternative propulsion aircraft in Tier 3.

The **"impact on the development of the sector"** will explore how to assess the impact of the incremental costs associated with the efforts to achieve the LTAG on the demand for international aviation. Under Tier 1, the LMR methodology would scope out an assessment of potential changes in future traffic estimates due to changes in the costs impacts of efforts to achieve the LTAG out to 2050.

Similarly, the methodology will also include an assessment of **"cost impacts of a changing climate"** relating to the costs of inaction to climate change, with an initial focus on extreme weather events.

Implementation and Output of the Methodology

The LMR methodology will be implemented, starting only with Tier 1 and reports will be delivered on a 3-year-cycle basis.

All the data and assessments will be integrated in a comprehensive output of the LMR methodology, in the format of a public ICAO technical report, to enable transparent and informed decision-making across the international aviation sector. Other reporting formats for communication to particular audiences will also be considered as resources permit.

Following the 42nd Session of the Assembly, ICAO will undertake the work to deliver the first Report from the LTAG Monitoring and Reporting to the 43rd Session of the Assembly in 2028.

With the creation of a robust monitoring and reporting methodology, this new framework provides a standardized global approach to measure aviation's progress towards decarbonization and to adjust the course of the sector as needed.

Path to net zero: Turning ambition into action

By Haldane Dodd (ATAG)

The aviation industry is at a crucial point in its journey towards net zero. In the three years since ICAO's last Environment Report, great strides have been made to move from commitment into action. ICAO, with the support of the industry, did incredible work to unite governments behind a common net zero goal for 2050. Now, with this clear direction in sight, there has been a move towards more policy support in many countries, and greater investment in the decarbonization pathway.

Despite these successes, we are also experiencing a more complicated operating environment than we have seen in recent years. Questions over the cost of the transition haven't gone away, but challenges brought about by the political mood are also causing concerns. Key stakeholders have stepped back from projects that place the climate at their center. Traditional energy providers are placing obstacles in the ramp-up and scalability of sustainable aviation fuel (SAF) production – or simply pulling back on their climate commitments.

However, the fundamentals remain the same. Air traffic will continue to increase every year to serve a global population that sees great benefits in connectivity, and with it the need to decouple carbon emissions from growth grows even more important. As impacts are felt by citizens with more frequent flooding and wildfires, climate change will increasingly be a part of public consciousness, with greater demands for political, consumer and corporate action. We also cannot ignore the business cost of inaction: carbon costs will rise, and the insurance markets are already starting to factor in climate impacts – this will only become more apparent if the world fails to get a grip on the situation. It's an uncomfortable picture, but there is hope and despite the hurdles, the civil aviation sector remains firm in its commitment to reach net zero carbon.

The next three to five years will be a vital time for the decarbonisation of our sector. We need to demonstrate a continued commitment to ensure that the early gains we've seen can be solidified into long-term transformation. Most importantly, multi-stakeholder collaboration on a global scale will be crucial to future success, removing barriers and allowing the industry to innovate at scale.

Collaborative action towards a common goal

Over the last three years, we have seen a number of examples of how collaboration drives change, and what we can achieve if we all work towards a common goal. Developments in modern fuel-efficient aircraft, propulsion systems and light-weight construction materials continue to reduce emissions, while operational improvements on the ground and in the air are contributing to the industry's common goal. One example for this collaborative approach is EUROCONTROL's Free Route Airspace, which will save one billion nautical miles and 20 million tonnes of CO_2 when fully implemented across the continent in 2029.

Today, about one third of the current global fleet uses the latest generation aircraft operating with maximum fuel efficiency. There is a production backlog of 15,700 aircraft to be fulfilled in the coming decade, which will provide further efficiency gains. We are also at an early but promising stage of development into hybrid electric and hydrogen powered aircraft technologies for smaller and short-haul operations – there is a real need to scale-up the production and distribution of liquid hydrogen to help support this shift. Since 1990, about 14.66 billion tonnes of CO_2 have been avoided due to new technology and operational efficiencies. The adoption of digital tools, particularly as more organizations figure out best uses for artificial intelligence in their particular field, will only serve to further these gains as increasingly efficient aircraft operate on increasingly efficient routes.

Alongside these initiatives, huge progress has been made by ICAO with the introduction of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA): airlines will need to purchase $20-30 billion in approved offsets for 1.2-2 billion tonnes of CO_2. This represents around 70% of the growth in international air transport emissions during the lifetime of the scheme. This is the result of extensive negotiations by developed and developing countries, the ICAO system, industry and civil society, and represents a measure that will be effective without having a disproportionately negative impact on developing nations and their capacity for growth. A total of 129 States have now volunteered for the first stage, making it likely to be one of the most successful UN-level carbon management projects.

Outside of carbon, collaboration is also key in the progress for contrail management. There is significant research currently going into understanding the complexities of contrails and their long-term impact on the environment, particularly into the potential to develop sensors for commercial aircraft that can help us understand where formation might take place, learning how avoidance might impact air traffic, and identifying the trade-off metric between contrail avoidance and CO_2 emissions. However, conversations are actively taking place between all stakeholders which demonstrates the progress we can make when stakeholders from all areas of the aviation and climate sectors work together.

Collaborative initiatives such as CORSIA, operational efficiency improvements, measures tackling non-CO_2 emissions, as well as innovation and infrastructure investment are all crucial for the industry's net-zero pathway. As we have known for some time, the most significant factor is the ramp-up of SAF. As of this year, there are 11 approved pathways for SAF production, and a further 11 are currently being assessed, which help diversify supply and create a menu of SAF options around the world, particularly in developing nations.

The good news is, we see an exponential increase in SAF production year over year, from 240,000 tonnes produced in 2022 to 500,000 tonnes in 2023 to one million tonnes in 2024. For 2025, we expect this number to double again to 2.1 million tonnes. More than 45 States have already introduced or are introducing SAF policies to incentivize SAF off-take. Additionally, 50 airlines globally, counting for 41% of global traffic, have committed to blends of more than 5% SAF by 2030. These initiatives from both the industry and regulators provide much needed confidence to suppliers and give a strong signal to ramp up SAF production. However, this momentum must be maintained – and accelerated – if aviation is to be able to narrow on a pathway to decarbonization.

Aviation cannot decarbonize in a vacuum

Current SAF output still represents less than 1% of all jet fuel, meaning more must be done to stimulate demand, which in turn would strengthen the supply side and ensure the development of fuel-producing plants. To achieve the long-term goal of up to 500 million tonnes per year, it requires stronger multi-stakeholder collaboration not only from governments and the civil aviation industry, but the financial investor community and traditional energy companies alike, the latter of which have recently scaled back their initial commitments on SAF production. It is up to governments to introduce measures that will hold oil companies accountable and ensure their crucial support in the scale-up of SAF.

Looking to the future, the next few years will be particularly crucial in our journey. Important commitments now need to be turned into clear actions. In the realm of SAF, an investment of at least $1.5 trillion will be required for SAF production over the next 25 years. Alongside the financing need, there is still a need to harmonize SAF regulation globally. This would provide confidence to airlines and the organizations involved in SAF production and allow for more effective planning. Governments, development banks and other institutional and private investors are beginning to increase funding for SAF, but financial mechanisms must also be expanded to help reduce the risk in these investments and accelerate adoption to the scale needed to fulfill the industry's net-zero targets.

Fundamentally, focused and consistent collaboration between all stakeholders is vital to overcome these challenges. Aviation can't decarbonize in a vacuum, and it is crucial for energy producers, the finance community and policymakers to fully align with civil aviation's energy transition and put their full weight behind SAF development and innovation. The past three years have shown what can be possible when the industry, governments and key stakeholders work together.

From progress on contrails, to SAF policy or CORSIA, significant developments are bolstering the industry's efforts to reach net zero. However, so much more needs to be done. The building blocks are in place. We have our plan, and we have a sector which – unlike almost any other – is used to working through global collaboration. The next phase of our mission will require even greater ambition, and a much faster implementation of solutions. Now is the time for us to work together, remove roadblocks and put systems in place that will allow the industry to innovate and execute faster than ever before. With the right policies, investments and commitments from across the stakeholder spectrum, there is every possibility that aviation can and will reach net-zero carbon.

Exploring the Contribution of Short-Lived Climate Pollutants (SLCPs) Mitigation to ICAO's Long-Term Aspirational Goal

By Supraja Kumar and Jayant Mukhopadhaya (ICCT)

Introduction

The aviation sector is rapidly growing with passenger air traffic expected to double in the coming decades. With this projected growth, the environmental impact of the sector shifts into greater focus. To date, the aviation sector has contributed to 2.4% of anthropogenic carbon dioxide (CO_2) emissions and about 4% of radiative forcing, when considering the climate impacts of both CO_2 and short-lived climate pollutants (SLCPs), such as nitrogen oxides (NO_x), particulate matter, and condensation trails (contrails).[1] As highlighted by the ICAO non-CO_2 symposium, while there is uncertainty in quantifying the exact impact of SLCPs, they do have a net warming impact and action should be taken towards mitigation.[2]

In 2022, the ICAO 41st Assembly adopted a long-term aspirational goal (LTAG) of reaching net-zero CO_2 emissions in international aviation by 2050. To chart the path towards this goal, numerous decarbonization roadmaps were developed by groups including industry, NGOs, and governments.[3] These roadmaps highlighted the mitigation levers needed to achieve net-zero, with over half of necessary reductions coming from sustainable aviation fuels (SAF), and the rest from a combination of fuel efficiency improvements, hydrogen-powered aircraft, operational improvements, and small reductions in flying as fuel costs increase.

When we consider the sector's progress over the past three years, despite substantial percentage growth year on year, SAF uptake remains low (about 0.3% of jet fuel in 2024), or about one-twentieth the CAAF/3 goal of 5% carbon emission reductions from alternative fuels in 2030.[4] Additionally, the introduction of hydrogen-powered aircraft has been delayed by manufacturers, and new aircraft types with significant fuel efficiency improvements are not expected to enter service until the mid-2030s. The current trajectory highlights the challenge with both achieving the LTAG and aligning with the Paris climate agreement if relying on only in-sector CO_2 mitigation. Based on these developments, the ICCT has been assessing the potential for Short Lived Climate Pollutants (SLCP) mitigation to contribute to aviation's climate goals.

1 M Klöwer et al., "Quantifying Aviation's Contribution to Global Warming," *Environmental Research Letters* 16, no. 10 (October 1, 2021): 104027, https://doi.org/10.1088/1748-9326/ac286e.
2 ICAO, "Interactive Summary of the Symposium on Non-CO_2 Aviation Emissions," 2025, https://www.icao.int/Meetings/SymposiumNonCO2AviationEmissions2024/Pages/Summary.aspx.
3 IATA, "Aviation Net-Zero CO_2 Transition Pathways: Comparative Review," April 2024, https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/nz-roadmaps.pdf.
4 IATA, "Slow Growth in SAF Production," December 10, 2024, https://www.iata.org/en/pressroom/2024-releases/2024-12-10-03/.

2023 Emissions Inventory

The starting point to understand the potential climate impact of aviation in the future is to quantify contributions from all pollutants in the present. To do so, we used ADS-B flight trajectory data purchased from Spire to develop a global inventory of 2023 aviation emissions, including CO_2, NO_x, non-volatile particulate matter (nvPM), sulfur oxides (SOx), water vapor (H_2O), and contrails.[5] The European Centre for Medium-Range Weather Forecasts' (ECMWF) ERA5 HRES data set was used for meteorological data input, as atmospheric conditions are relevant for aircraft performance modeling and contrail lifetime simulations. The Python version of BADA3 (pyBADA) was used with pyContrails to model the quantities of each pollutant and calculate their effective radiative forcing (ERF).

The International Panel on Climate Change (IPCC) uses the Global Warming Potential (GWP) metric to compare the impacts of different pollutants, which quantifies the warming impact of a given pollutant relative to 1 tonne of CO_2 emissions. Here, we consider 2023 aviation emissions under 20- and 100-year timescales (GWP20 and GWP100) for perspective in reference to climate targets.

Under a 20-year timescale (Figure 1, left), the total climate impact of the sector could increase by over two times that of CO_2 emissions when including warming from SLCPs. This is in the lower range of potential SLCP impact when considering the range indicated in Lee et al. (2021), which could be nearly 7 times that of CO_2.[6] Under a 100-year timescale (Figure 1, right), CO_2 emissions appear to make up the majority of the sector's warming. However, SLCPs could add to this by almost 40%, and given the large uncertainty associated with contrail warming, even end up nearly tripling the sector's climate impact.

The warming of NO_x emissions and contrails appear to be similar in magnitude across both metrics, however, there is a much larger range associated with contrail impact, and our 2023 contrail ERF estimate of 17.3 mW/m^2 is at the lower end of the estimate from Lee et al. Additionally, there is uncertainty associated with whether aviation NO_x will have a net warming or cooling effect in the future, due to potential changes in background levels of atmospheric ozone and methane. Regardless of the metric being used, non-CO_2 emissions, particularly contrails, will likely increase the total climate impact of the sector. When expressed in GWP100, the climate impact of the year's aviation activity increases between about 12-280% when including non-CO_2 emissions.

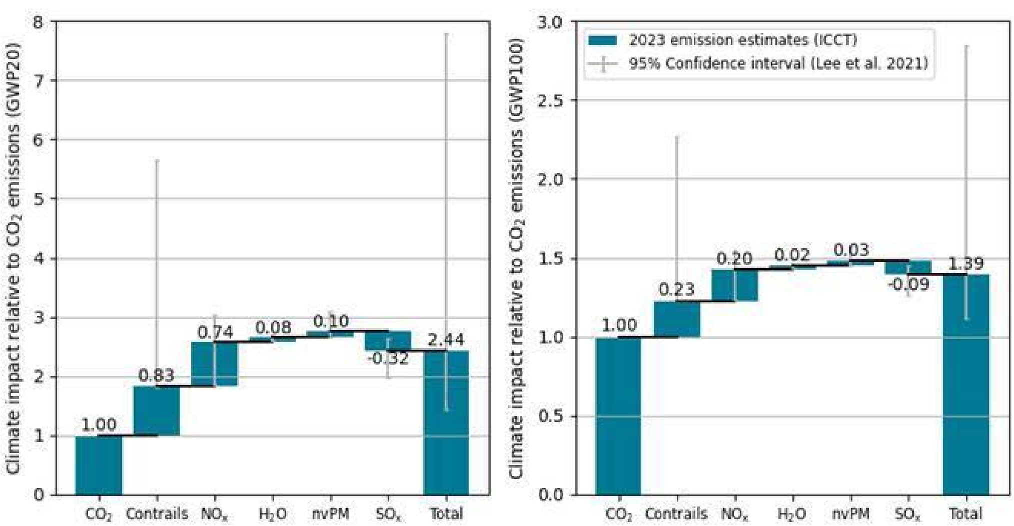


FIGURE 1: Climate impact from 2023 aviation emissions in GWP20 (left) and GWP100 (right)

5 Models used for each pollutant are as follows: BADA3 for fuel burn with constant emissions factors for CO_2, SOx, and H_2O, Boeing Fuel Flow Method 2 (BFFM2) for NO_x, T4/T2 method for nvPM, and CoCIP for contrails.

6 D.S. Lee et al., "The Contribution of Global Aviation to Anthropogenic Climate Forcing for 2000 to 2018," *Atmospheric Environment* 244 (January 2021): 117834, https://doi.org/10.1016/j.atmosenv.2020.117834.nitrogen oxides (NO_x

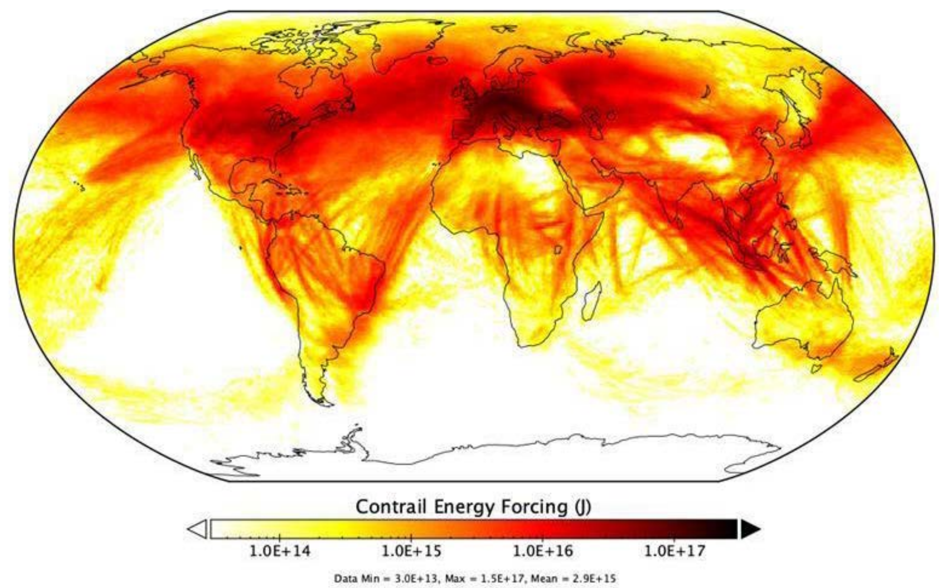


FIGURE 3: Global contrail energy forcing in 2023

Estimating the contribution of contrails to climate change remains challenging, in part because persistence and warming varies based on both climatological and meteorological conditions. To better understand regional differences in contrail impact, we plotted the energy forcing from contrails across all routes flown in 2023 in Joules (Figure 2). Here, we can see that most of the energy forcing occurs from flights departing Europe and North America flying over the North Atlantic region. If we categorize by World Bank income categories, over 95% of contrail warming is concentrated from departures from high- and upper-middle income countries, highlighting the need for developed aviation markets to take swift action to reduce their impact.[7]

Using this base emissions inventory, we are developing a model to project the potential warming contributions and surface temperature response from all aviation emissions through 2050 under different mitigation scenarios, including a business-as-usual case and various levels of CO_2 and non-CO_2 emissions reductions. While this work is still ongoing, we see the potential for targeted SLCP mitigation to buy time as other technologies mature and scale.

When considering the future growth of the sector and current progress made towards CO_2 emissions reductions, SLCP mitigation could present a way for the sector to reduce its climate impact while still allowing for sectoral growth. Some mitigation measures that are being pursued for CO_2 emissions can help to reduce SLCPs – namely SAF, which can reduce nvPM and contrail impact, and new engine technologies, which can reduce NO_x and nvPM emissions. Absolute, long-term reductions in radiative forcing will require new airframe, engine, and alternative fuel technologies, notably advanced SAF produced from cellulosic biofuels or e-kerosene. However, these will take time to penetrate the market. The most feasible short-term lever for SLCP control is contrail avoidance, which could provide a 73% reduction in warming for a 0.1% fleetwide increase in fuel burn.[8] While flight trials are ongoing, tactical avoidance in contrail-prone regions in the coming decades could allow for significant reductions in contrail climate impact with minimal fuel burn penalty.

7 World Bank, "World Bank Income Groups," 2025, https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

8 A Martin Frias et al., "Feasibility of Contrail Avoidance in a Commercial Flight Planning System: An Operational Analysis," *Environmental Research: Infrastructure and Sustainability* 4, no. 1 (March 2024): 015013, https://doi.org/10.1088/2634-4505/ad310c.also known as contrails, contribute a substantial portion of aviation's overall climate footprint. Contrail impacts can be reduced through smart flight planning that avoids contrail-forming regions of the atmosphere. While previous studies have explored the operational impacts of contrail avoidance in simulated environments, this paper aims to characterize the feasibility and cost of contrail avoidance precisely within a commercial flight planning system. This study leverages the commercial Flightkeys 5D algorithm, developed by Flightkeys GmbH, with a prototypical contrail forecast model based on the Contrail Cirrus Prediction (CoCiP

Conclusions

Our findings highlight the value in targeted action from ICAO CAEP (Committee on Aviation Environmental Protection) towards non-CO_2 emissions – specifically, in monitoring impact, identifying climate metrics for impact assessment, and including their impact in aviation emissions trends projections.

Currently, the scope of the LTAG is limited to aviation's CO_2 emissions, and we believe this could be omitting a large and mitigable share of aviation's climate impact. Including non-CO_2 emissions in the LTAG would better reflect the full picture of aviation's total climate impact and could enable rapid reductions in aviation warming through contrail avoidance as new airframe, engine, and fuel technologies mature to address CO_2.

To Achieve LTAG: Ways to Address and Minimize Residual CO_2 Emissions

By Rabab Mehnaz and Alejandro Block (IATA)

Introduction

IATA's framework for net-zero 2050 is simple: Reduce energy use (and in turn, fuel use), change the energy source from fossil fuels to renewable alternatives, and re-capture residual CO_2 emissions. IATA estimates that even in a scenario where 90% of the fossil fuel is replaced by SAF, residual CO_2 emissions could still amount to nearly 500 million tonnes in 2050. While there is no standard definition for what constitutes residual CO_2 emissions, it can be broadly explained in the net zero context as the amount of CO_2 emissions leftover after all other decarbonization levers have been applied. In the air transport context, as per the ICAO LTAG scenarios, this would mean the CO_2 emissions leftover after the emission reductions through the use of sustainable aviation fuel (SAF), energy efficiency and operation improvements, and hydrogen and battery electric aircraft. According to many decarbonization roadmaps for aviation, including IATA's Net Zero Roadmaps, the amount of residual CO_2 emissions to be addressed in 2050 represents about 20% of the total baseline emissions, a proportion higher than the emissions which are expected to be tackled from more efficient operations, or from zero-carbon energy aircraft like battery or hydrogen.[1]

IATA recognizes the important role of market-based measures to address the residual emissions as an integral part to deliver the LTAG in 2050. This has also been widely recognized already in several decarbonization roadmaps.[2] Carbon dioxide removals (CDR) are identified as one of these market-based measures (MBMs). In fact, this solution can already be used today in the form of CORSIA Eligible Emissions Units, for operators to comply with their CORSIA obligations. This article focuses on the role of CDR in addressing residual CO_2 emissions directly and the importance of maximizing the use and increasing the potential of deep emission reductions to minimize the amount of residual emissions that need to be addressed.

Leveraging Carbon Dioxide Removal to address residual emissions

According to the IPCC, "carbon dioxide removal (CDR) refers to a cluster of technologies, practices, and approaches that remove and sequester carbon dioxide from the atmosphere and durably store the carbon in geological, terrestrial, or ocean reservoirs, or in products". The International Panel on Climate Change (IPCC) acknowledges the use of CDR **as a means to counterbalance residual CO_2 and greenhouse gas (GHG) emissions from hard-to-transition sectors, which includes the aviation sector**.[3] CDR can exist in the form of many different technologies and methods, each with a unique means of capturing and storing CO_2 from the atmosphere. Using CDR, CO_2 can be stored in other parts of the Earth's sphere from the atmosphere i.e. in ocean

1 IATA (2024). *Net Zero Roadmaps*. [online] Iata.org. Available at: https://www.iata.org/en/programs/sustainability/roadmaps/.
2 IATA Net Zero Roadmaps suggest that roughly 400 to 1,300 Mt CO_2 of residual emissions must be addressed through out-of-sector measures (market-based measures and CDR). Likewise, ATAG's "Waypoint 2050", Royal Netherlands Aerospace Centre's (NLR) and SEO Amsterdam Economics' (SEO) "DESTINATION 2050 for European Aviation", and the two Mission Possible Partnership (MPP) roadmaps also consider MBMs as part of their decarbonization levers.
3 Coppola, E., John and Dunne, P. (n.d.). Coordinating Lead Authors: Lead Authors: Contributing Authors: Climate Change Information for Regional Impact and for Risk Assessment. *United States of America)*. [online] DOI: https://doi.org/10.1017/9781009157896.014.

bodies, biological sinks, and geological reservoirs. CDR is one way to directly address residual emissions that will be left over after deep emission reduction measures such as SAF, hydrogen, and battery electric aircraft are applied.

The concept of CDR durability is also a key aspect of consideration for quality assessment and is increasingly scrutinized to determine the appropriateness of different types of CDR in addressing CO_2 emissions. Durability refers to the timescale in which CO_2 is stored without being re-released to the atmosphere. Definitions of how to quantify durability can vary across scientific literature and market standards. CDR methods that use biological sinks, such as afforestation and reforestation, typically have lower durability scales spanning decades. Meanwhile, CO_2 storage utilizing deep underground reservoirs such as saline aquifers is able to store CO_2 for longer periods of time without reversal, spanning several millennia.[3] A popular thought among the scientific community is that anthropogenic CO_2 emissions, which persist in the atmosphere for centuries, must be appropriately removed by removals that store these CO_2 emissions over similar timescales, i.e., via geological storage.[4] Therefore, ambiguity still exists on the applicability of each of these measures and their appropriateness to address residual CO_2 emissions, not just from a net zero perspective, but also from an overall climate neutrality perspective.

There is also ongoing debate about the role of storage mediums that can store CO_2 at shorter timescales. Some have suggested that these types of CDR can be used to counterbalance shorter-lived greenhouse gases, such as methane emissions, compared to the greenhouse warming potential (GWP) of CO_2.[5] For many CDR methods utilizing biological sinks, more clarity is required on establishing baseline emissions before the removal activity and subsequent measurement of the net carbon uptake, as this can be challenging to monitor. Additionally, more clarity is needed on terms like net-zero, carbon neutrality, and climate neutrality, as well as what types of residual emission mitigation measures would be most appropriate to meet the LTAG.

However, CDR is **not meant to be a substitute for deep emission reductions** in a net zero emissions goal, but can rather serve as a complementary strategy to enable short to medium-term targets or to ultimately reach net zero CO_2 and GHG emissions in the longer term. Even now, there are opportunities for the sector to engage through CORSIA, as a market-based measure, with emissions units that incorporate CDR methodologies. In the context of air transport, this means that CDR should act as a **complementary** solution to the other basket of measures. CDR is also unique in that it is not a decarbonization solution that will solely be used by the air transport sector, but it will also be utilized and required in all other sectors that are trying to decarbonize, especially other hard-to-abate sectors, such as steel, cement, and shipping.

Maximizing deep emission reductions

While CDR will be an increasingly important component in addressing residual emissions from the air transport sector, the reliance on CDR, and other similar MBMs, can be reduced by maximizing deep emission reductions using "in-sector" measures (reducing energy use and changing the energy source). To do so requires encouraging innovation in key technologies and the recognition of existing emission reduction measures in emission life-cycle accounting.

Some of the measures to maximize the potential of in-sector emission reductions can be outlined as follows:

- Reducing in-flight energy: Transition to new, more efficient aircraft and encourage further innovation in developing new aircraft and engine types that can maximize emission reductions through efficiency improvements. Historically, every new aircraft generation has been 20% more efficient than the one it replaces.[1]

- Change the energy source: Increase support and faster adoption of hydrogen and battery electric aircraft for at least short-haul flights well before 2050. Based on IATA's estimations, a focus on the transition to hydrogen-powered aircraft (for regional

4 Allen, M.R., Friedlingstein, P., Girardin, C.A.J., Jenkins, S., Malhi, Y., Mitchell-Larson, E., Peters, G.P. and Rajamani, L. (2022). Net Zero: Science, Origins, and Implications. *Annual Review of Environment and Resources*, [online] 47(1), pp.849–887. DOI: https://doi.org/10.1146/annurev-environ-112320-105050.

5 https://roberthoglund.medium.com/how-much-carbon-will-we-need-to-remove-26fda7b5e19a

and narrow-body aircraft) **alone** will displace close to 37 (million tonnes) Mt of fossil jet fuel in 2050. This would reduce the respective residual CO_2 emissions from 117 Mt to 21 Mt if green hydrogen was used, or 40 Mt if blue hydrogen was used, considering life-cycle emissions.[1]

- Encouraging an economy-wide shift to renewables will increase the access and reduce the price of renewable energies for aviation. This will improve the availability and lower the life cycle emissions of aviation fuels, including Power-to-Liquid (PtL) SAF for conventional aircraft and green hydrogen for hydrogen-powered aircraft, both of which use green electricity as inputs. Based on the IATA Net Zero Roadmap baseline scenario, residual CO_2 emissions if only fossil jet were used in 2050 would amount to about 1,940 Mt (baseline scenario, zero SAF or hydrogen use, and no further improvements in aircraft technology beyond 2018-level technology). Implementing only efficiency measures brings this down to 1,820 Mt. Residual emissions could be lowered to 1,120 Mt based on the F2 scenario for SAF deployment in the IATA Net Zero Roadmaps (or the LTAG report), if the emission reduction factor (ERF) of all SAF over its life cycle averaged 60% below the fossil-based jet fuel baseline. This could be further reduced to 546 Mt CO_2 if the ERF of SAF used averaged 90%. It is even lower with the respective type of SAF implemented together with efficiency measures. With the incorporation of hydrogen aircraft and SAF averaging 90% ERF, this is brought even further down to about 330 Mt of CO_2 in 2050 (Figure 1).[1]

Adopt and enable greater recognition of emissions reductions in the lifecycle of aviation fuels through new technologies such as carbon capture and storage (CCS).[6] One study suggested that for a specific alcohol-to-jet (AtJ) facility design, implementing and maximizing deep emission reductions such as using renewable electricity, green hydrogen, and renewable heat can yield CI reductions of the SAF over its life cycle. Particularly, the application of CCS and sustainable farming practices can contribute to large CI reductions that can potentially yield more than 100% emission reductions over a life-cycle basis.[7]

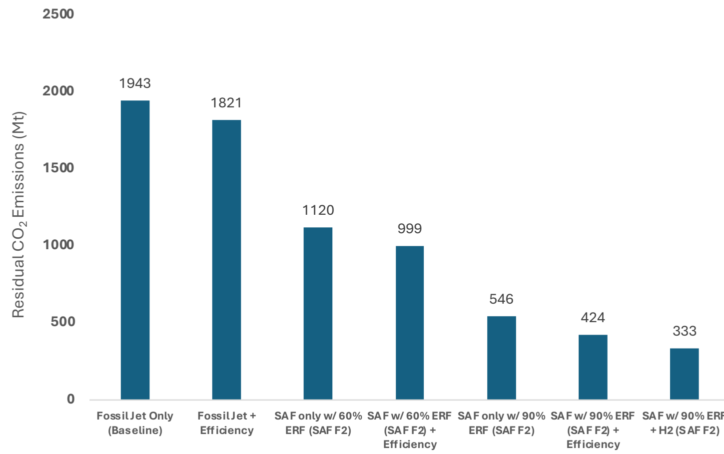


FIGURE 1: Residual CO_2 emissions in 2050, depending on the mitigation strategy used.

In 2050, All the remaining fuel used by aviation from fossil origin should be LCAF.[8]

Future work

Many of the aspects mentioned in this article are core to the work and mission of the ICAO CAEP. Its Working Group 5, Fuels, constantly evaluates SAF pathways and better methodologies to account for their life cycle emissions. CAEP Working Group 3, Emissions Technical, has developed the first-ever CO_2 standard and recently recommended, along with Working Group 1, Noise Technical, a dual stringency standard that should continue to encourage more efficient aircraft entering the fleet. All these groups aim to maximize and improve emission reductions, which will reduce the residual emissions toward 2050. To address the remaining residual emissions that will inevitably be there even after maximizing the potential deep emission reductions to 2050 will be a continued discussion both in the context of CORSIA, in Working Group 4, and the Long-Term Aspirational Work Monitoring and Reporting Task Group (LMR-TG), where progress towards the LTAG will be constantly monitored.

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6 Carbon capture and storage (CCS) refers to, in this case, carbon captured and stored from a particular emitting point source.
7 Yoo, E., Lee, U. and Wang, M. (2022). Life-Cycle Greenhouse Gas Emissions of Sustainable Aviation Fuel through a Net-Zero Carbon Biofuel Plant Design. *ACS Sustainable Chemistry & Engineering*, 10(27), pp.8725–8732. DOI: https://doi.org/10.1021/acssuschemeng.2c00977.
8 LCAF is defined as fossil-based jet fuel that meets at least 10% emissions reductions over its life-cycle (defined as $89gCO_{2e}/MJ$ in ICAO) through measures taken across the oil supply chain such as using renewable electricity and using CCS during refinery operations

Message from Airbus' Chief Sustainability Officer (CSO)

By Julie Kitcher (Airbus)

The upcoming ICAO 42nd Assembly in September is set to be a critical event for the aviation industry. Just three years ago, at the 2022 Assembly, the entire sector united to commit to achieving net-zero carbon emissions by 2050. **The adoption of the Long Term Aspiration Goal (LTAG) marked an historic milestone,** signaling our industry's ambitious journey towards sustainability.

Building Momentum: ICAO's Framework Driving Aviation's Decarbonization Journey

The progress achieved in the past few years, particularly through **the LTAG and the CAAF/3 frameworks, has been instrumental in providing a global framework for our collective decarbonization journey.** The CAAF/3's emphasis on concrete actions and the facilitation of emissions reductions aligns perfectly with Airbus' commitment to tangible progress. We believe that the framework's call for enhanced cooperation and the exploration of various decarbonization tools directly supports the accelerated deployment and adoption of Sustainable Aviation Fuels (SAF). As we gather for this year's Assembly, we stand at the threshold of a transformative era, driven by innovation and a shared vision for a sustainable and safe future.

Sustainable Aviation Fuels: A Near-Term Imperative

For Airbus, SAF represents a cornerstone of our decarbonization strategy. With the potential to reduce lifecycle emissions by up to 80%, SAF offers a tangible and impactful solution. Realizing our ambitious decarbonization targets is directly dependent on the widespread availability and affordability of Sustainable Aviation Fuels (SAF). With SAF currently making up less than 1% of the total aviation fuel supply, a significant and rapid increase in its production and adoption is absolutely essential. This requires the concerted effort of all stakeholders, including governments, fuel producers, and the aviation industry.

Airbus strongly advocates for the establishment of robust policy frameworks and meaningful incentives to catalyze the global scaling of SAF production. These policies are essential to create a viable business case for airlines to transition to SAF, ensuring a level playing field and preventing competitive disadvantages. We believe that just as global regulations have fostered unparalleled safety in aviation, similar supportive frameworks are now crucial to unlock the full potential of SAF and drive its uptake across the industry.

Beyond SAF: A Holistic Approach to Decarbonization

While SAF is critical for immediate emissions reductions, **Airbus is pursuing a parallel strategy focused on key technological advancements for long-term impact**. Continuous innovation in aircraft design and operational efficiency, enabled by digital tools and AI, delivers vital incremental fuel savings.

Concretely, **Airbus advances key technologies which include more efficient engines, including disruptive "open fan" designs, long foldable wings allowing for significant aerodynamic gains, next-generation batteries to enable hybrid architectures, lightweight materials and integrated systems for a connected aircraft.** Airbus is working towards entry into service of the next generation of single-aisle aircraft in the second half of the next decade, with a likely launch of the programme by the end of this decade.

We still firmly believe that hydrogen will play a critical role in the long-term decarbonization of aviation, complementing the benefits of SAF. Airbus is making substantial progress in developing the technologies required to bring the first hydrogen airliner to market, recognizing its unique ability to eliminate in-flight carbon emissions. This ambitious undertaking involves overcoming complex engineering challenges related to cryogenic storage and distribution, propulsion, and airport infrastructure.

Addressing unavoidable residual emissions necessitates the development and deployment of carbon capture technologies like Direct Air Capture (DAC). While regulatory frameworks are still emerging, Airbus recognizes their significant potential and actively supports the establishment of clear international policy frameworks to facilitate their crucial role in achieving net-zero.

Looking Ahead: Partnering for a Sustainable Aviation Future

The aerospace industry has consistently demonstrated its capacity for transformative change, and the journey towards decarbonization will be no exception. With ICAO's leadership providing a clear direction and the collective commitment of stakeholders, we are prepared to enter a new era of sustainable air travel. **Airbus stands firmly alongside ICAO, governments, our industry partners, and the broader community, ready to contribute our innovation, expertise, and unwavering determination to achieve the ambitious goals we have set.** We approach the 42nd Assembly with optimism and a strong collaborative spirit, confident that together, we will not only meet the decarbonisation roadmap but also shape a safer and more sustainable future for generations to come.

Empowering Policy and Progress: How Boeing's Cascade Tool Maps Paths to Aviation's Future

By Boeing

Ensuring responsible growth for aviation, which reduces the impact on our planet, requires a multi-faceted approach — combining the right technologies, operational improvements and energy solutions with policy frameworks, investment and collaboration. It also requires robust, systems-level planning and better tools to plan, measure and manage impact.

In response to aviation's complex challenge to decarbonize, Boeing developed the Cascade Climate Impact Model[1]: A data modeling and visualization tool designed to help decision-makers, and the entire aviation ecosystem explore and compare the most effective strategies for reducing aviation's carbon emissions. Cascade can be used to guide critical decisions towards ICAO's and civil aviation's shared aspiration of net zero emissions by 2050.

Cascade[1] is a publicly available, interactive tool that leverages published flight traffic and energy data to assess aviation's future out to 2050 through assumptions related to five key areas of action: Traffic, Aircraft, Operations, Energy and Carbon Offsets & Removals. The tool helps users understand not just where emissions come from, but how the actions in each of these strategies can help reduce them over time.

Boeing publicly launched Cascade in 2023 and has been evolving[2] the tool together with governments, airlines, academia and industry partners.

Upgrade to 2.0: A Strategic Tool for Decision Making

In early 2025, Boeing unveiled[3] a new version of Cascade – Cascade 2.0, which has evolved the tool into an even more powerful platform capable of offering a more personalized and actionable approach to evaluating aviation's emissions.

Cascade offers real-time modeling for real-world impact – serving as a bridge between complex climate data and actionable insights. It provides users, including states and decision makers, with robust data and modeling to help put facts and evidence front and center in their policy conversations and decisions – whether to operationalize the Long-Term Aspirational Goal (LTAG), shape national commitments, or develop regional partnerships.

There is no one-size-fits-all approach to reducing aviation's emissions and Cascade's new functionalities reflect just that:

- **Enhanced customization for tailored planning:** Acknowledging diverse conditions across the globe, Cascade allows users to analyze the unique conditions

1 https://cascade.boeing.com/
2 https://cascade.boeing.com/perspectives/what-have-we-learned-so-far/
3 https://cascade.boeing.com/perspectives/introducing-cascade/

that apply to specific countries and regions and assess different policy scenarios to understand their potential impact on emissions towards 2050. Users can tailor their analyses by region or aircraft type.

- **Comprehensive analysis with actionable insights:** Enhanced aircraft[4] and energy[5] strategies as well as a selection of new charts provides further insights that enable assessing the impact of technological, investment, and policy decisions over time on a regional scale. Technical Documentation[5] includes information on models, datasets and key assumptions for a deeper understanding of the modeling logic behind the tool.
- **Ease of use driving collaboration and progress:** Through personalized dashboards, Cascade allows users to create, save and share scenarios with their stakeholders, as well as export data when needed – further enhancing collaboration across sectors to advance a responsible and resilient aviation system.

The Perspectives[6] page on Cascade website serves as a supportive platform to the app – offering valuable industry insights and articles on aviation's future.

Enhancing Regional Energy Production

Cascade's ability to simulate emissions pathways under varying conditions makes it a valuable tool especially for governments as they develop long-term climate strategies and monitor progress against ambitions, and advance energy transition and economic prosperity.

For example, Boeing is partnering with ICAO Member State delegations across the Middle East to bring Cascade to their State Action Plan workshops, where delegates use the tool to explore their national baseline scenarios, evaluate mitigation options available and model expected outcomes aligned with their ambitions.

Through the latest updates to functionalities, the user has granular control over data through modifying the decarbonization strategies by specific parameters such as Sustainable Aviation Fuel (SAF) feedstock types, electric aircraft introductions, and renewable energy availability. Cascade allows users to modify different energy carriers for aviation such as SAF, hydrogen, and electricity, explore the benefits and tradeoffs of each for a particular region or nation, and assess different scenarios to determine the production levels required towards 2050. Then, users can evaluate progress and see where more action is needed to further strengthen energy resilience.

Cascade empowers aviation stakeholders — from governments to airlines, to energy players — to test "what if" scenarios. For example, in the scenario shown here[7], by 2050:

- Two thirds of the total energy used by aircraft globally will come from SAF.
- 110 billion gallons (416 billion liters) of SAF will be required.
- 2.77 trillion kWh (2,770 TWh) of renewable electricity will be required to produce the necessary amount of e-fuels. This is equal to 33% of the total renewable energy that was produced globally in 2023.

Looking Ahead

Boeing continues to develop Cascade adding new capabilities and features in incremental steps, reflecting the latest climate conversations, technology developments, and policy updates.

There is no single solution for achieving aviation climate goals, and no one organization can do it alone. Cascade supports governments, airlines and the aviation industry in navigating tailored, integrated strategies, prioritizing impactful actions and crafting data-driven pathways for a resilient and responsible aviation future, together.

4 https://cascade.boeing.com/perspectives/introduction-to-aircraft-strategy/
5 https://docs.cascade.boeing.com/
6 https://cascade.boeing.com/perspectives/
7 https://cascade.boeing.com/perspectives/introduction-to-energy-strategy/

How to Integrate non-CO_2 Effects in Monitoring, Reporting and Verification Mechanisms – an Insight into Technical Options

By Florian Linke and Malte Niklass (DLR German Aerospace Center)

Introduction

Aviation contributes to global climate change, not only with its carbon dioxide (CO_2) emissions but also through non-CO_2 effects. These include emissions of nitrogen oxides (NO_x), water vapor, soot particles, and the formation of condensation trails (contrails), which significantly contribute to global warming. Recent scientific assessments estimate that non-CO_2 effects are responsible for around one-half to two-thirds of aviation's total climate impact. Unlike CO_2, which has a long atmospheric lifetime and a globally uniform effect, non-CO_2 effects are highly variable, depending on factors such as flight altitude, geographic location, weather conditions, and the chemical composition of emissions.

Effectively addressing these climate effects requires more than simply counting carbon. A sophisticated system is needed to quantify and monitor the total climate impact of aviation emissions in a comparable unit—CO_2 equivalents (CO_{2e}). This allows for integrating CO_2 and non-CO_2 effects into a single climate accountability framework. The process involves selecting suitable climate metrics, identifying required flight and emission data, managing data uncertainties, and recommending practical implementation pathways.

This article presents key scientific insights and results on how to calculate the climate impact of aviation emissions, especially non-CO_2 effects, with the purpose to integrate this understanding into monitoring, reporting and verification (MRV) systems.

Understanding Non-CO_2 Effects in Aviation

Aviation emissions impact the atmosphere through multiple mechanisms. While CO_2 emissions are directly linked to fuel consumption, other substances such as NO_x alter atmospheric chemistry, leading to the formation of ozone and reduction of methane—both greenhouse gases. Contrails, created when aircraft fly through ice-supersaturated air masses, can trap outgoing infrared radiation and form cirrus clouds that can have a warming effect, especially at night.

However, not all contrails are equal: studies show that only about 20% of flights form contrails, and among these, only a small fraction cause strong warming. In fact, around 5% of flights are responsible for the majority of contrail-related warming. This means that both the timing and location of emissions are critical in determining their climate impact. Meteorological conditions such as temperature, humidity, and solar angle further influence the net effect.

Importantly, recent research indicates that it is possible to significantly reduce non-CO_2 climate effects through operational measures. Examples include avoiding contrail-prone regions through appropriate flight planning or using sustainable aviation fuels. However, these measures must be evaluated in the context of their total climate impact, including possible trade-offs with CO_2 emissions.

Quantifying the Climate Impact: Climate Metrics

To integrate non-CO_2 effects into climate policy and emissions reporting, they must be expressed in the same unit as CO_2 emissions. This is done through climate metrics that convert the warming impact of different emission species into CO_2 equivalents.

This can be generally done in two different ways, either with a climatological approach, which evaluates the impact of a flight that is repeatedly offered over a longer period of time, or with a weather-based approach that considers the current weather situation at the time of an individual flight. Which approach to use depends on the suitability for a particular aircraft operator. The weather-based approach, however, has a larger climate mitigation potential and should therefore be the preferred one[1].

Based on an evaluation of different climate metrics regarding transparency, stability, scientific soundness, and policy compatibility the following two metrics turn out to be best suited for use in an MRV[1]:

- Global Warming Potential (GWP): The most widely used metric, particularly over a 100-year time horizon (GWP100), integrates the radiative forcing (a measure of atmospheric energy imbalance) over time. While GWP is stable and widely understood, it does not fully capture the short-term dynamics of aviation emissions.
- Average Temperature Response (ATR): This metric measures the average temperature increase caused by emissions over a specific period. ATR is closer to temperature-based climate goals and better accounts for the atmospheric response to short-lived pollutants. It is also relatively stable and suited for comparing new fuels and aircraft technologies.

Comparative studies suggest that ATR and GWP offer the best balance between scientific accuracy and policy usability, especially for long-term climate goals. For consistency with existing international frameworks and to take into account that short time horizons can lead to climate mitigation measures that might help in the short-term, but have less beneficial consequences in the long-term, a time horizon longer than 70 years is generally recommended. In case the GWP is chosen, it is recommended to adjust the metric such that it also accurately captures the climate effect of aviation non-CO_2 emissions by considering the efficacy of the different species[1].

Modeling Aviation Emissions and Climate Effects

To calculate the CO_{2e} in one of the above climate metrics, models are needed that can capture how different emissions affect the atmosphere. An MRV framework should generally be flexible enough to work with various different climate models and to incorporate new models as well.

For the climatological approach climate response models (e.g., AirClim) that combine emission inventories with precomputed atmospheric responses to estimate large-scale, long-term impacts are well suited. For the weather-based approach a combination of statistical models (e.g., algorithmic Climate Change Functions, aCCFs) and detailed physical models (e.g., CoCiP) can be used. While statistical models use precomputed correlations between meteorological conditions and climate effects, enable fast estimates and provide reasonable accuracy, the detailed physical models can simulate contrail formation and lifecycle in high resolution, using weather forecasts and aircraft-specific data. These models can inform precise contrail avoidance strategies[1].

Each model has its strengths. Simpler models are suitable for large-scale assessments and routine reporting, while detailed models are better for evaluating specific mitigation strategies, such as rerouting or fuel switching. All models require flight data, meteorological input, and assumptions about emission characteristics. They must also be periodically updated to reflect advancements in climate science.

1 See also: de Haes et al., 2024, “Support for establishing a monitoring, reporting and verification system for non-CO_2 effects in aviation, stemming from the revision of the ETS Directive”, final report.

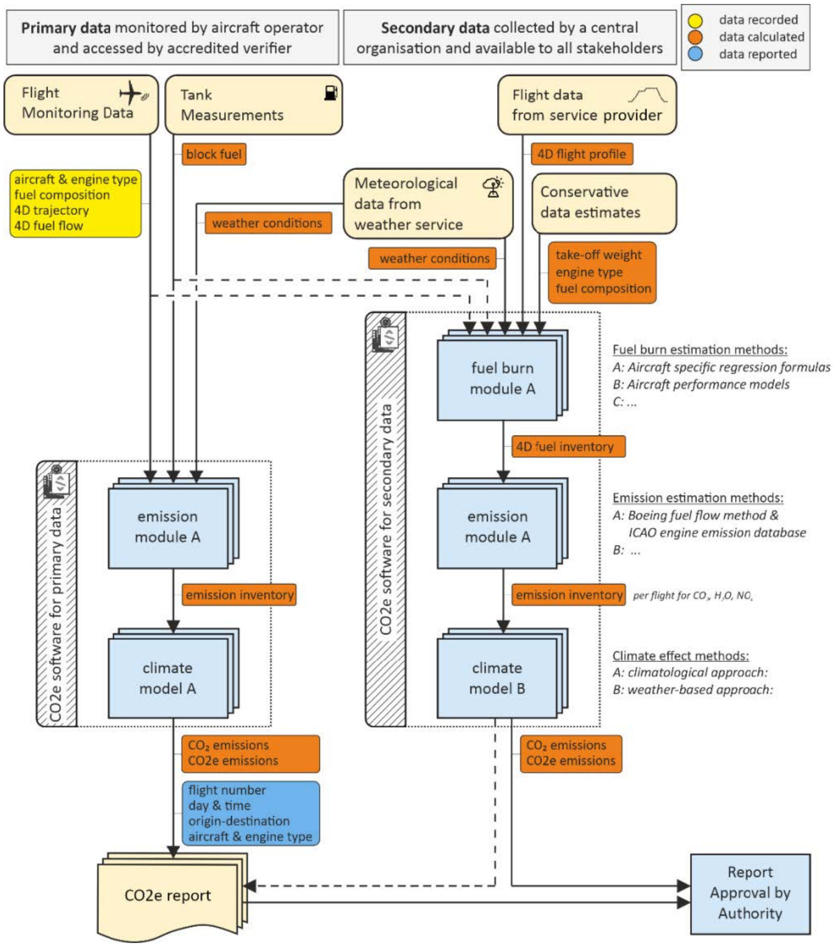


FIGURE 1: Flowchart of possible MRV framework for aviation non-CO_2 emissions (adapted from Niklass et al., 2024[2]).

Data Requirements for Effective Monitoring

To monitor, report, and verify aviation's non-CO_2 climate effects, flight data is required. The data collection should be limited to what's necessary for environmental benefit while minimizing MRV effort. Data needs vary by modeling approach, mitigation strategies, and MRV purpose.

It is useful to distinguish between three different data types[2]: primary (directly monitored by operators and verifiable), reporting (basic data to assign emissions), and secondary (used for conservative emissions estimates by services like EUROCONTROL). Secondary data also supports cross-checking by authorities. Operators can optionally provide more detailed data to improve accuracy.

Minimum data needed for basic assessments include at least:

- Aircraft and engine type,
- Flight profile: (departure, arrival, altitude),
- Fuel consumption,
- Flight times and distances.

Additional data that improve accuracy:

- Real-time 4D flight trajectory data (with timestamps),
- Fuel composition (especially hydrogen and aromatic content),

2 Niklass et al., 2024, "Implementing an EU Agreement on Monitoring, Reporting and Verification of Non-CO_2 Climate Effects in Aviation", German Aerospace Congress 2024, Hamburg.

- Meteorological data during the flight (e.g., temperature, humidity, wind),
- Engine performance parameters.

For simplified models, historical averages and assumptions may suffice. More advanced models, especially those enabling flight-specific assessments, require high-resolution, flight-by-flight data.

Managing Data Gaps and Uncertainties

In practice, full data availability cannot always be guaranteed. Therefore, strategies are needed to manage data gaps[1]:

- Default values and estimation methods: Where specific data are missing, conservative default values based on aircraft type or historical averages can be used.
- Substitution from trusted databases: Aircraft and engine registries, fuel specifications, and meteorological archives can provide reference data.
- Interpolation and extrapolation: Missing segments in flight paths or weather data can be estimated using nearby or similar flights.

Uncertainty is inherent in estimating non-CO_2 climate effects. Key sources include model assumptions, variability in meteorological conditions, and incomplete understanding of contrail dynamics. These uncertainties must be incorporated and examined through suitable validation, evaluation, and assessment processes to enhance understanding and enable the quantification of risks and impacts. Although these uncertainties exist, they can be managed through transparent methodologies, conservative assumptions, and continuous model refinement and should not prevent the implementation of MRV frameworks[1].

Enabling Implementation in Aviation Monitoring Systems

For practical use, these insights must be embedded in operational systems that allow airlines, authorities, and verification bodies to monitor and report non-CO_2 climate impacts. The proposed setup includes[1]:

- A central platform to process flight data and apply the chosen climate models and metrics.
- Interfaces for airlines to upload flight and fuel data.
- Verification mechanisms to ensure data quality and compliance.
- Modular design to allow gradual integration of advanced models and technologies.

Operators can choose between simplified approaches (using average values and basic models) and advanced methods (using weather-dependent models and full data sets), depending on their capabilities and ambitions. This flexibility supports broad adoption while encouraging continuous improvement.

Incentivizing the Reduction of Aviation's Climate Impact

The ultimate goal of quantifying non-CO_2 effects is to reduce aviation's total climate impact. By making these effects visible and measurable, airlines can be incentivized to:

- Avoid contrail-prone regions and altitudes,
- Adopt sustainable fuels,
- Optimize aircraft design and flight operations,
- Invest in innovative low-emission technologies.

While technical and economic challenges remain, integrating non-CO_2 effects into climate accountability frameworks is a critical step toward climate-responsible aviation.

Conclusion

By selecting appropriate climate metrics, modeling tools, and data strategies, aviation stakeholders can take meaningful steps toward measuring and mitigating their full climate impact. The path forward involves balancing complexity with feasibility, managing uncertainties transparently, and building systems that can evolve with new technologies and scientific insights. As the climate urgency intensifies, addressing all climate-relevant emissions from aviation becomes not just a scientific necessity but a policy imperative.

Institute for Sustainable Aviation: Three Years of Interdisciplinary Research and Training Excellence

By Prof. Laurent Joly (ISAE-SUPAERO)

Located in Toulouse, at the heart of the European aeronautics metropolis, the Institute for Sustainable Aviation (ISA) is a large academic consortium dedicated to advancing research and training for sustainable air transport. Bringing together leading institutions of the University of Toulouse, such as ISAE-SUPAERO, ENAC, and the Toulouse School of Economics (TSE), ISA fosters interdisciplinary collaboration at the intersection of engineering, economics, and environmental sciences. Over the past three years, ISA[1] has been driving forward key initiatives that contribute to shaping the future of air transport. This article highlights some of the most impactful research projects, partnerships with stakeholders, and training programs, demonstrating its commitment to preparing the next generation of experts in sustainable aviation.

Pioneering Research for a Greener Aviation Future

AeroMAPS: A Comprehensive Decision-Support Platform

The AeroMAPS (Aviation Environmental Roadmap for Multidisciplinary Assessment of Prospective Scenarios) framework has been developed as an open-source tool designed to model and evaluate decarbonization pathways for air transport. This platform integrates models of air traffic evolution, fleet renewal strategies, alternative fuels, and environmental impact assessments to provide a holistic view of aviation sustainability. Its growing scope and transparency have brought it much legitimacy and interest from Airbus, EUROCONTROL, and a growing user community.

More than just a modelling tool, AeroMAPS serves as a collaborative platform enabling researchers, policymakers, and industry stakeholders to explore future scenarios. By simulating various technological, economic, and regulatory measures, it helps anticipate challenges and optimize strategies for reducing aviation's environmental footprint. Its accessibility through a web application[2] positions it as an ideal resource for young researchers seeking to engage with real-world sustainability challenges in aviation.

PhD Research: Transforming Fleet Assignment for Decarbonization

Research led by Paco Viry focuses on advancing global fleet assignment models to better capture the dynamics of aircraft allocation on different routes. Traditional fleet

1 www.isa-toulouse.com
2 https://aeromaps.isae-supaero.fr/

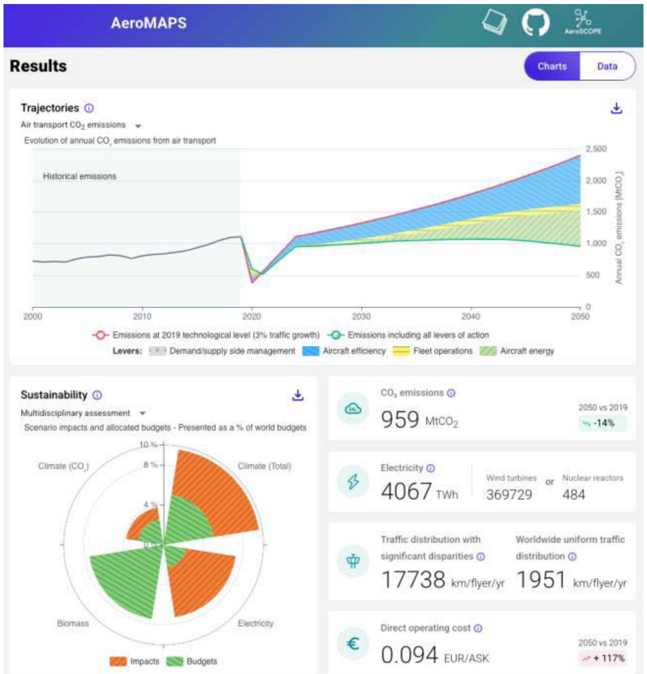


FIGURE 1: Overview of the AeroMAPS modelling tool.

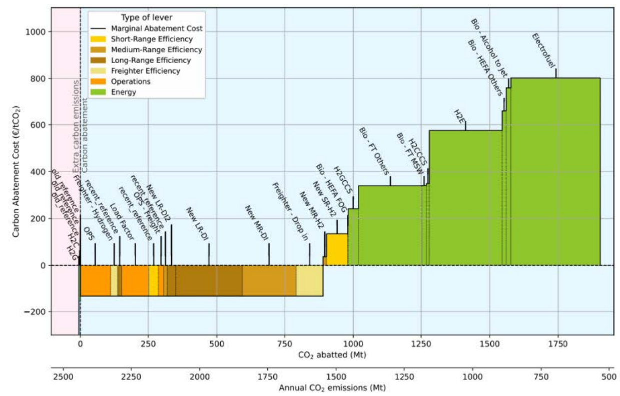


FIGURE 2: Example of carbon abatement cost assessed with the Climate and Aviation - Sustainable Trajectories (CAST) simulation framework.

segmentation approaches rely on static classifications of aircraft by size and range, which fail to account for evolving aircraft capabilities and market changes.

By employing an adapted weighted multinomial logit model, this research introduces a more flexible, data-driven approach to fleet renewal planning. The model incorporates route-specific characteristics, fuel efficiency trends, and competition dynamics, allowing for a more precise estimation of how new aircraft types—such as hydrogen-powered or hybrid-electric planes—will integrate into airline operations. This work lays the foundation for more accurate projections of fleet evolution and its impact on aviation decarbonization strategies.

PhD Research: The Economic Viability of Low-Carbon Fuels

Research conducted by Antoine Salgas explores the economic implications of integrating low-carbon fuels into future aviation scenarios. Using the Climate and Aviation - Sustainable Trajectories (CAST) simulation framework, this study links fuel production costs to industry-wide sustainability strategies. Access the PhD report here[3].

Findings indicate that while sustainable aviation fuels (SAF) and hydrogen will play a critical role in reducing emissions, their adoption comes with significant financial challenges. By analysing various cost scenarios, including the impact of carbon pricing and policy incentives, this research supports decision-making processes aimed at designing pathways that balance environmental goals with economic feasibility. Such insights are essential for shaping investment decisions in aviation's transition to a low-carbon future.

PhD Research: Welfare Effects of Decarbonizing Aviation through market-based policies

Mudit Dhakar's research, conducted at the Toulouse School of Economics (TSE), investigates the welfare effects of market-based policies aimed at reducing aviation emissions. The study focuses on the impact of taxation mechanisms such as fuel taxes, carbon pricing, and airport charges on air traffic demand, airline strategies, and consumer welfare.

By employing a two-sided market model, the research assesses the trade-offs between environmental gains and economic costs, providing insights into how taxation policies can be optimized to achieve decarbonization goals with minimal adverse effects on passengers and industry stakeholders. This work is instrumental in guiding policymakers toward effective and balanced aviation decarbonization strategies.

3 https://depozit.isae.fr/theses/2025/2025_Salgas_Antoine.pdf

Innovating Education for Future Leaders in Sustainable Aviation

The TransitionS Program: A New Educational Paradigm

To equip future professionals with the knowledge and skills required for sustainable aviation, ISAE-SUPAERO and ENAC have jointly developed the TransitionS program, a groundbreaking interdisciplinary training initiative. This program redefines aviation education by integrating online learning, engineering expertise, and socio-economic perspectives.

TransitionS offers a diverse range of courses tailored to different audiences:

- **MOOCs (Massive Open Online Courses)**: Short, accessible courses (57 hours) designed for the general public, launching in 2025.
- **Certification Programs**: More in-depth modules (30-60 hours) aimed at undergraduate students and industry professionals, available from 2025.
- **Online Master's Degree**: A comprehensive 500-hour program focusing on sustainable aviation strategies, set to launch in 2026.

Beyond conventional aeronautical engineering training, TransitionS emphasizes systemic thinking. Participants explore the economic models of aviation (functional and circular economies), evolving travel behaviours, and the environmental impacts of aviation (climate, biodiversity, andresource use). The curriculum is designed to develop three core competencies:

1. **Environmental impact assessment** of aviation-related products and services.
2. **Designing sustainable solutions**, including new aircraft concepts, alternative fuels, and regulatory strategies.
3. **Implementing transformation strategies** in aviation organizations, ensuring a practical, real-world approach to sustainability challenges.

By leveraging online education, the TransitionS program breaks the barriers of traditional classroom learning, making high-quality, interdisciplinary training accessible to a global audience. This initiative demonstrates a commitment to engaging bright minds worldwide in the quest for sustainable aviation.

Collaborating with Industry for a Sustainable Future

Partnership with Airbus: Advancing Environmental Impact Assessment

Collaboration with Airbus focuses on refining methodologies for assessing the environmental impact of air transport. This partnership aims to develop comprehensive Life Cycle Assessment (LCA) tools that account for both CO_2 and non-CO_2 climate effects, as well as the broader environmental consequences of aircraft operations.

Through the integration of improved climate models into AeroMAPS, this initiative bridges the gap between theoretical impact assessments and practical industry applications. Work includes refining NO_x emissions impact models, updating aviation life-cycle inventories, and developing open-source climate assessment tools. Additionally, a complementary research project examines the influence of climate risks on passenger demand. This initiative explores how financial and environmental uncertainties shape travel behaviours, providing Airbus with insights into future market trends and sustainable business strategies. These efforts contribute to Airbus' long-term strategy for reducing the environmental footprint of air transport and tailoring AeroMAPS to become Airbus' reference scenario platform.

Collaboration with Thales: Tackling Air Traffic Inefficiencies

In partnership with Thales, research is being conducted to address inefficiencies in air traffic management (ATM) to improve operational sustainability. By analysing real-world flight data and simulating optimized air traffic scenarios, researchers are developing new methodologies to measure and mitigate inefficiencies in the ATM system.

The project employs a dual approach: a data-driven analysis of past flight trajectories to quantify operational inefficiencies, and a simulation-based method to model and optimize air traffic flows under various constraints.

This work is crucial in identifying and reducing excess fuel burn, unnecessary delays, and operational bottlenecks, all of which contribute to aviation's carbon footprint.

Through this partnership, these findings are being implemented into real-world scenarios within the AeroMAPS platform, demonstrating tangible pathways for increasing the efficiency of global air traffic operations.

Looking Ahead: The Next Chapter in Sustainable Aviation

As a leading academic consortium, ISA will continue to expand its research and education efforts. New projects are on the horizon, focusing on hydrogen-powered aviation, air-rail multimodality, and enhanced regulatory frameworks. By fostering collaboration between researchers, industry leaders, and policymakers, ISA aims to accelerate the aviation sector's transition to a more sustainable future.

ICAO

CHAPTER THREE

Climate Change Mitigation – Aircraft Technologies

Technology Solutions to Support ICAO's Long-Term Global Aspirational Goal (LTAG)

By ICAO Secretariat

The ICAO Strategic Objective on Environmental Protection is to minimize the adverse environmental effects of civil aviation activities. To minimise civil aviation impact on global climate, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal. The achievement of the LTAG will rely on the combined effect of multiple CO_2 emissions reduction measures, including the accelerated adoption of new and innovative aircraft technologies, streamlined flight operations, and the scaled-up production and deployment of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF), and other aviation cleaner energies.

ICAO under its technical Committee on Aviation Environmental Protection (CAEP) undertook extensive work on the feasibility study of LTAG, which was made publicly available on the ICAO website in 2022[1]. For transparency and comprehensiveness, the Technology-focused Appendix M3 (Figure 1) to the LTAG Report provides details on methodology used for assessing CO_2

FIGURE 1: LTAG Report and Appendix M3 on Technology.

1 https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

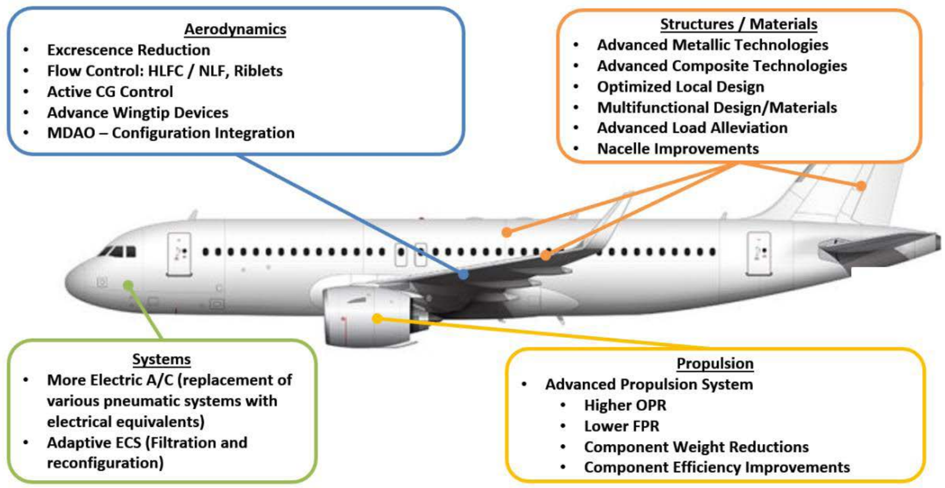


FIGURE 2: Scope of potential technologies to mitigate CO_2 emissions for narrow-body aircraft.

reduction potentials in 2050 based on the Independent Expert Integrated Review (2019 IEIR) Report[2]. From a high-level perspective, the LTAG methodology involved four main steps including creating the technology reference aircraft, assessment of advanced tube and wing configurations, assessment of advanced concept aircraft, and generation of the necessary information for the fleet-wide modeling and cost assessment. For example, a scope of potential technologies to mitigate CO_2 emissions for wide-body aircraft is presented on Figure 2.

Noting that the technologies and innovations considered in the LTAG feasibility study varied in terms of their technology readiness levels, ICAO is continuing to monitor, through the Technologies tracker[3], the projects that can potentially contribute to reaching the LTAG. This Tracker provides a variety of information on initiatives related to technologies and innovation aimed at reducing the environmental footprint of aviation, including details of past and ongoing initiatives and embracing electric, hybrid and hydrogen powered propulsion systems, novel aeroplane designs and advanced air mobility projects. The Tracker also includes information from the ICAO Global Coalition for Sustainable Aviation[4] partners (Figure 3), which is a forum of stakeholders facilitating the development of new ideas and accelerating the implementation of innovative solutions that will further reduce greenhouse gas emissions at source, on the ground or in the sky.

To complement outreach facilitation, ICAO is raising awareness and transparency on Technologies through the annual Stocktaking process, which started with the ICAO Stocktaking Seminar on aviation in-sector CO_2 emissions reductions in 2020. In June 2025 it is held as ICAO Aviation Climate Week - *Skyward Action: Realizing Aviation's Sustainable Future*[5], at the ICAO Headquarters. On top of the Stocktaking best practices, this three-day

FIGURE 3: Partners of ICAO Global Coalition for Sustainable Aviation.

2 "Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft", ICAO Doc 10127, 2019. https://www.icao.int/environmental-protection/Pages/ClimateChange_TechGoals.aspx
3 https://www.icao.int/environmental-protection/SAC/Pages/Technology.aspx
4 https://www.icao.int/environmental-protection/SAC/Pages/learn-more.aspx
5 https://www.icao.int/Meetings/2025AviationClimateWeek/Pages/default.aspx/

event is aimed at providing an opportunity for participants to be informed of the overall progress achieved and discuss the latest developments on all environmental topics, prior to the 42nd Session of the ICAO Assembly.

During this Aviation Climate Week, Session 3 will focus on Aircraft Technologies to Mitigate Aviation Emissions, bringing forward the airframe and engine design concepts needed to tackle aviation climate impact. Additionally, the ICAO efforts in making more stringent aeroplane CO_2 emissions and noise design Standards will be at the center of discussions.

And the following Session 4 on Building the ecosystem for electric- and hydrogen-powered aircraft will discuss how to build an ecosystem that is ready for these cutting-edge technologies, addressing associated opportunities, systemic environmental benefits and challenges.

With the near-term outlook on technological standards, ICAO is taking firm steps towards LTAG to take effect in the coming years. During its 13th meeting in February-March 2025, CAEP proposed more stringent aircraft noise and CO_2 emissions standards – this is the first time when both standards have been made more stringent simultaneously for aviation. The intent is to shape the next generation of aircraft designs by moving manufacturers toward solutions that address these closely related environmental impacts, one of which is fuel efficiency. More details on this and other work carried out by CAEP's Working Group 3 (WG3) can be found in the next article of this Chapter. The outcomes of CAEP/13 will be considered by the ICAO Council and will inform crucial global policy decisions at the 42nd Session of the ICAO Assembly in October 2025.

This Chapter also reflects the growing attention to non-CO_2 emissions, such as nitrogen oxides (NO_X) and contrail-related effects, which may contribute significantly to aviation's overall climate impact. The article led by DLR, NRC, and ONERA explores emerging solutions to reduce non-CO_2 impacts, reinforcing that future technologies must be evaluated holistically to ensure cleaner and more competitive aviation.

Conclusion

With innovation at the heart of its mitigation strategy, ICAO is embracing a wide scope of technology solutions—not only within aviation but also from adjacent sectors, including information technologies such as artificial intelligence (AI) and potential out-of-sector synergies. ICAO remains firmly committed to fostering the enabling environment needed to transition the global civil aviation sector toward its LTAG, laying the foundation for a more sustainable, resilient, and climate-friendly aviation system in the decades ahead.

Emissions Technical: Progress of CAEP/13 Working Group 3

By Bethan Owen (UK)[1] and ICAO Secretariat

The ICAO Committee on Aviation Environmental Protection (CAEP), through its working groups, has advanced a broad range of activities in the field of aircraft environmental performance under its thirteenth cycle.

While historically CAEP has considered CO_2 Emissions and Noise stringency analyses independently (i.e., in different cycles), this was the first time when both were analysed at the same time. This integrated approach — known as the *Integrated Dual Stringency* (IDS) analysis — was a major step forward in understanding how environmental and cost impacts interact when multiple standards are applied simultaneously. It required a new and integrated approach to consider interdependencies between CO_2 emissions (fuel burn) and noise.

The execution of the integrated dual stringency analysis for aeroplane CO_2 emissions and Landing and Take-off (LTO) noise was jointly conducted by CAEP Working Group 1 (WG1, *Noise Technical*), Working Group 3 (WG3, *Emissions Technical*), the Modelling and Databases Group (MDG), and the Forecasting and Economic Support Group (FESG). This integrated effort has culminated in the completion of a comprehensive analysis presented for CAEP's consideration.

The Integrated Dual Stringency Analysis

Following the agreement reached at CAEP/12 in February 2022, the integrated stringency work was developed to support a dual standard-setting process for aeroplane CO_2 and noise emissions. The collaboration between WG1, WG3, MDG, and FESG was coordinated under the Integrated Stringency Coordination Group (ISCG), ensuring consistency and alignment across technical analyses and modelling assumptions.

The CAEP/13 integrated dual stringency analysis includes the assessment of stringency options (SOs) concerning (1) New Type (NT) standards for aeroplane CO_2 emissions and Noise and (2) the In-Production (InP) standard for aeroplane CO_2 emissions (only).

Summary of Results: Dual CO_2 and Noise Stringency Analysis for New Type Aircraft (NT)

To carry out this assessment, two modelling methods were used to simulate future aircraft fleet responses: the A1 approach, which assumes aircraft respond immediately once a standard is in place, and the M.07 approach, developed during CAEP/13, which reflects a scenario in which responses are delayed—representing the time required for new technologies to enter the market. Both modelling approaches are scenarios and the "reality" is likely to lie in between these.

The analysis considered various combinations of CO_2 Stringency Options (CSOs) and Noise Stringency Options (NSOs). CSOs and NSOs represented different levels of stringency for the New Type aeroplane CO_2 and noise standards, labelled progressively from A to G and A to E respectively. Each higher letter (e.g., CSO D compared to CSO A) indicated a more stringent emissions requirement,

1 Bethan Owen is Co-Rapporteur of Working Group 3 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

meaning fewer aeroplanes can comply without requiring a Technology Response — design or performance adjustments made by manufacturers to meet the standard.

A1 Approach Results

Under the A1 method, results showed a clear pattern: more stringent CSOs led to greater reductions in cumulative CO_2 emissions. As stringency increased from CSO A to CSO D, the share of aircraft passing without needing TRs dropped significantly—from 76% at CSO A to just 38% at CSO D. A major drop in emissions occurred at CSO D, particularly because no aircraft in a specific sub-market segment could meet the standard. In such cases, a modelling rule called Empty Competition Bin Management (ECBM) was applied: demand was fulfilled using larger aircraft from the next market segment, leading to fewer total flights and reduced fuel use.

For noise, increasing NSOs led to greater reductions in population and area exposed to 55 dB levels. The highest noise reductions were achieved with NSO E, the most stringent level. Cost outcomes followed a similar trend to emissions, with more stringent CSOs and NSOs (especially scenario CSOD\NSOE) resulting in larger reductions in total cumulative costs — driven by fewer operations, lower fuel consumption, and reduced capital and operating expenses.

M.07 Approach Results

The M.07 approach allowed assessment of scenarios that were not possible under A1 due to ECBM constraints. Unlike A1, M.07 assumes aircraft take longer to adapt to new standards. As a result, environmental benefits under M.07 tend to emerge later and can be more moderate especially in view of the fixed analysis time out to 2050.

In CO_2 terms, results under M.07 were mixed. For example, CSO D and the highest level, CSO G, showed lower emission reductions than some less stringent options. This is because, when no aeroplane(s) in a Competition Bin can be modified to meet a given CSO, M.07 reverts that bin to its original 2029 baseline configuration. That means no environmental improvement from that segment—unlike A1, which fills the gap with larger, more efficient aeroplanes. Nonetheless, CSO E and F scenarios still showed strong CO_2 reductions under M.07.

For noise, as in A1, greater NSO stringency led to better (quieter) results.

Top-Performing Scenarios

In summary:

- Under the A1 approach, scenario CSO D\NSO E delivered the strongest combination of benefits in cost, CO_2, and noise.
- Under the M.07 approach, CSO F\NSO C ranked highest in cost and CO_2 reductions, while CSO C\NSO E performed best for noise.

Scenario rankings remained stable even when discount rates (3%, 7%, 9%) were applied, especially for the top performers. This consistency reinforces the reliability of the analysis and provides a solid technical foundation for decision-making on future international standards.

As part of the CAEP/13 integrated assessment, the CO_2 standard for In-Production (InP) aeroplanes were also evaluated using the A1 fleet evolution modelling approach. Results showed that higher stringency levels led to greater reductions in CO_2 and costs. CAEP considered the purpose of an InP standard for CO_2, recognizing that the InP regulatory level was established in CAEP/10 as part of the first CO_2 standard to prevent backsliding of in production products over time and to provide a production cut off for low performing products. The CAEP agreed that the regulatory focus for a technology standard should be the New Type regulatory level which can influence the clean sheet designs of future aeroplane designs.

Summary of Integrated Dual Stringency Results

After consideration of the stringency options for the Annex 16, Volume III provisions, CAEP recommended amendments to the CO_2 Standard for subsonic aeroplanes with 10 per cent / 3 per cent more stringent limits for large / small aeroplanes with an applicability date on 31 December 2031 for new aeroplane types, and more stringent emissions standard for in-production aeroplane types applicable on 1 January 2035. CAEP also recommended amendments to the Noise Standard for subsonic aeroplanes with 6dB

/ 2dB more stringent limits for large / small aeroplanes applicable on 1 January 2029.

These recommendations, along with other recommendations agreed during the 13th CAEP meeting held at ICAO Headquarters from 17 to 28 February, will be considered by the Council in due course in 2025.

Other WG3 Work during the CAEP/13 Cycle

Beyond the dual stringency analysis, WG3 advanced several other activities across its full Work Programme for the CAEP/13 cycle. These included work on emissions characterization, certification requirements, supersonic transport, fuel composition effects, and coordination with other groups on environmental trends.

For example, WG3 Emissions Characterisation Task Group addressed a wide range of topics including:

- Updates to ICAO Doc 9889 *Airport Air Quality Manual* to reflect new modelling methodologies and emissions data;
- Assessment of nvPM and NO_X emissions and their relation to cruise operations;
- Review of potential new NO_X metric systems for future aircraft engine emissions standard setting processes;
- Study of ambient conditions corrections and particle size changes affecting nvPM emissions.

The WG3 Certification Task Group worked to maintain and update Annex 16, Volume II (engine emissions) and Volume III (aeroplane CO_2 emissions) with the associated Environmental Technical Manual (ETM) Volumes II and III, as well as CO_2 and emissions engine certification databases.

Notably, the CTG submitted drafted amendments to align Volume III with the new CAEP/13 Aeroplane CO_2 Standards for NT and InP. These updates addressed clarity in compliance methods (direct flight testing or performance models), definitions, SARPs applicability, and editorial improvements to ensure consistency across regulatory material.

The WG3 Supersonic Transport Task Group STG addressed certification requirements and environmental impacts associated with supersonic transport aircraft. The group worked in parallel with WG1's related activities and assessed appropriate regulatory paths and timeline considerations.

Additionally, WG3 worked in close coordination with the Fuels Task Group (FTG, WG5 in the current CAEP/14 cycle) and the Impacts Science Group (ISG) to assess emissions effects of fuel composition, particularly Sustainable Aviation Fuels (SAF). The cross-cutting work supported the integration of SAF effects into emissions quantification and ensured coordinated input to MDG and other groups.

WG3 also contributed to the ICAO Environmental Trends Assessment, including providing assumptions for emissions projections and delivering inputs for the modelling activities led by MDG.

Finally, WG3 collaborated with WG1 and MDG on public data analysis reflecting interest in leveraging public datasets for future stringency assessments.

Conclusion

The CAEP/13 cycle has marked a significant advancement in the ICAO community's ability to assess and develop certification standards for improved aircraft environmental performance. Through the integrated dual stringency work—spearheaded jointly by WG1, WG3, MDG, and FESG—and the broader programme of technical development under WG3's Work Programme, ICAO continues to deliver the data-driven, collaborative foundation needed to inform regulatory progress. The extensive technical work conducted, culminated in the CAEP/13 Report with the related appendix containing regulatory impact assessment information to support the rulemaking processes of ICAO Member States for implementation of the integrated CO_2 and noise standards stringencies, provides the basis for critical decisions on the integrated dual stringency in support of the Organization's long-term environmental goals.

The CAEP/13 work developed by Working Group 3 is now under ICAO Council consideration for final approval.

Enabling a zero-carbon future for aviation

By Alejandro Block (IATA) and Jennifer Desharnais (ACI)

Aviators are innovators. Within a single lifetime, aviation has evolved and reinvented itself many times over. It has progressed from canvas-and-wood aircraft powered by piston engines and wooden propellers to multi-engine swept-wing passenger planes, routine transatlantic crossings, and today's cutting-edge cabin technology.

Modern aircraft are built from ultra-light, ultra-resistant composite materials, with engines operating at temperatures exceeding the melting point of their metal components. Passenger capacities now approach 500, offering unprecedented levels of comfort and safety. This is possible at a fraction of the cost, energy, and environmental impact it would have had eight decades ago. What do we imagine aviation to be like in eighty years' time? What do we need to do today to secure that future? The authors of this article coincide with the same view: maximum safety and efficiency levels with lowest environmental and noise impacts. This article highlights recent progress on zero-carbon air travel and the steps which must continue to happen today to ensure a sustainable future for our sector.

Progress since the 2022 Environmental Report

IATA and ACI have identified 44 airports and 35 airlines which have expressed interest in a hydrogen future for aviation. These numbers areI think three times higher than they were in 2022. Public announcements cite initiatives going from feasibility studies and memorandums of understanding to investment in technology companies. Some airports[1] are already building hydrogen infrastructure on-site for ground support equipment and ground transportation, preparing for a hydrogen future for travelers.

In its Net Zero Roadmap (2023), IATA highlights130 individual milestones required to reach net zero by 2050. These milestones are spread into technology, operations, infrastructure and policy items which must be met at specific times for us to be on track. Fortunately, we have identified progress across these milestones in 44 individual aircraft concepts from 23 companies which are advancing the critical technologies needed for a zero-carbon future. While it is acknowledged that many of these projects will not result in a commercial-flying product, and that many of the target dates might change, what matters is that technologies are being matured and tested, and we see progress.

The contribution that these aircraft will make towards the ICAO Long Term Aspirational Goal (LTAG) depends on how soon they come into the market, how many passengers they will carry, how far they can fly, and how fast production rates can be scaled-up. Their successful implementation will also be limited by the aviation sector's access to affordable low-carbon hydrogen and energy, for which enabling policies are urgently required.

IATA studied a *Regional Aircraft-First* strategy, where hydrogen and battery-powered aircraft start entering service in the 2030s, first with regional aircraft (less than 69 passengers), followed by single aisles nearly a decade later. This scenario resulted in around 20% of the fleet being powered by hydrogen or batteries in 2050 (about 10,00 aircraft), resulting in a 6% reduction in CO_2 emissions, compared to a case where these aircraft don't exist. This

1 See Rotterdam Airport, Toulouse Airport, Kansai Airport, Toronto Pearson Airport.https://www.iata.org/globalassets/iata/publications/sustainability/concept-of-operations-of-battery-and-hydrogen-powered-aircraft-at-aerodromes.pdf
https://store.aci.aero/product/integration-of-hydrogen-aircraft-into-the-air-transport-system-an-airports-operations-and-infrastructure-review/#:~:text=ACI%20world%2C%20in%20partnership%20with,should%20they%20come%20into%20service.

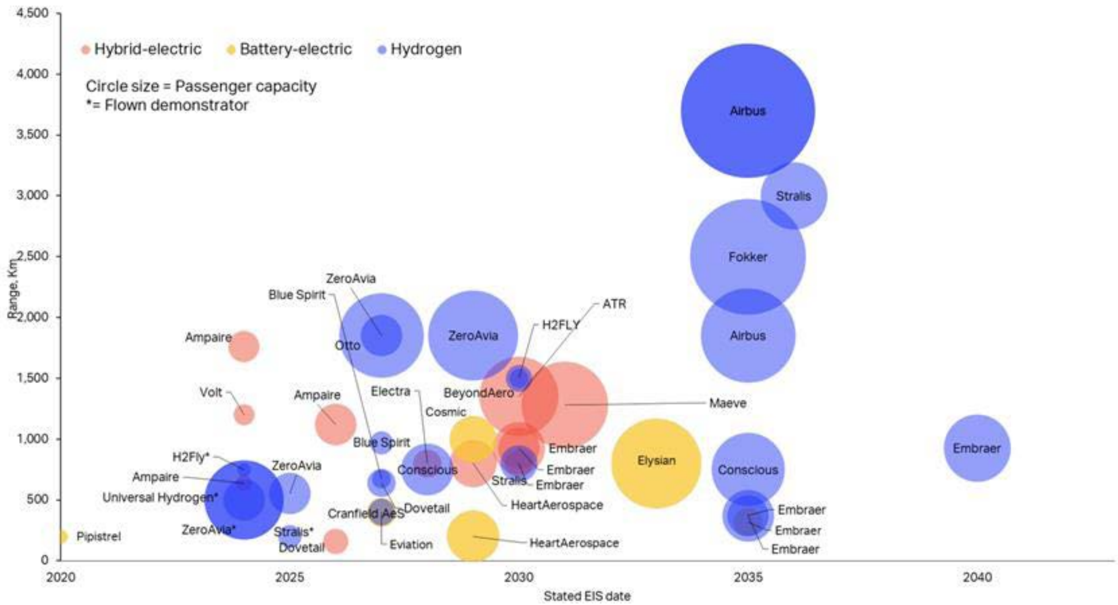


FIGURE 1: Future aircraft concepts, their passenger capacity, announced entry into service date, and energy source. Source: IATA Sustainability and Economics.[1]

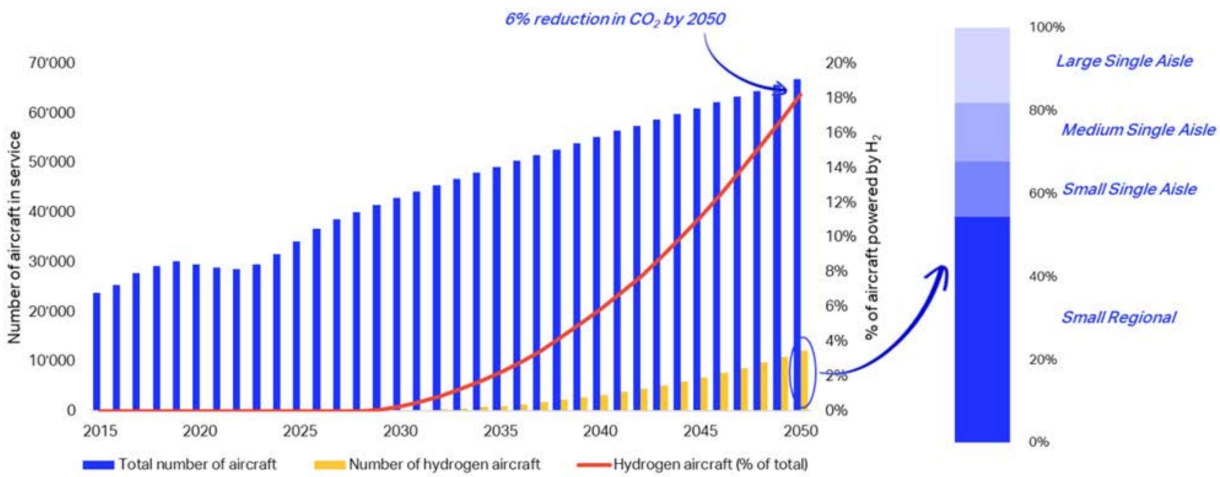


FIGURE 2: Deployment of hydrogen fleet according to the IATA Roadmaps. Source: IATA Sustainability and Economics:[3]

number could change considerably if the dates are delayed or accelerated, and if the aircraft class is changed.

To make this a reality, we need to develop infrastructure at airports, procedures and standards, regulation, personnel skillset, and an economically feasible and reliable hydrogen supply chain.

How is the ecosystem preparing for this?

While each stakeholder will adapt at its own pace, clear patterns are emerging in how the ecosystem prepares for the energy transition. Some of the key steps are outlined below, taken from examples observed of action all over the world, and some of which can be found in the ICAO

2 https://www.iata.org/en/iata-repository/publications/economic-reports/aviation-is-innovation-a-peek-into-future-aircraft-concepts/
3 https://www.iata.org/en/iata-repository/publications/economic-reports/evolution-of-hydrogen-aircraft-fleet-to-2050/

Eco-Airport Toolkit e-collection publication on new energies at airports and the hydrogen and battery-powered aircraft CONOPS[4]

1. **Funding research and boosting innovation and technology:** The first building block to make zero-carbon flight a reality is to mature the critical enabling technologies which will enable these aircraft to fly. Public and private initiatives are raising funds both through government and private finance to materialize their roadmaps.
2. **Formation of alliances, consortiums, working groups:** Effective collaboration and coordination across the full supply chain (States, airports, airlines, technology developers, energy and hydrogen providers, regulators, investors, etc.) to accelerate the introduction of non-conventional aircraft in a timely and safe way is critical and should be backed up by roadmaps and concrete milestones, strong financing partners, and government support. The reader is directed to examples of good practices like: H2CanFly (Canada), Hydrogen Flight Alliance (Australia), AZEA (Europe), Jet Zero Council (United Kingdom).
3. **Deploying hydrogen and/or battery-powered vehicles at the airport:** Several airports are taking the lead on deploying hydrogen- or battery-powered ground support equipment, both airside and landside. These activities will not only help airports decarbonize their operations and eventually improve local air quality (once the fleet is large enough), but also provide valuable learnings on how to safely handle and operate vehicles powered by an energy source other than hydrocarbons, including permitting, firefighting and rescue procedures and training, maintenance, and community engagement considerations.
4. **Deploying hydrogen and/or battery-powered vehicles at the airport for passengers:** Some airports are taking an additional step by using hydrogen or battery-powered buses to transport passengers from the gate to the aircraft. In addition to the benefits above, it also exposes passengers to new energies, an important step for public acceptance.
5. **Deploying small hydrogen or battery-powered aircraft:** The next natural step is to use the existing infrastructure to power small aircraft, some which may not carry passengers initially, but which will operate within the commercial set-up and limitations of a large passenger airport. Many roadmaps of implementation include this milestone as an important enabler to the fully commercial introduction of a flying zero-carbon aircraft.

Shedding a light into the operations of zero-carbon aircraft

While the infrastructure challenges for airports were tackled in the 2022 ICAO Environmental report and in the *Integration of Hydrogen Aircraft into the Air Transport System*[5] joint publication from ACI and the Aerospace Technology Institute, operations surrounding battery or hydrogen aircraft at the airport require further attention. A recent industry effort led by IATA, ACI, and Airbus (as a member of ICCAIA) under the Airport Compatibility of Alternative Aviation Fuels Task-Force (ACAAF-TF) explores potential changes with respect to the aerodrome operations of these new aircraft concepts.

The publication, which was released in February 2025 and included 35 partners, focuses on hydrogen (gaseous and liquid), fully battery electric, and hybrid-battery electric aircraft. It highlights that while the approach, landing, taxiing and departure operations are not expected to change, the refueling/recharging operations are those which require particular attention[1] .Special focus also needs to be given to abnormal operations, incidents and accidents, and how these will be different to conventional aircraft.

Refueling/recharging zero-carbon aircraft

Aviation jet fuel is a well-understood substance which can be handled in an extremely safe way. There are strict standards and procedures on the quality of fuel

4 https://www.iata.org/globalassets/iata/publications/sustainability/concept-of-operations-of-battery-and-hydrogen-powered-aircraft-at-aerodromes.pdf
5 Integration of Hydrogen Aircraft into the Air Transport System: An Airports Operations and Infrastructure Review - Store | ACI World

(chemical composition, contamination, water content, and microbiological contamination) and the way to handle it, from the fuel farm to the aircraft tank. The energy carriers for zero-carbon aircraft, however, lack this experience in the aviation sector. The ACAAF-TF explored the following aircraft concepts.

- **Case 1 -** Aircraft powered by hydrogen and refueled via a hose with liquid or gaseous hydrogen
- **Case 2 -** Aircraft powered by hydrogen but refueled via the exchange of a gaseous or liquid tank module
- **Case 3 -** Aircraft fully powered by batteries
- **Case 4 -** Hybrid Aircraft powered by batteries and conventional aviation fuel or SAF

The overall activities related to refueling or recharging will remain the same, but several details on these operations still need to be better understood, for example:

For **battery-powered** aircraft, fast chargers will be required to ensure a fast turnaround. It is possible that these aircraft will require extra ground support equipment connected to the aircraft to condition the batteries for charging. Conditioning could be cooling them down during fast re-charge or warming them up if they are to be charged in extremely cold ambient temperatures. It is also still unknown how charging will be supervised, whether by a person or by remote cameras and sensors. Project TULIPS in the EU, is currently testing technologies to answer some of these questions. For hybrid-electric aircraft, it is still unknown if charging and refueling can be done at the same time, and if not, which should occur first, and what additional safety provisions will be needed (e.g., fueling safety distances).

For **hydrogen aircraft**, fuel safety zones remain an open question. Today's recommended fuel safety zone for conventional aircraft is three meters. Should this increase considerably, it could limit the number of parallel activities allowed during refueling. There are also unknowns around the cryogenic nature of liquid hydrogen, stored below -253° C. Will aircraft fuel systems need pre-chilling to prevent thermal shock? Should hydrogen sensors be placed around refueling points to detect leaks or dangerous hydrogen concentrations – and if so, where? Additionally, how would a hydrogen spill, large or small, differ from a jet fuel spill, and what new hazards might arise? Finally, what personal protective equipment will be required for into-plane refuelers, or for rechargers handling electric aircraft?

FIGURE 3: Hydrogen aircraft concept being refueled at an aerodrome: Courtesy of Airbus

While there are instances where operations will be more complex than today's, there may also be advantages to these new fuels, like improved local air quality at airports, lower exposure of ramp-workers to carbon particulates and NO_x emissions, and for hydrogen specifically, lower environmental hazards in case of a spill. While many questions still remain, we observe that never before in aviation's history has there been so many initiatives to solve them.

This article began by reflecting on aviation's evolution over the past 80 years, since ICAO's formation. Today, hundreds of highly capable professionals are working to secure aviation's sustainable future for the next 80 years. The sector's transformation will be highly complex, costly, and take time. The 130 milestones identified by IATA is just a start, and we need to keep progressing to ensure the safe, timely and efficient energy transition of the sector.

Taking Flight Towards Greater Sustainability with CFM International's RISE Initiative

By Valérie Guénon (Safran)

The Research and Technology development program RISE, launched by CFM International in 2021, aims at reducing fuel burn and CO_2 emissions by 20% for the next generation of narrowbody aircraft engines, while ensuring compatibility with alternative fuels and meeting customers' durability expectations. This program is a major undertaking in support of the aviation industry and ICAO's long term aspirational goal (LTAG) of net-zero carbon emissions by 2050.

For more than 50 years, CFM has been one of the most successful transatlantic joint-ventures in the aerospace industry. The 50/50 joint-venture between GE Aerospace (United States) and Safran Aircraft Engines (France) was created in 1974 to revolutionize air transport with a new generation of turbofan engines significantly reducing fuel burn and CO_2 emissions compared to other engine options available at the time. The CFM56 engine began commercial operations in the early 1980s and then became the industry's best seller with more than 33,000 engines delivered. As of today, a CFM-powered aircraft takes off somewhere in the world every two seconds.

This success story has taken another step forward with LEAP (Leading Edge Aviation Propulsion), based on the company's DNA of pushing the boundaries of innovation, ensuring customer satisfaction with reliable engines, and world-class support. In 2016, CFM introduced into service the LEAP engine, the successor to the CFM56. The LEAP engine delivers improved performance of 15% better fuel efficiency than previous generation engines, and reduced emissions and noise thanks to the integration of disruptive technologies such as new combustor and composite materials.

Contribution of GE Aerospace and Safran Aircraft Engines to ICAO's Committee on Aviation Environmental Protection (CAEP)

GE Aerospace and Safran Aircraft Engines have participated in the ICAO CAEP for decades, through the International Coordinating Council of Aerospace Associations (ICCAIA), contributing to the technical working groups supporting the creation of environmental standards for the industry: noise, polluting emissions, and CO_2. The contribution of manufacturers to CAEP is necessary for ICAO to establish the most relevant and efficient environmental standards using metrics, stringencies and measurement methods. In return, the ICAO standards are instrumental for guiding research efforts, innovation and ultimately effective progress. Key to ICAO's standard setting process has been a technology-following approach rather than an approach that is technology forcing.

The RISE program

As part of the efforts to help decarbonize aviation, and in line with aviation industry and ICAO's long term Aspirational (LTAG) commitment to net zero carbon emissions by 2050, CFM International is preparing the next step, called **RISE** (*Revolutionary Innovation for Sustainable Engines)*. RISE is CFM International's Research and Technology program aimed at reducing fuel burn and CO_2 emissions while meeting customer expectations for durability and maintenance. New engine technologies are also being tested for compatibility with alternative energy sources like Sustainable Aviation Fuels (SAF) to provide further lifecycle emission reductions. The RISE programme was unveiled in 2021 and involves more than 2,000 engineers across CFM's parent companies. To date, CFM has completed more than 250 tests, including aerodynamics, aeroacoustics and materials performances. Technologies matured as part of this program will serve as the foundation for the next generation CFM engine that could be available in the second half of the 2030s.

Open Fan architecture: A step change in propulsion efficiency

The pursuit of ever-increasing propulsive efficiency has driven the growth of engine fan diameter in commercial jet engines. This progression is ultimately leading to the Open Fan concept being developed as part of the RISE program. Open Fan is a new design of jet engines that removes the traditional casing, allowing for a larger fan size with less drag to improve fuel efficiency. The advanced Open Fan architecture, which is currently the most efficient option to improve the propulsive efficiency of the engine, will fly at the same speed as current single-aisle aircraft (up to Mach 0.8, or 80 percent the speed of sound) with a noise level meeting anticipated future regulations set by ICAO.

The engine industry has studied and demonstrated Open Fan architecture concepts for more than four decades. One of the best examples is the GE36 Unducted Fan (UDF) which was initially flight-tested on a McDonnell Douglas MD-80. The GE36 was never introduced into commercial service primarily because oil prices fell substantially, and customer interest waned as a result. There was also a second challenge: the technology was not advanced enough to achieve acceptable noise levels. Since the 1980s, CFM has continued to develop the Open Fan architecture and has identified new technologies that are resulting in improved efficiency, durability, and maintainability, lower emissions, and lower noise. More recently (2017), Safran Aircraft Engines ran a Counter-Rotating Open Rotor (CROR) engine in the frame of Sage2, a European project funded by the Clean Sky public-private research partnership. The Sage2 open rotor demonstrator engine, which ran at Safran test facilities in Istres, included two counterrotating, unshrouded fan stages. The engine achieved a double-digit improvement in fuel consumption and CO_2 emissions compared to today's most efficient powerplants, as well as comparable noise levels. This test also demonstrated key technologies like multi-variable power control, a pitch actuation system and advanced power gearbox integration. The RISE program will use this experience and incorporate lessons learned into potential future jet engines.

CFM parent companies, GE Aerospace and Safran Aircraft Engines, are committed to continuous investment to develop and mature new technologies. Their involvement in various research programs backed by government investment is crucial to ensuring the full maturation of the disruptive technologies required to meet industry sustainability goals. Open Fan calls on the most advanced set of technologies. Lightweight materials such as carbon fibre and organic matrix composite blades manufactured with a 3D weaving process is an enabler of such architecture and will build on the successful LEAP fan blade technology, applying it to a larger scale. An advanced compact core will increase the thermal efficiency, which is another way to improve the overall engine efficiency and therefore decrease the fuel consumption. High performance metal alloys and ceramic matrix composites will allow for higher combustion temperatures, further increasing the thermal efficiency. Hybrid electric systems will further decrease the dependency on liquid fuels.

The pace of the CFM RISE program continues to accelerate, with rigorous testing and research continuing around the world. In 2024, the first 300-plus hours of wind tunnel testing were completed at a facility run by ONERA[1], the French national aerospace research center and long-term research partner of Safran, using a one-fifth scale model of the Open Fan turbine. GE Aerospace has also partnered with the U.S. FAA, NASA, and the U.S. Department of Energy's National Laboratories on technology development and testing. In fact, GE Aerospace is now one of the largest users of U.S. exascale supercomputers, a breakthrough capability for optimizing new engine designs.

It is becoming more real every day, with the first full-scale demonstrator parts that are now manufactured.

1 https://www.geaerospace.com/news/articles/aint-no-stopping-us-now-cfms-rise-program-gaining-momentum

The full system is planned for ground and flight tests by the end of this decade. CFM is collaborating with Airbus on an Open Fan-powered A380 flight demonstration and actively working with the airframe manufacturer to optimize the engine-to-aircraft integration through tests and simulations. Flight tests are critical to advance understanding of engine performance, safety, noise, and aerodynamics in a real flight scenario — a key step before a groundbreaking engine can be developed.

How hybrid-electric technology can facilitate better adoption of sustainable aviation fuel

By Stéphane Viala (Ascendance)

Introduction

The global climate situation remains critical in 2025, despite significant advancements in clean energy technologies and various environmental commitments from countries worldwide. According to the Copernicus Climate Change Service, 2024 was the warmest year on record globally[1] - partly due to global carbon emissions from fossil fuels hitting a record high in 2024 - with "no sign" that the world has reached a peak[2].

Despite the relatively low contribution to global carbon emissions - accounting for 2.5% of global energy-related CO_2 emissions in 2023 - aviation-related emissions are on the rise, increasing by 19.5% between 2022-2023[3]. The industry has a target to reach net-zero emissions by 2050, but already in 2025 the International Air Transport Association (IATA) has sounded the alarm that this target is sliding off course. IATA places part of that blame on fuel companies, saying they have ignored their own sustainable aviation fuel (SAF) supply promises.

Regardless of where the blame lies, relying so heavily on SAF at the expense of other solutions will not lead us anywhere near the drop in emissions that we, as a collective industry, need by 2050.

The role of SAF in reducing aviation's carbon footprint

Much has been lauded about the benefits of SAF: its production being from renewable resources like waste oils and agricultural residues, its low carbon emissions lifecycle and its ability to be used in existing aircraft. It's also, crucially, been proven by a number of parties to lower greenhouse gas emissions by up to 80% compared to traditional aviation fuel. But its high production costs, reliance on feedstocks (which are in limited supply), production using hydrogen (which therefore still faces significant energy hurdles) and requirements for specific (expensive) infrastructure are proving to be obstacles too high to overcome at the scale needed.

If SAF is to be a viable decarbonisation route, coordinated global policies are essential to facilitate its widespread adoption. To date, countries have adopted various policies and initiatives to encourage SAF production and adoption, including:

- **European Union:** The ReFuelEU Aviation Regulation has set a minimum supply mandate for SAF in Europe, starting with 2% in 2025 and increasing to 70% in 2050[4]. It obligates fuel suppliers to meet the specified SAF blending percentages, with compliance mechanisms to monitor and enforce adherence.

1 https://climate.copernicus.eu/copernicus-2024-first-year-exceed-15degc-above-pre-industrial-level
2 https://wmo.int/media/news/record-carbon-emissions-highlight-urgency-of-global-greenhouse-gas-watch
3 https://www.statista.com/statistics/1491003/international-aviation-emission-change-worldwide/
4 https://www.easa.europa.eu/en/domains/environment/eaer/sustainable-aviation-fuels

- **United States**: The U.S. aims to produce three billion gallons of SAF by 2030 and 35 billion gallons by 2050, supported by incentives and policy frameworks to encourage production and adoption[5].
- **United Kingdom:** The UK's SAF mandate started in 2025 at 2% of total UK jet fuel demand, increasing on a linear basis to 10% in 2030 and then to 22% in 2040. It comes along with incentives for fuel suppliers to supply SAF into the market and a revenue certainty mechanism for SAF producers who are looking to invest in new plants in the UK[6].

But not enough progress is being made. SAF now urgently needs to be backed up by technological innovations that can facilitate an increase in its adoption and embed it in the broader aerospace ecosystem. The industry needs to reconsider the heavy extent of its reliance on SAF and explore - and invest - in ways to reduce carbon emissions whilst utilising lower levels of SAF.

Alongside other modifications to operations and modernisation of infrastructures, technology has a critical role to play here: combining decarbonised fuels with fuel optimisation technologies will be what unlocks a real net-zero aviation. Here's where hybrid-electric innovations come in.

Hybrid-electric technologies are the key to unlocking the potential of SAF

As with the automotive industry, the aviation industry first began exploring all-electric forms of transportation - before quickly encountering range and infrastructure limitations, including heavy batteries and long recharge times. Whilst a number of great innovations are still happening in the all-electric space - from the likes of the first certified electric airplane Pipistrel Velis Electro, flying taxis from companies such as Joby Aviation or Archer, and Eviation with its business aviation aircraft in particular - the result of these innovations on the overall environmental impact of aviation will be minimal due to poor performance not matching the operational requirements from operators and won't lead to any drastic reductions in carbon emissions. All-electric aircraft will certainly have a place in the future aviation industry, but won't play a leading role in getting us there.

In contrast, hybrid-electric solutions - based on a propulsion architecture combining electricity and combustion power - integrate alternative energy sources, such as SAF now and hydrogen in the future, while reducing fossil fuel consumption by up to 50%. This means that twice as many aircraft can be powered from the same volume of SAF. At the same time, hybrid-electric fuel optimisation technologies also reduce the amount of traditional aviation fuel used in-flight, bringing down overall carbon emissions.

Ascendance: for the skies of tomorrow

Since its founding in 2018, Ascendance has been on a mission to create hybrid-electric solutions to decarbonise both current and future aviation. Founded by four ex-Airbus engineers who had first-hand experience of the limitations of all-electric aircraft, hybrid-electric was a deliberate and strategic choice from day one.

Sterna

In 2021, it unveiled its patented hybrid-electric propulsion architecture: Sterna. Designed for airframers and operators seeking rapid decarbonisation, Sterna enables the replacement of a plane's conventional nose- or wing-mounted engines with a combination of batteries, electric motors and an engine running on SAF or hydrogen. Thanks to this hybrid-electric architecture, the engine and batteries are interconnected and deliver power in tandem. This innovative modular architecture is controlled by algorithms in a highly sophisticated energy management system developed and patented by Ascendance.

Sterna uses its batteries to provide the high levels of power needed for the takeoff and climb phases of flight,

5 https://aviationacrossamerica.org/news/2024/01/05/global-sustainable-aviation-fuel-saf-production-set-to-double-in-2024-future-growth-policy-dependent/
6 https://www.gov.uk/government/speeches/sustainable-aviation-fuel-initiatives

FIGURE 1: Cessna Caravan with conventional propulsion system (left hand side) vs. Cessna Caravan equipped with STERNA hybrid-electric technology (right hand side).

then switches to the engine for the cruise phase when less power is needed. This means not only that the engine can be smaller and used at maximum efficiency, Sterna is also an enabler of a whole new generation of engines which reduce carbon emissions but need hybridization to boost their performance for high thrust. Thanks to this combination of optimally sized systems, a conventional aircraft retrofitted with a Sterna powertrain can achieve overall fuel savings and reduce pollutant emissions by up to 50%.

Ascendance's Sterna technology can be readily adapted to existing aircraft. Today, we estimate that there are at least 25,000 turboprop aircraft flying that could benefit from a hybrid-electric retrofit: no modifications to flight operations are needed, offering simplicity and enabling continuity of use. The opportunity for this hybrid technology will only increase when it is integrated in future new developments from aircraft Original Equipment Manufacturers (OEMs).

And it's not just traditional aircraft: Sterna is designed to be integrated into aircraft of all sizes, from regional aircraft up to 70 passengers to unmanned aerial vehicles (UAVs), with real-life applications full-steam ahead. In 2023, Ascendance and Daher, the aircraft manufacturer, announced a collaboration with Ascendance researching new ways of hybridising the propulsion systems of Daher aircraft and testing its hybrid-electric propulsion systems on Daher aircraft.

Making sustainable aviation a reality

Growing climate urgency is coming at the same time as increasing global uncertainty and an increasingly fragmented world - when what's needed to reach net-zero emissions and to slow global warming is collaboration and an agreed approach.

Whilst country-specific targets and initiatives will continue to shift, those at the coalface of aviation decarbonisation must stay committed to the collective goal of net-zero emissions by 2050. This will require radical innovations - many of which are already in existence - supported by extremely substantial financing and tight global and industry collaboration.

Innovations like that of Ascendance's prove that decarbonising aviation can be done in many different - but complementary - ways - from modifications to existing aircraft, to new purpose-built aircraft with sustainability at their core. But too much attention and expectations are being placed on SAF alone right now. Whilst ramping up SAF production and adoption is undoubtedly critical to the future sustainability of the aviation industry, so too is modernising fleets and creating aircrafts for the future. The two will go hand-in-hand in developing long-lasting change.

Beyond Aero: A Startup Revolutionizing Aviation Towards a Hydrogen-Electric Future

By Jacques-Alexis Verrecchia (Beyond Aero)

Introduction

Achieving ICAO's long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 requires a paradigm shift in aircraft propulsion and energy sources. While established manufacturers invest heavily, particularly in sustainable aviation fuel (SAF), **agile and innovative startups are essential for accelerating the development, maturation, and deployment of disruptive technologies.** These nimble companies often explore novel concepts and architectures, reducing risks associated with technologies that can later be scaled for broader industry adoption. Startups typically operate with a focused mission and can attract specialised talent and venture capital for high-risk, high-reward projects. They face fewer constraints from legacy systems or existing product lines, enabling them to pursue radical innovations like hydrogen-electric propulsion, novel hybrid systems, or ultra-efficient airframes from a clean sheet.

Their efforts provide vital proof of concept, reduce technology costs through iteration, and help establish the necessary supply chains and regulatory frameworks for future sustainable aviation solutions. By focusing on a clean-sheet design approach and leveraging hydrogen's unique properties, Beyond Aero is one of those companies seeking to develop a more efficient future for aviation.

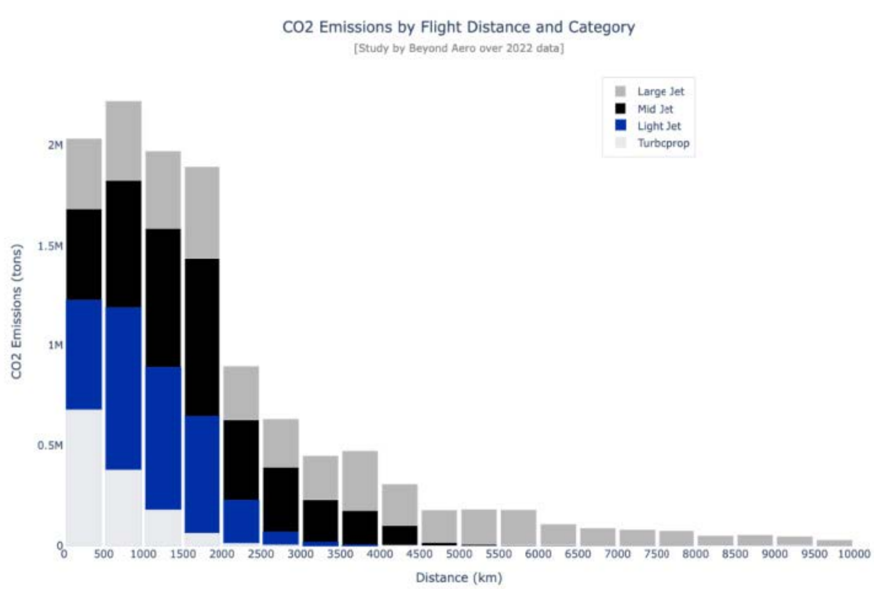


FIGURE 1: CO_2 emissions by Flight distance and Category

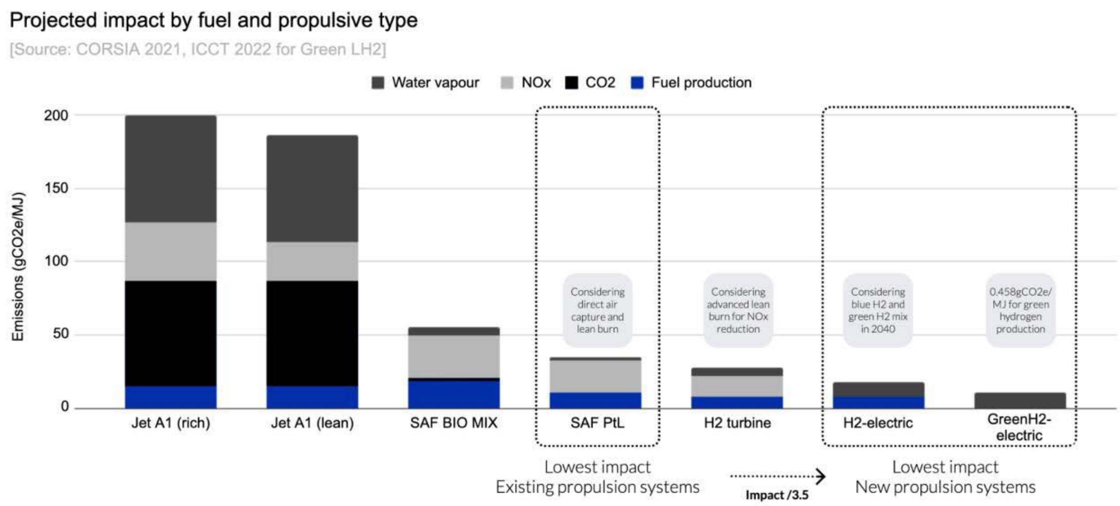
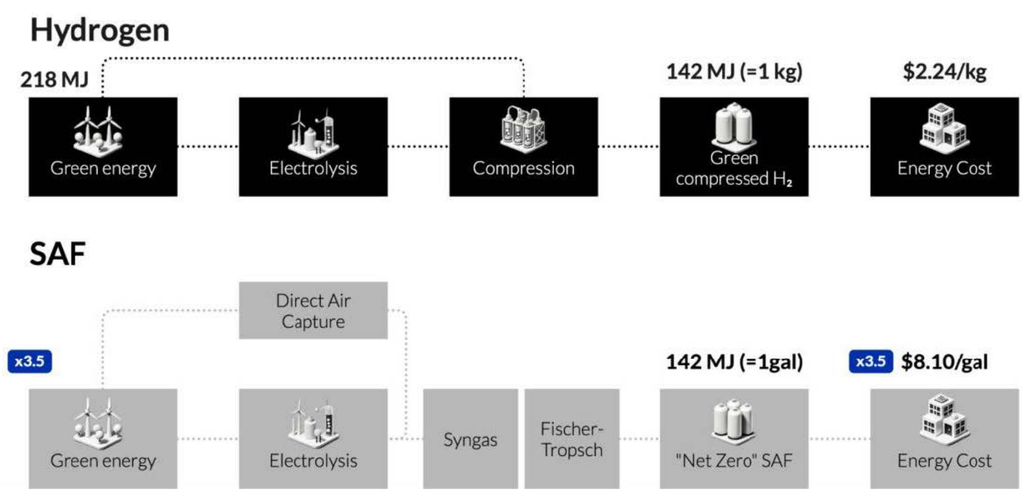


FIGURE 2: Projected impact by fuel and propulsive type.



The emissions challenge and the need for disruption

While sustainable aviation fuels provide a transitional solution, they continue to depend on combustion and encounter challenges related to feedstock availability and lifecycle emissions. While promising for short distances, battery-electric propulsion is hampered by energy density constraints. Thus, a more comprehensive and disruptive solution is required.

Hydrogen represents a promising viable long-term solution for electric aviation. Its high specific energy density and potential for zero CO_2 emissions (only water) when used in an electric power plant make it a compelling alternative to traditional fuels.

Hydrogen-electric propulsion offers numerous advantages

Hydrogen's significantly higher energy density compared to batteries makes it suitable for longer-range flights, overcoming the limitations faced by battery technology. Additionally, compared to SAFs that produce during combustion NO_x and other pollutants, hydrogen fuel cells emit only water and heat. Furthermore, hydrogen production can be decoupled from fossil fuels.

At the core of Beyond Aero's propulsion system is the proton exchange membrane (PEM) fuel cell. These fuel cells generate electricity through electrochemical reactions between hydrogen and oxygen, featuring no moving parts and emitting only water. The decision to start with gaseous hydrogen is justified by the maturity of the technology: over 25,000 fuel cell electric vehicles are in circulation, and more than 1,000 H_2 refueling stations operating at 700 bars are already in use today, with their numbers growing rapidly.

Beyond Aero aims to achieve a state-of-the-art level of 0.8 kW/kg for its low-temperature proton exchange membrane (LT-PEM) airworthy system, demonstrating the viability of hydrogen-electric propulsion for light aircraft today.

Hydrogen safety and infrastructure

Concerns about hydrogen safety, often stemming from historical events, are addressed through modern safety measures and rigorous testing protocols. Extensive studies in space launch systems, military aviation, and fuel-cell vehicles have demonstrated hydrogen's safety when handled properly. For instance, NASA has safely managed massive quantities of liquid and gaseous hydrogen for decades in its space programs, including during the Apollo and Space Shuttle missions, with an exemplary safety record. In military aviation, the U.S. Air Force's Hydrogen Aircraft Program in the 1950s successfully operated experimental aircraft like the Martin B-57B using hydrogen fuel without safety incidents, proving that hydrogen could be safely integrated even into demanding flight environments. More recently, thousands of hydrogen fuel-cell vehicles have been deployed globally — from passenger cars to buses — covering millions of kilometers without major safety issues, often achieving higher safety ratings than conventional gasoline vehicles. These real-world examples across high-risk industries show that with the right protocols and technologies, gaseous hydrogen can be managed safely. Hydrogen's properties, such as rapid evaporation and low detonability, make it safer than conventional fuels in many aspects.

Robust infrastructure and logistics for green hydrogen are important and must be accelerated. Low-carbon electrolytic hydrogen production, transport, and on-site storage are crucial for a sustainable hydrogen ecosystem. Hydrogen refueling stations at airports, both fixed and mobile, to facilitate safe and swift adoption will also be a key enabler. . By equipping key business airports with hydrogen refueling capabilities, hydrogen-electric aircraft can be enabled to serve a significant portion of global missions. For example, Beyond Aero signed partnership agreements with key airport operators, such as Groupe ADP (Aéroports de Paris), which operates some of Europe's largest airports for business and commercial aviation, and Edeis, a major player in regional aviation.

The clean-sheet design approach

Retrofitting existing aircraft provides a short-term solution, but a truly optimised hydrogen-electric aircraft requires a design specifically tailored to the distinct properties of hydrogen. This includes integrating gaseous hydrogen storage systems, thermal management, and electric engines in a manner that maximises performance and efficiency.

A clean-sheet design also has the advantages of enhancinge weight distribution, aerodynamics, and overall performance. This approach can also facilitate the incorporation of new design and manufacturing technologies, as well as maintenance-oriented requirements.

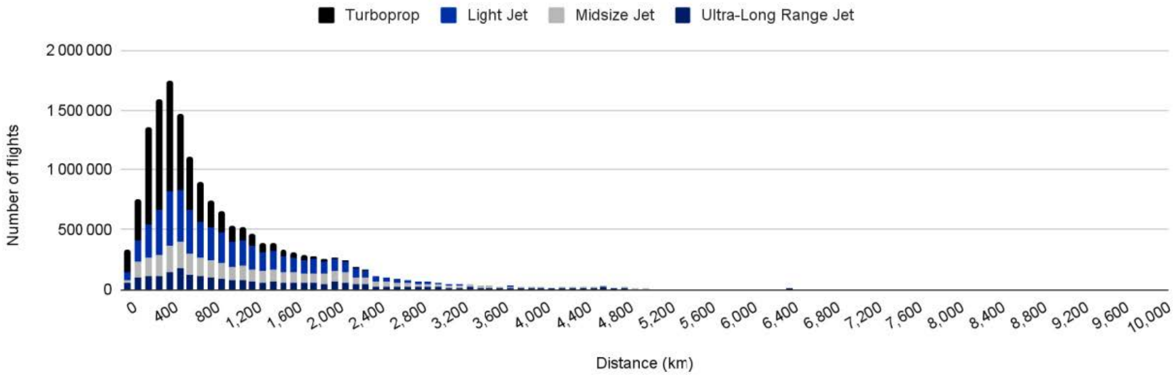
The business case: starting with business aviation

Beyond Aero's initial product is a high-end clean-sheet, hydrogen-electric light jet, called BYA-I. While business aviation represents a small percentage of overall aviation emissions, it is the most CO_2-intensive per passenger. It is an ideal market for introducing disruptive technologies that can be later scaled to larger aircraft, addressing more and more CO_2-emitting markets.

Furthermore, business aviation has a history of pioneering innovation. By introducing hydrogen-electric propulsion in this segment, costs can be driven down and the way can be paved for mass-market affordability in regional and commercial aviation. Beyond Aero estimates that 80% of business aviation flights are within the range of their hydrogen-electric aircraft, making it a viable and practical option.

Business aviation: flights by distance (worldwide, 2019-2022)

[Source: Beyond Aero analysis]



A hydrogen-powered business jet could offer cost-effective operations with lower maintenance costs (due to the lack of a combustion engine, and fewer moving parts) and competitive operating costs compared to traditional jets,. Customer feedback indicates a strong desire for a more sustainable way of flying, with many delaying orders to wait for a better option.

Scaling up: a three-step plan

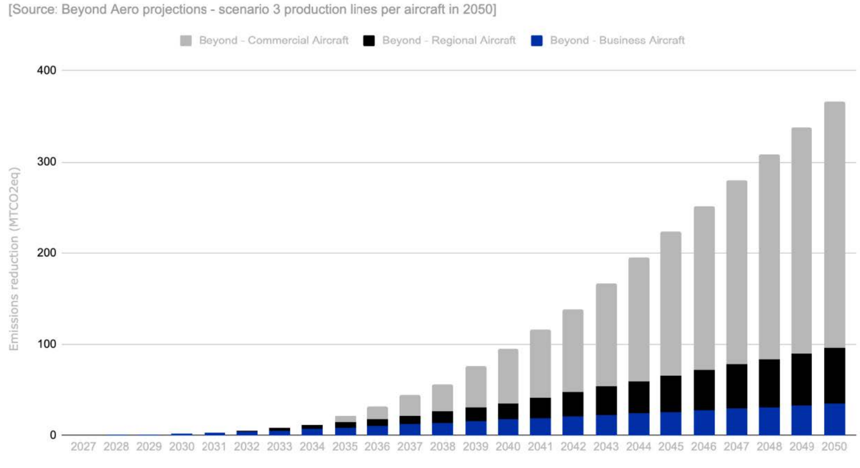
A three-step plan for scaling-up hydrogen-electric technology is suggested:

- **Step 1:** Pioneering development and certification: Develop, certify, and bring to market the first aircraft, establishing a new paradigm for efficiency and comfort. This initial aircraft will fund the development of larger platforms.
- **Step 2:** Mastering scale for regional aviation: Based on the same architecture, develop a scaled-up powerplant for a 70-passenger regional aircraft, certified under EASA CS25 and FAA FAR25 regulations.
- **Step 3:** Maximizing climate impact for commercial aviation: Develop a 150-passenger commercial aircraft, leveraging the acquired knowledge and technology, to address the largest source of aviation emissions.

Beyond Aero's long-term target is to deploy a high-tech hydrogen-electric fleet by 2050, contributing to the reduction of hundreds of megatons of CO_2 emissions.

Beyond Aero contribution to emissions reduction

[Source: Beyond Aero projections - scenario 3 production lines per aircraft in 2050]



Startup advantage and innovation

Newer startups benefit from their agility and freedom to explore innovative solutions without the constraints faced by established players. These companies can shorten cycles from concept to flight validation and adopt an agile approach that includes extensive testing. This can enable them to bring disruptive innovations to maturity more quickly and cost-effectively.

Other industries, such as smartphones, electric cars, and space launchers, have demonstrated the ability of startups to drive technological disruption. Aviation is next and a startup can successfully scale clean-sheet hydrogen-electric aircraft to market by 2050.

Conclusion

Beyond Aero is dedicated to transforming aviation through electrification and digitalisation. By concentrating on hydrogen-electric propulsion and a clean-sheet design approach, the company is paving the way for a more efficient aviation future. Aerospace start-ups have characteristics that could position them strongly to play a crucial role in decarbonising the aviation industry and aligning it with global climate goals.. Beyond Aero's efforts will support the ICAO's environmental objectives and expedite the transition to a cleaner, more sustainable aviation ecosystem.

Addressing Non-CO_2 Emissions – the way towards clean and competitive aviation

By Christiane Voigt (DLR), Anthony Brown (NRC), Greg Smallwood (NRC), Leonid Nichman (NRC), Sean Yun (NRC), Pervez Canteenwalla (NRC), and Philippe Novelli (ONERA), and Adél Schröpfer (DLR/IFAR)

The International Forum for Aviation Research (IFAR) is a global network that connects 26 active aviation research organizations from all inhabited continents, collectively employing over 40,000 researchers. As the only global network of its kind, IFAR fosters collaboration through its core activities, which include facilitating information exchange and networking among member organizations, discussing technical challenges to enable multilateral international collaborations, supporting human resource development for early-career researchers, and forming partnerships with external entities such as International Civil Aviation Organization (ICAO) and International Council of the Aeronautical Sciences (ICAS). IFAR maintains a strong partnership with ICAO. Together, we strive to advance innovation in aviation with a focus on sustainable development.

This scientific paper originates from IFAR's active participation in the ICAO Symposium on Non-CO_2 Emissions, held in Montreal in September 2024. Developed as part of IFAR's dedication to tackling the challenges of sustainable aviation, the paper synthesizes insights from presentations delivered by IFAR members, DLR (Deutsches Zentrum für Luft- und Raumfahrt), NRC (National Research Council Canada), and ONERA (Office National d'Etudes et de Recherches Aérospatiales) during the symposium. These insights focus on key research areas, including the physics underlying contrail, cloud, and emission formation and interactions, the evaluation of current and future aviation technologies' climate impact, and the exploration of mitigation strategies aimed at reducing the combined effects of CO_2 and non-CO_2 emissions.

DLR Insight

Today, the effective radiative forcing from contrails is on par with that from aviation's CO_2 emissions since the historical start of air traffic. Also, global air traffic has recovered from the 2020 pandemic and is expected to triple by 2055. Hence, the international aviation strategy needs to combine aviation competitiveness and growth with a scenario that curbs aircraft emissions, and related climate effects. DLR and international IFAR partners investigate short, mid and long-term reduction measures by air traffic management, sustainable aviation fuels (SAF) and e-fuels, including hydrogen, as well as engine technology. In addition to CO_2, some of these measures have the potential to reduce aircraft non-CO_2 effects, e.g. particle emissions and contrails (see Figure 1).

The implementation of ATM measures to avoid contrails by climate optimized flight routing within the next decade could have fast positive effect on climate at low operational costs. In this context, DLR and partners develop models to predict regions with warming contrails on a single flight and a fleet bases and support airline demonstration trials to study the operational feasibility by ATM. Here, DLR advances science to assess the contrail climate benefits and related trade-offs with respect to operational costs. DLR also supports the development of the Monitoring, Reporting and Verification System for non-CO_2 effects by the European Parliament.

Before the release to the market, the engine's particle emissions are measured and monitored by ground tests for specific test points during the take-off and landing

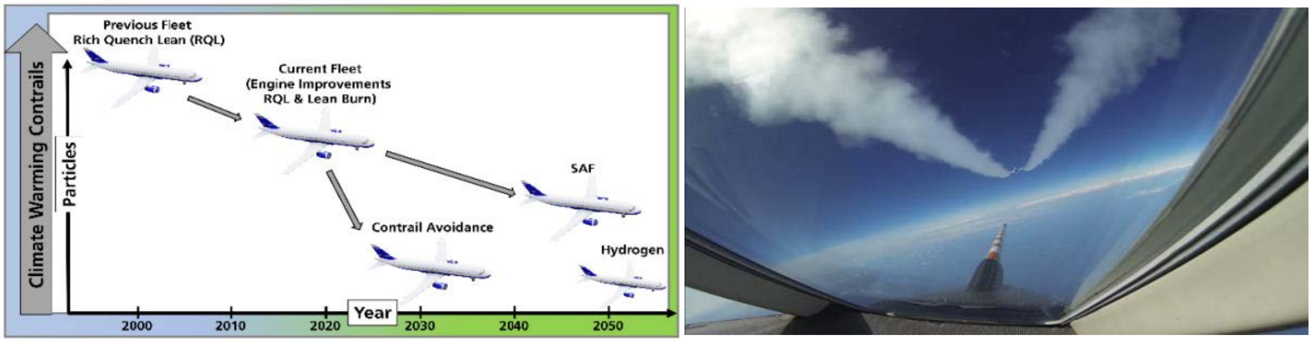


FIGURE 1: Left: Timescales of aviation particle reduction measures through ATM, low aromatic fuels and engine technology. Right: DLR research aircraft Falcon probing the contrails from an Airbus aircraft fueled with 100 % SAF (Märkl et al., ACP, 2024; Dischl et al., ACP, 2024; Harlass et al., ACP, 2024) (right).

cycle. While the extrapolation of aircraft CO_2 emissions to cruise flight altitudes is straightforward, there is the need to measure the engine's particle emissions at cruise altitudes in order to quantify non-volatile and volatile particle concentrations emitted at cruise and to calculate related climate effects. Over the last four decades, DLR, together with partners from industry, has built up a unique expertise for chase flights for research. With its instrumented research aircraft Falcon, DLR can probe the emissions and contrails in 50 m to 100 km distance to the preceding aircraft. The acquired data sets quantify engine trace gas and particle emissions at cruise help to constrain models and measure the particle and contrail reduction impact by SAF and e-fuels. DLR has worked with NRC, Airbus and Rolls-Royce on particle reduction by 100% sustainable aviation fuels within the ECLIF3 project[1] (see Figure2).

NRC Insight

Canada has the second largest airspace in the world and because non-CO_2 emissions can have magnified wide-area, regional and local effects on the climate, there is a rationale and an opportunity for Canada to make significant contributions to this field of study. With a robust foundation in atmospheric modeling and meteorology, Canada aims to leverage its expertise to contribute meaningfully to international efforts in understanding and mitigating these emissions. The NRC has been at the forefront of research efforts in measuring emissions from aircraft using Jet A1 and SAF, commencing in 2011. Also, since 2011, NRC has supported major emissions ground test campaigns, leading innovations in measuring black carbon[2], and developing new technical standards and regulations. Through its High-Altitude Atmospheric Research Aircraft, the NRC has conducted comprehensive in-flight emissions and contrail studies, revealing significant reductions in particulate matter and contrail optical density and reflectivity with certain fuels.

Figure 2, Left: NRC ground emissions support during ECLIF3 test campaign. Right: NRC in-flight emissions and contrail measurement test campaign (right).

Future Directions

In addition to NO_x, VOC and nvPM emissions, persistent contrails and contrail cirrus clouds are known to contribute to non-CO_2 emissions climate impacts. To further aid the international scientific community, NRC is either actively involved in, or formulating projects to solve emission related challenges:

- NRC is a collaborator with a European consortium of 10 partner organizations on Understanding Non-CO_2 Impact for Decarbonized Aviation (UNIC). The project aims to "*primarily further increase the scientific understanding related to the impact of aerosols on clouds as well as the contribution of aviation NO_x emissions to climate change*."

1 DLR has also partnered with ONERA, AIRBUS, and CFM in the NEOFUELS-VOLCAN project, as well as with NASA, Boeing and GE during the ECO-Demonstator project to explore particle emissions and contrail formation from lean-burn combustors

2 Also known as nvPM, nonvolatile particulate matter

- NRC continues the development of emission measurement technologies and participation in ground tests to measure aircraft engine emissions
- NRC continues the development of calibration methods for the instruments used to quantify nvPM emissions, ultimately leading to improved characterization of the climate impacts associated with nvPM.
- NRC investigates measurement methods to quantify emissions of lubrication oil and other volatile particulate matter (vPM) in support of studies on the non-CO_2 climate impacts associated with lubrication oil (and other vPM) emissions from aircraft gas turbine engines.
- NRC will also Investigate the development of a ground facility for simulating contrails. This would allow more controlled and relatively cost-effective experiments on the ground to understand the effects of new fuels and engine technologies prior to undertaking more complex in-flight test campaigns, including ice nucleation studies.
- The renewal of NRC's in-flight emissions and contrails capabilities with our High-Altitude Atmospheric Research Aircraft[3] is also being investigated
- Aviation emissions are not occurring in isolation and often interact with the pre-existing complex ambient environment therefore it is important to put the aircraft emission measurements and monitoring into context. For that purpose, NRC is also focusing on Environmental research with airborne studies of the atmospheric composition and interactions including cloud formation processes. To further bolster our research capabilities in this area, NRC is renewing its aircraft capability with a Medium-Long range Aircraft Platform for Environmental Research (MAPLE) as part of the Government of Canada's commitment to revitalize and modernize NRC facilities
- The Arctic is the most sensitive region to climate change, and one of greater warming rate. For example, in Alaska and Western Canada, winter temperatures have increased by 3-4°C in the last 50 years. Black carbon fallout from aviation emissions exacerbates cryosphere melt, whilst contrail formation promotes atmospheric warming. These regions have disproportionately high throughput of intercontinental aviation traffic. Scientific studies in the Canadian Arctic are a priority for increased understanding. In future Arctic deployments, the NRC plans to study the formation of contrails at different altitudes during the Polar night of the Arctic winter.

ONERA Insight (or CLIMAVIATION initiative in France)

The CLIMAVIATION initiative in France, which aims to re-engage the French community on the non-CO_2 emissions topic and bring a contribution to the efforts on non-CO_2 effects, is a five-year research program supported by the French government and carried out in partnership between ONERA and Institute Pierre Simon Laplace (IPSL).

Contrails is a first major axis of the initiative, for which a first goal is to set up a complete simulation of the whole life cycle of a contrail from ice crystal formation to fully developed contrail, allowing an in-depth investigation of the parameters influencing contrail properties and providing contrails characteristics for initializing climate models. Microphysics mechanisms leading to ice crystals formation are in particular studied for low soot emissions case, for which volatiles are a potential sources of condensation nuclei for water condensation. The resulting models are included in a detailed near-field simulation tools taking into account the detailed aircraft geometry and dynamics of the interaction between the engine plume and aircraft wake. Simulation is further extended up to 15 minutes behind the aircraft to extract the properties that serve as initial characteristics in the LMDZ-INCA global climate model (GCM) used for the climate impact assessment. This model has received a number of upgrades during CLIMAVIATION to improve the representation of ice supersaturated regions (ISSRs) in which contrails are likely to appear and persist. Representation of contrail and contrail-cirrus radiative effect is also investigated, the goal being to better understand and evaluate the uncertainties introduced at radiative model levels and

3 This aircraft has a suite of sensors to measure nvPM, volatiles, NO_X, CO_2 and ice particles. The aircraft platform needs to be versatile enough to obtain both near field and far field measurements and traverse throughout the contrail to get a holistic measurement in all regimes of the contrail, as current NRC cross-sectional measurements have shown significant non-uniformity throughout the contrail. With a renewed capability, the aim is to undertake studies to better characterize the cirrus transition process (0-60 minute aged contrails) and gather in-flight data to understand the impact of new fuels and engine technologies

through the simplifications that are necessarily done in GCM, such as, for example, neglecting 3D effects.

NO_X influences radiative forcing through a complex chain of chemical reactions. First, NO_X produces ozone through a photochemical process, which increases the oxidation capability of the atmosphere due to OH formation that produces a destruction of methane. The decrease of methane produces, on a longer time scale, a lower production of ozone and water vapor. These multiple mechanisms act in opposite directions. They are relatively balanced but with different time scales. Their combination results in a significant uncertainty on the final effect on radiative forcing. A first scientific issue is the significant discrepancy between model results, the origin of these differences being not understood. A second one is that the multiple possible reactions are not always represented. In particular, there are questions today regarding interactions with aerosols. There are also reactions within the aircraft plume that are not captured at the grid scale of climate models. Last, the effect of NO_X depends on background concentrations and so on emissions from the other sectors[4].

Interactions between particles and clouds are today particularly uncertain and notoriously difficult to represent in climate models. Uncertainty on the effect is such that no estimate could be provided by David Lee in his synthesis of 2021. A first scientific question is what are the concentration, the size and nucleating properties of aerosols after hours of residence in the atmosphere, for which there would be a critical need for observations that are however quite difficult. Next question is how far these aerosols are transported horizontally and vertically. Accordingly, studies are carried out in CLIMAVIATION on removal mechanisms for black carbon in the atmosphere. Last question is how clouds respond to aviation aerosols and how aviation aerosols compete with other aerosols. This is investigated through LES simulation of cloud response to aerosol perturbations.

All the model improvements are integrated in the LMDZ-INCA model of IPSL in order to perform a global assessment of current aviation impact on climate. For this, a complete inventory of aviation emissions is being build based on the air traffic for 2024 and reference methodologies for fuel burn and emissions estimates. Effort is also developed for exploiting observation data from satellite or ground observations in order to validate tools. This include development of algorithms for automated detection of contrails on images.

Besides CLIMAVIATION, ONERA is also involved in a number of national and European projects, with a strong focus on the impact of the new fuels and low soot combustors on contrails[5].

Conclusion

Long-term partnerships and international coordination are essential for advancing the understanding of non-CO_2 impacts in aviation. By sharing data and avoiding duplication of efforts, IFAR members can ensure effective use of resources, translating scientific knowledge into practical solutions and policy interventions to reduce emissions and their climate impacts.

Through these initiatives, IFAR members are committed to pioneering advancements in aviation emission research, contributing to global efforts in climate change mitigation, and fostering sustainable aviation practices for the future.

4 All these questions are investigated within CLIMAVIATION, and also in collaboration with other partners in European projects such as ACCACIA, to improve the modelling in LMDZ-INCA.

5 Impacts of hydrogen and SAF were investigated with Airbus and Safran in the VOLCAN and Cirrus H^2 projects. ONERA is now leading the UNIC European project, in collaboration with NRC and other partners, aiming to a better scientific understanding of the real-world emissions of aircraft at flight altitude and the specific role these aviation-derived non-CO_2 emissions (gaseous, volatile, and non-volatile particulates) play on contrail and contrail-cirrus formation and aerosol-cloud interactions. ONERA has also developed a micro-Lidar for in flight characterisation of contrails that is to be operated in the coming months

ICAO

CHAPTER FOUR

Climate Change Mitigation – Operations

Overview of operational improvements and ICAO's path to net-zero carbon emissions by 2050

By ICAO Secretariat

Introduction

As the global aviation sector faces the pressing challenges of climate change, the International Civil Aviation Organization (ICAO) is supporting States and aviation stakeholders to implement effective mitigation measures. The urgency for immediate action is underscored by the extreme weather events that threaten aviation infrastructure and flight operations. This article explores key operational improvements and air traffic management (ATM) strategies that support ICAO's Long-Term Global Aspirational Goal (LTAG).

Operational Measures and Their Contributions

In the context of aviation, "operations" can refer to a wide range of activities, such as Air Traffic Management (ATM), Aircraft Operator activities, Airport activities, ground operator activities, flight planning activities, airspace design, network management etc. The Operational Improvements wedge of the ICAO Basket of Measures has many practices that can reduce noise, carbon dioxide (CO_2) emissions, fuel consumption, and enhance local air quality.

Operational measures provide an opportunity to improve fuel efficiency across different phases of flight and in turn, reduce the environmental impacts. These include the implementation of innovative new concepts, more efficient flight paths, aircraft weight management, enhanced ground procedures, and the integration of new technologies. Such measures can contribute to reducing CO_2 emissions, particularly in the short to medium term, and complement longer-term technological and cleaner energy-based solutions.

During the assessment of contributions from operational improvements reaching net-zero carbon emissions by 2050, the CAEP focused on identifying and analyzing operational measures to reduce CO_2 emissions from international aviation. As the basis of the work, CAEP utilized the work already undertaken in the CAEP/11 cycle by WG2 on the environmental assessment of the Global Air Navigation Plan – Navigation Plan – Aviation System Block Upgrades (GANP-ASBU). This data included operational improvements for the years 2028, 2038 and 2050 for Horizontal Flight Efficiency (HFE). This previous analysis, which served as the baseline, had created 53 rule of thumb fuel saving benefits to be expected from the implementation of 31 measures in total.

TABLE 1: List of Operational Measures assessed by CAEP.

✓ Remote Tower ✓ Enhanced MET information ✓ Flexible use of airspace ✓ Flex routes ✓ Free Route Airspace ✓ User Preferred Routings ✓ Space-based ADS-B surveillance ✓ Datalink En-route ✓ Datalink Departure Clearance ✓ FF-ICE Planning Service ✓ Continuous Descent Operations ✓ Continuous Climb Operations ✓ PBN STARs ✓ PBN SIDs ✓ Flight-based Interval management ✓ Ground-based Interval Management ✓ ATFM	✓ Short-Term ATFCM Measures ✓ Advanced FUA (ATFM / Airspace Management) ✓ RNP-AR approaches ✓ Airport – Collaborative Decision Making ✓ Wake Vortex Re-categorization ✓ Time-Based Separation ✓ Arrival Manager ✓ Extended Arrival Manager ✓ Terminal Flight Data Manager ✓ Advanced – Surface Movement Guidance and Control System ✓ PBN approaches (Radius to Fix) ✓ PBN to xLS approaches ✓ GBAS CAT I/II/III ✓ Multi-segment approaches/ glideslopes

Together with these measures, CAEP found other innovative measures that should be taken into account and assessed. Table 2 below lists the other measures that were taken into consideration.

✓ Dynamic Sectorization ✓ Reduced Extra Fuel On-board ✓ Best Practices in Operations Minimizing Weight ✓ In-Trail Procedure (ITP) ✓ Airline Fuel Management System ✓ Optimized Runway Delivery Support tool and Reduced Pair-Wise Weather Dependent Separation between Arrivals ✓ Electrical Tug Detachable Aircraft Towing Equipment	✓ Support for Optimized Separation Delivery and Reduced Pair-Wise Weather Dependent Separation between Departures ✓ Formation Flight ✓ Geometric Altimetry and RVSM Phase 2 ✓ Global Air Traffic Flow Management ✓ Satellite Based VHF for oceanic/ remote areas ✓ APU Shut Down ✓ MAINTENANCE - difference between maintenance and modification to aircraft, technology related

TABLE 2: List of additional Operational Measures assessed by CAEP

Figure 1 below shows how CAEP categorized the operational measures into five flight efficiency areas that optimize fuel use and reduce emissions.

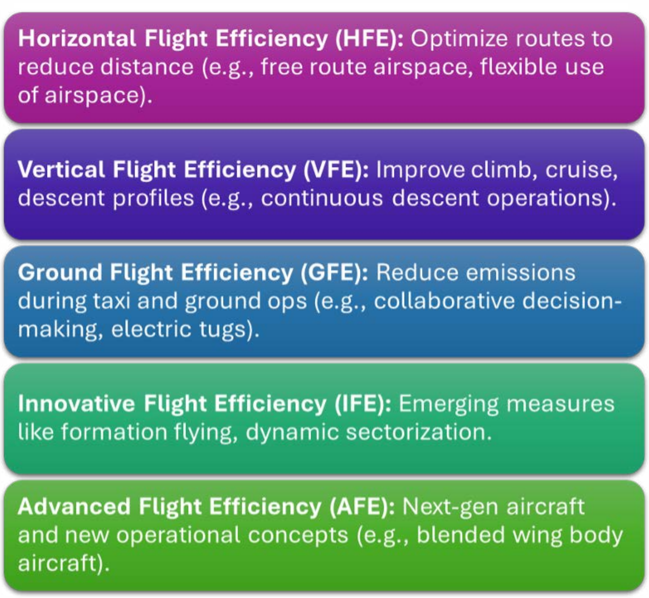


FIGURE 1: Categories of operational measures.

Following categorization, CAEP generated the description of three different scenarios and created "Rules of Thumb" for each individual operational measure and updated the baseline that had previously been established in CAEP. There were three scenarios suggested: aggressive, medium, and conservative. These scenarios were constructed according to different rates at which the five above categories of measures were assumed to be implemented.

Based on that it has been found that Operational Improvements could reduce CO_2 emissions by up to 11% by 2050, under the most aggressive scenario.

Resul of three scenarios:

- Conservative: Low action, 5% reduction by 2050.
- Medium: Moderate action, 8% reduction by 2050.
- Aggressive: High action, 11% reduction by 2050.

ICAO Tracker Tools on Operations

Since the LTAG of net-zero carbon emissions by 2050 was adopted, ICAO has been maintaining a close eye on developments around the world that could help lower CO_2 emissions. Air operations, ground operations, green infrastructure, and latest news are the four categories in which the Operations Tracker gathers news from across the globe.

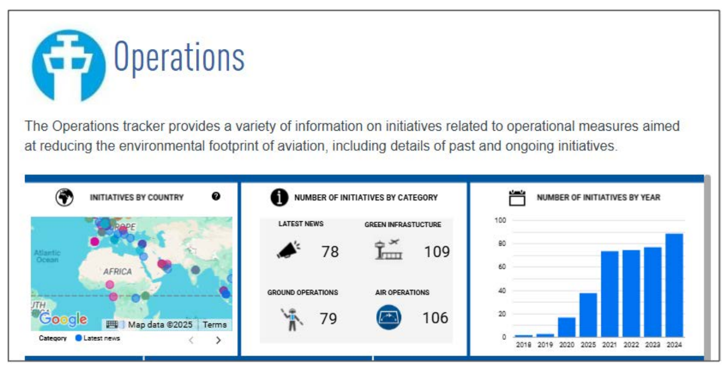


FIGURE 2: ICAO Operations tracker.

Note: This is based on information that the Secretariat is able to obtain from publicly available sources and news sources. It is possible to submit supplementary initiatives to the ICAO Secretariat.

Implementation of Operational Concepts Through the Global Air Navigation Plan (GANP)

ICAO's Global Air Navigation Plan (GANP) serves as the framework for harmonized implementation of operational improvements worldwide. The GANP aims to support the development of a global air navigation system that is adaptable, safe, secure, sustainable, and efficient. The Aviation System Block Upgrade (ASBU) framework serves as a programmatic approach, enabling Member States to enhance their air navigation capacities based on specific operational needs.

In the CAEP/11 cycle ICAO's Committee on Aviation Environmental Protection (CAEP) has assessed ASBU modules for their fuel and emissions reduction potential. In the next 3 years, CAEP will continue reviewing the ASBU framework in addition to the other aspects of "Operations" (including flight planning, network operations and airspace design) to assess additional operational elements and provide insights into potential fuel savings. This systematic approach aligns closely with LTAG objectives, ensuring effective integration of operational concepts into the broader strategy for achieving net-zero carbon emissions by 2050.

Considerations for Implementation

Leading airlines, airports, air navigation service providers and other aviation stakeholders are already integrating operational practices into standard operations, demonstrating the feasibility of broader adoption; key steps include:

Establishing governance structures to oversee implementation and monitor progress	**Integrating sustainability objectives into corporate planning cycles**
Regional coordination to harmonise approaches and avoid fragmentation	**Setting clear milestones and performance indicators**

Conclusion

In order to achieve net-zero carbon emissions by 2050, the aviation sector should immediately start implementing operational measures. With the implementation of these measures, airlines can more effectively manage the growing demand for travel by optimizing the use of airspace and airport capacity. Increased resilience and flexibility could enable the system to adapt to fluctuating weather patterns and aviation traffic volumes. In addition to that, operational measures implemented on board and on ground can also contribute to reducing CO_2 emissions and complement the achievement of LTAG.

Reaching net-zero carbon emissions by 2050 will require comprehensive efforts across all facets of aviation. The examples outlined in this article represent just a subset of the available operational improvements and air traffic management strategies that can contribute to emissions reductions. With continued innovation, investment, and collaboration, the aviation sector can align its growth with global climate objectives and support a more sustainable future.

ICAO's Progress on Sustainable Airports and Flight Operations – CAEP Working Group 2 Report

By David Brain (EUROCONTROL)[1] and Ted McDonald (Transport Canada)[1]

Introduction

The Committee on Aviation Environmental Protection (CAEP)'s Working Group 2 - Airports and Operations addresses environmental issues relating to airports, aircraft operations near airports, and aircraft operations in general. The main objectives of the work programme of WG2 are to undertake operational analysis, develop guidance material and address the current and emerging environmental issues related to airports and operations for aviation stakeholders such as States, airports, airlines, Air Navigation Service Providers (ANSPs) and aviation authorities, whilst supporting the achievement of the Long-Term Aspirational Goal (LTAG) of net-zero carbon emissions by 2050. The development of global best practices in these areas continually evolve and can lead to the improvement of environmental management policies.

When visualizing the ICAO basket of measures to reduce CO_2 emissions, the 'Operational Improvements' wedge encompasses a wide range of operations such as those related to Air Traffic Management (ATM), Aircraft Operator activities, airport operator activities, flight planning, network management and airspace design. Although these areas constitute the multiple facets of operations, the focus is often on other measures to support the decarbonization process, such as Sustainable Aviation Fuels (SAF) or new aircraft technologies. However, despite traditionally being depicted as having a smaller contribution to net-zero, ATM and operational improvements offer a significant potential for reducing CO_2 and related emissions in the short to medium term. This has clearly been demonstrated in the work of the CAEP Long Term Aspirational Goal (LTAG)-Task Group (TG) work whose results were reported in the 2022 Environment Report.

CAEP WG2 Activities During the CAEP/13 cycle (2022-2025)

WG2 – Airports and Operations is the operational working group of CAEP and has been responsible for delivering some of the key analyses to support the calculation of the environmental benefits that may be realized from implementing the operational measures defined in the ICAO-GANP Aviation System Block Upgrades (ASBU) framework together with new innovative measures looking out to the coming decades.

In the CAEP13 cycle, WG2 undertook its most ambitious work programme to date. This included five Eco-Airport Toolkit e-publications, an updated Climate Adaptation Synthesis, a CAEP report on "Operational Opportunities to Reduce Climate Effects of Contrails and non-CO_2", a CAEP report on "Emerging Trends in Aviation: Community Engagement Practices and Considerations", a CAEP report on "Noise Monitoring System Good Practices", an updated Climate Adaptation Synthesis, operational analysis based

1 David Brain and Ted McDonald are Co-Rapporteurs of Working Group 2 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

on the interdependencies between different operational scenarios, technical content updates to the new CDO Manual anda scoping study on the "Cost impacts of climate change effects on international aviation" to address Assembly resolution A41-21, paragraph 9.

The majority of these deliverables are elaborated in Chapter 4 (Climate Change Mitigation – Operations), Chapter 10 (Noise), Chapter 12 (Green Airports) and Chapter 13 (Climate Adaptation & Resilience).

FIGURE 1: New Deliverables from WG2 in CAEP/13

In 2013, CAEP recognized the importance of community engagement, and undertook a task of collecting case studies of recent community engagement activities and developed a Circular highlighting both lessons learned and good practices (Circular 351). The publication of the case studies was expected to assist States and the aviation industry, in particular airports, airlines, and ANSPs, to engage local communities to help address environmental matters.

This thread of community engagement has further developed since CAEP/10 with the advent of new mandates for PBN implementation which have led to evolving strategies for the deployment of airspace modernization programmes in terms of engaging communities. Experiences with adapting to the post-COVID environment together with the introduction of emerging technology aircraft such as Unmanned Aircraft and Advanced Air Mobility vehicles have further influenced strategies for community engagement.

In the CAEP/13 cycle, WG2 considered these emerging trends and set about determining whether there are community engagement needs and considerations as a result of these developments. The objective of the task was to conduct a preliminary assessment of community and stakeholder engagement considerations resulting from significant changes occurring and anticipated within the aviation sector, but not limited to ATM change as previous work had been and included the three following emerging trends in aviation:

- Risks and opportunities related to the growing focus on climate change and the effects, trade-offs and interdependencies of that on local noise issues and mitigation;
- Recent, new and emerging airspace users, such as Remotely Piloted Aircraft System (RPAS), UAM, hydrogen-fueled aviation, commercial space vehicles etc.; and,
- The impact of COVID-19 on community engagement strategies following low traffic levels and community responses to noise as operations return.

The analysis identified key trends, insights, and potential challenges and opportunities related to community engagement for the three thematic areas, with the objective to bring an important awareness of the risks and opportunities facing the aviation industry from the emerging trends. Together, the three outcomes highlighted a common theme – that change is continuing at a rapid pace, that interests are diverse, that many of the longstanding principles for community engagement stand, but that there are also new expectations within our communities.

For the interdependencies between noise and emissions, it was seen that while climate change is a significant

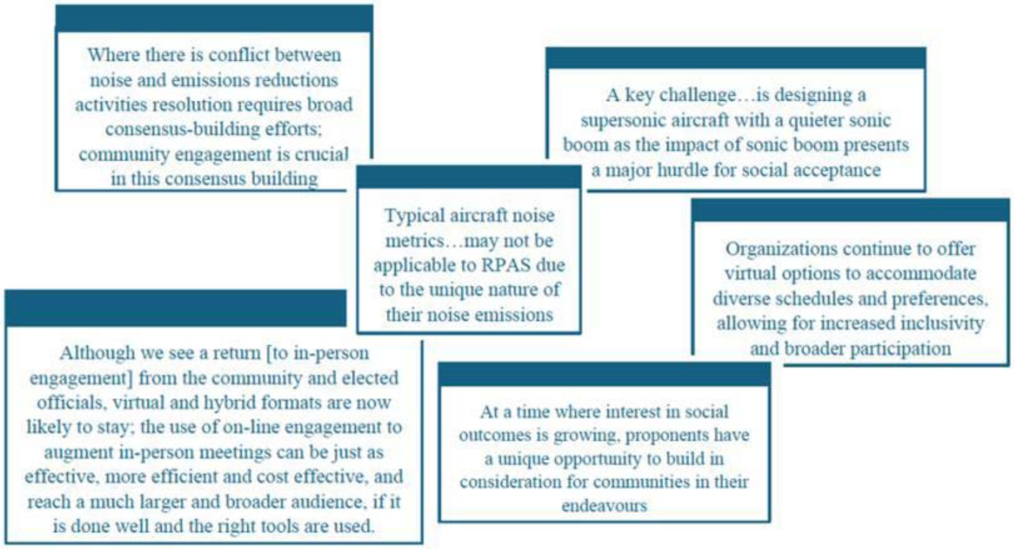


FIGURE 2: some key outcomes from Airports and Operations community engagement in the context of Emerging Technology Aircraft, Post-Pandemic dynamics and noise versus emissions

and growing concern across large sections of the global population, the noise impacts of adjusted routes, say, to achieve lower emissions, often causes even greater concern among populations living close to airports; communities around airports at the same time are increasingly sensitive to noise. Where there is conflict between noise and emissions, reductions activities resolution requires broad consensus-building efforts; community engagement is crucial in this consensus building.

Innovation and problem solving has always been a core feature of the development of aviation. The pace and scale of this innovation and change is increasing, with emerging aviation technologies such as urban air mobility, alternatively powered air transport, supersonic aircraft and spaceflight. The analysis found meaningful work being undertaken to advance social acceptance, but at this stage formal frameworks for community engagement often do not yet exist, which may affect social acceptance. However, it can be difficult for communities and other stakeholders to identify the sole responsible user - such as an airport or ANSP - to contact when they have concerns or questions about operations. This is likely to be a barrier to effective community engagement and social acceptance of these new aviation entrants as their operations grow.

The analysis showed that the pandemic has had a profound impact on all parts of the aviation system and required innovative ways to ensure continued business operations including the accelerated use of online tools to support continued community engagement. These online engagement methods have been and are being used to augment traditional in-person engagement after the pandemic restrictions were lifted. Lessons learned from engagement techniques used during the pandemic restriction periods will be valuable in connecting with communities in further emerging areas such as non-CO_2 emissions, and the integration of clean energy into the air transport system.

With the Operational Improvements wedge of the ICAO basket of measures to reduce CO_2 expected to deliver a significant contribution in the short to medium term, previous operational analyses within WG2 identified Continuous Descent Operations (CDO) as one of the operational improvements with the highest potential to increase operational efficiency. The first global vertical flight efficiency (VFE) analysis using a harmonised data source as detailed in the ICAO Environmental Report in 2022 revealed that for the descent phase, the average per flight inefficiency (or non-optimised CDO), generated an average extra consumption of 41kg fuel per flight across all ICAO regions. In addition, the ratio between

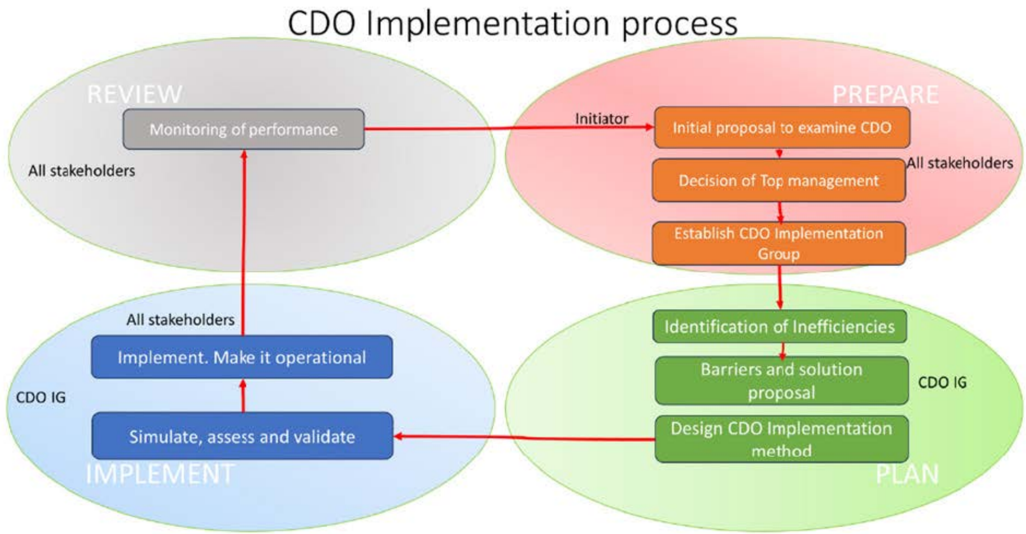


FIGURE 3: Updated CDO Implementation process from updated Doc 9931.

the extra consumption in the most efficient regions and least efficient regions was three-fold (20-60kg per flight). The costs of fuel of the inefficiencies per region were determined by multiplying the additional fuel burn with the kerosene price and number of flights for each region. For the climb phase, the average per flight inefficiency (or non-optimised Continuous Climb Operation (CCO)), generated an average extra consumption of 7kg fuel per flight across all ICAO regions. The total estimated benefit pool for 2019 was estimated to be around $1,000 Million (USD) for the descent phase and $160 Million (USD) for the climb phase.

In 2010, ICAO published the CDO Manual (Doc 9931) to provide guidance to stakeholders in implementing CDO including a detailed implementation process and focused aircraft operator techniques to leverage the most efficient vertical flight trajectory in the descent phases of flight.

Following key developments in areas such as Europe – with the development of the European CCO / CDO Action Plan – it became apparent that the Manual could benefit from an update to consider new information such as optimizing Letters of Agreement (LoAs) between air traffic centres and sectors, reducing fuel uplift and dynamic Route Availability Document (RAD), together with enhanced performance monitoring and training material.

To that end, in the CAEP/13 cycle, WG2 worked on the update to Doc 9931 in full cooperation with the ICAO Air Navigation Bureau. This work included a revised structure for Part A (CDO) and B (CDO Implementation guidance) and the addition of two new Appendices on CDO performance measurement and monitoring and tactical intervention on a descending aircraft over a climbing aircraft. The content of this latter Appendix was based on detailed technical analyses performed by WG2 which – supported by OEM data – demonstrated counter intuitively, that in general, even though climbing aircraft are heavier and thus burn more fuel burn, a prioritization of the optimization of the efficiency of the descent profile over the climb profile can result in bigger fuel and emissions savings.

WG2 also proposed inclusion of a new Attachment on CDO case studies/implementation examples such as examples of CDO performance dashboards and fuel/emissions savings related to optimizing LoAs.

In addition, while maintaining the detailed implementation process for practitioners to follow, WG2 also proposed introducing a new streamlined high level implementation roadmap for stakeholders with more practical experience of the airspace optimization process. Finally, new material on flight crew and ATCO awareness and training were added, information on noise aspects were integrated in various parts of the document, whilst ANSPs and Aerodrome

Operators were encouraged to ensure that information on CDO procedures at all airports under their responsibility should be promulgated in a harmonized format and structure in the Aeronautical Information Publication.

The updated Manual will now undergo the full ICAO provisions approval process. Once completed, it will be published in the ICAO Store.

Update on the GANP Performance Framework: Environmental Key Performance Area

The Global Air Navigation Plan (or GANP), detailed in ICAO Doc 9750 is the plan to drive the evolution of the global air navigation system to meet the ever-growing expectations of the aviation community. Updated on a triennial basis, alternating between a minor and major update, the 41st session of the ICAO Assembly agreed that the next edition of the GANP (eighth edition) would focus on resilience and the environment and establish consistent terminology related to the environment Key Performance Area (KPA) for both the GANP and its environmental strategic objective, ensuring alignment across ICAO's Strategic Objectives.

The GANP Performance Expert Group (GANP-PEG) was set up to lead this work and liaised with CAEP Working Groups to develop the four key areas of the ENV KPA, namely; Focus Areas, Performance Ambitions, Performance Objectives and Performance Indicators. The group identified the three Focus Areas of Climate Change, Noise and Local Air Quality.

The performance ambitions together with the associated 'supporting texts', first developed in 2019, were updated to reflect the latest LTAG net-zero carbon emissions by 2050 goal on climate change to align with the latest Assembly decisions. A second ambition was also created to ensure that all of three Focus Areas were covered by performance ambitions, differentiating the noise and local air quality 'local' impacts from the more 'global' impacts of climate change.

WG2 previously undertook the first global environmental benefits assessment of the ASBU framework (see the ENV Report 2019[2]). The outcomes of this analysis were reviewed in order to identify the individual benefit mechanisms that were associated with the implementation of operational improvements that could enhance environmental performance. These benefit mechanisms could be defined as individual performance objectives. For example, by performing a CDO, the following performance objectives could be realised under the right conditions:

- Reduce fuel burn / CO_2 emissions by minimising uncertainty about the optimum Top of Descent (ToD) point
- Reduce fuel burn / CO_2 emissions by minimising descent constraints after ToD has been chosen and executed
- Reduce fuel burn / CO_2 emissions by minimising vertical trajectory constraints

Ideally, each performance objective should be linked to one (or more) ASBU element(s) so that when a stakeholder wishes to use the Environmental Performance Framework (ENV PF) to identify which aspect of environmental performance to improve, the associated benefit mechanism detailed in the performance objective tree leads straight to related ASBU element(s) where available. However, this step will be undertaken in the next iteration of the GANP-PEG, in coordination with CAEP WG2.

The final element of the ENV PF to be developed were the Performance Indicators. The GANP already included some generic performance indicators using time / distance proxies for environmental performance - such as KPI12: taxi-in additional time – but the only existing KPI that could be potentially adapted to become an ENV KPI was KPI16 – Additional Fuel Burn. A review of global performance work did not reveal any new performance indicators mature enough to be considered at the global level for climate change, despite much work on indicators being under development e.g. in the AVENIR Working Group in EUROCONTROL. However, the GANP-PEG proposed to update the KPI16 to measure Additional Fuel Burn / CO_2 so it could be classed as an ENV KPI and identified a commonly used noise indicator – People / Area impacted

2 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg138-144.pdf

Environment performance ambitions of the GANP:

"To minimize, through operational improvements that in particular reduce fuel burn, the adverse environmental impacts of aviation activity on the climate."

"To minimize, through operational improvements, the adverse local environmental impacts of aviation regarding noise and local air quality."

FIGURE 4: Updated Environment performance ambitions of the GANP.

by significant noise - to be added to the PF as new indicator KPI24, to measure environmental performance related to the Noise Focus Area.

The next steps for the GANP-PEG group will be to align the new ENV KPA Performance Objectives with those in the KPA Efficiency to ensure alignment and identify which benefit mechanisms in the Performance Objectives are enabled by which ASBU element(s).

In February 2025, CAEP approved the LTAG Monitoring and Reporting (LMR) methodology, which combines backward-looking assessments to track actual performance against milestones (e.g., CAAF/3) and forward-looking assessments to project progress toward 2050. These assessments consider factors like traffic, technology, operations, and SAF, and their impact on CO_2 reductions. The LMR methodology adopts a tiered approach, with Tier 1 as the core methodology and Tiers 2 and 3 requiring additional resources, data and modelling. This phased approach will evolve over future CAEP cycles.

As the LMR work in CAEP progresses, updates to the environmental KPA in the GANP may be necessary. To ensure effective tracking, it is crucial that the benefits of operational measures that fall under the GANP can be accurately measured using the LTAG monitoring methodology and metrics. Close coordination between the GANP SG and CAEP will ensure that the benefits can be accurately measured as implementations of both current and future innovative operational improvements evolve at both the regional and global levels.

Taking into account the experiences observed in the CAEP/13 cycle together with emerging priorities identified by CAEP WG2 Members and Observers and ongoing engagement with aviation stakeholders, WG2 plan to continue some current threads of work during the CAEP/14 (2025-2028) cycle whilst also addressing several of these priorities. These include:

- Reviewing the ICAO CCO Manual with a view to updating it to bring it in line with the updated Doc 9931;
- Updating Circular 351 on Community Engagement based on the latest developments highlighted in the CAEP 11-13 reports;
- Assessing the practical application of the ICAO Balanced Approach to noise management based on the experiences of aviation stakeholders;
- Delivering a state of play document related to PFAS contamination at airports;
- Updating the 2022 Climate Risk Assessment, Adaptation and Resilience Reports;
- Developing aviation sectoral guidance for sustainable plastics management;
- Continuing developing the eco-airport toolkit e-publications to support global aviation environmental practitioners at and around airports; and,
- Performing the global environmental assessment of the potential of 'Operational Improvements' to contribute to reaching net-zero carbon emissions by2050.

Vertical Flight Efficiency En-Route (VFE-ER)

By David Brain and Francisco Hoyas (EUROCONTROL)

Vertical Flight Efficiency En-Route (VFE-ER)

Proposal to identify inefficiencies in the Vertical trajectory during Cruise

Reducing fuel burn and CO_2 emissions remains one of the most pressing challenges for the aviation sector. While much attention has been given to technological innovation and sustainable aviation fuels (SAF), operational improvements—particularly in how aircraft fly—offer immediate and scalable opportunities for environmental gains. This study focuses on the cruise phase of flight, to identify and quantify the inefficiencies in flying at sub-optimum cruising levels that leads to excess fuel consumption. By developing a methodology to assess VFE en-route, this work aims to support data-driven improvements in flight operations and airspace management that can directly reduce the environmental footprint of aviation.

In the 2022 ICAO Environment Report[1], ICAO reported how the Committee on Aviation Environmental Protection (CAEP) had undertaken the first global vertical flight efficiency (VFE) analysis for the climb and descent phases of flight. In this analysis - in the absence of a fit for purpose methodology to measure VFE in the en-route phase - there was insufficient time and effort available to continue the work within CAEP Working Group 2 (WG2). To address this challenge, a small global group of experts worked together to develop two new methodologies to measure global VFE in the en-route phase under the umbrella of EUROCONTROL, the European Organization for the Safety of Air Navigation.

The key challenges involved identifying an appropriate set of methodologies, data sources and performance indicators, together with agreeing on a set of assumptions to minimise the uncertainties associated with such a global analysis.

The data source used in this study was global Automatic Dependent Surveillance–Broadcast (ADS-B) ADS-B data provided by Flightradar24. Where gaps in ADS-B coverage were identified e.g. over the Oceans, assumptions were made to connect multiple parts of the same profile. The performance indicator selected – average time spent at inefficient cruising levels - was a variant of the Global Air Navigation Plan (GANP) indicators on VFE (KPI17 – level-off during climb; and KPI19 – level-off during descent), adapted for the en-route phase. This indicator was selected as it could be applied to all ICAO regions, at sub-regional or national levels and also be applied to different data sources.

One of the key aspects of the methodologies to be developed for the en-route analysis was to ensure alignment with the VFE study of the climb and descent phases in terms of definitions of flight phase and indicator usage. This would ensure that both analyses (climb / descent and en-route) could be undertaken with the same data set, using the same data points, employing similar performance indicators using 'TIME' with no overlapping of data points in the various flight phases.

In the VFE en-route study, the measurement of (in) efficiency was focused on the level segments that are flown during the cruise phase at inefficient flight levels below a calculated Reference Flight Level (FL), with the following principles agreed:

- The source of data to compare with the Reference FL was:
  - For pre-tactical analysis (planned trajectories): Flight Plan data; and
  - For tactical analysis (flown trajectories): real Correlated Position Report(CPR), Flight Data Monitoring (FDM) or ADS-B data source.

1 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO ENV Report 2022 F4.pdf

- Only time flown below the Reference FL was considered inefficient, with some margins explained below.
- For all studies where the whole flight was analysed, the vertical profile between the Top of climb (ToC) and the Top of descent (ToD) is compared with the reference FLs.
- To adapt the study to a more local analysis (i.e. a Flight Information Region (FIR), specific airspace or country), the vertical profile of the cruise phase between the entry and exit points of the specific geographical entity was compared with the Reference FL that corresponds to that airspace.
- Time at inefficient levels can be converted into excess fuel figures based on the Base of Aircraft Data(BADA), an aircraft performance model developed and maintained by EUROCONTROL[2], aircraft type performance database.

Reference FL Calculation (FL1 and FL2)

The FL used to compare the planned/actual profiles with is called the **Reference FL**. Airbus defines the Optimum Flight Level as "*The Optimum FL, (………) is the flight level which provides the greatest specific range (nm/kg) at a given gross weight*"[3] i.e. NM flown per unit of fuel burn). The optimum FL of a flight depends on various factors, like aircraft type, weight, wind, cost index, tropopause altitude, weather conditions, etc. not to mention the air traffic management (ATM) conditions and traffic flows. For the purpose of a study or performance monitoring, not all of these factors can be taken into account, so the calculation of this Reference FL is unlikely to fully match the definition of optimum FL, hence the term "Reference FL".

Based on the Great Circle Distance between the aerodrome of departure (ADEP) and the destination (ADES), two different calculations were made to set the Reference FL:

- Reference FL1: Flights with a city pair distance greater than 1000 NM use a Reference FL derived from the BADA database based on aircraft performance.
- Reference FL2: Flights with a city pair distance below 1000 NM use a Reference FL derived from a statistical calculated value.

Note: For flight lengths below 1000NM, it is assumed that traffic levels/airspace complexity are the main constraints to aircraft reaching their optimum level. Aircraft are lighter, so the optimum FL based only on fuel consumption (BADA) becomes too high, with the sector length short enough for the flight not to climb as high as the BADA optimum FL. This value is under discussion and could be lower to 500 NM, based on future analysis.

In developing the Reference FLs for all aircraft types and distances flown, a number of considerations were made:

- If an optimum FL is estimated to be an intermediate value, it is always rounded down e.g. an optimum FL of FL387 will actually be rounded down to a Reference FL380;
- A 1000ft buffer is created below the Reference FL segments to account for Flight Level Allocation Scheme (FLAS)[4]; and,
- Depending on the calculation of the optimal FL for each a/c type and stage length, the Reference profiles will consist either of a single level segment or of a set of level segments connected by climb segments (to reflect real-time climbing of aircraft on medium / long-haul flights as weight decreases.

Reference FL1 - BADA calculation

Each aircraft type has three associated weights in BADA (low, nominal and high) together with its corresponding performance at each FL, fuel burn and speed. Based on the data in the BADA performance tables, an optimum FL can be calculated for each weight based on maximum Specific Range (NM/kg) values extracted from speed, fuel flow and FL. Speed correction or Cost Index variations are not taken into account, as that information is not available for each individual flights, so the nominal speeds of BADA at each level are the only ones taken into account.

2 https://www.eurocontrol.int/model/bada
3 https://ansperformance.eu/library/airbus-cost-index.pdf
4 https://skybrary.aero/articles/flight-level-allocation-scheme-flas

Stage Length	1	2	3	4	5	6	7	8	9
Trip Length Range (nm x 1000)	0-0.5	05-1	1-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	>6.5
Representative range (nm)	350	850	1350	2200	3200	4200	5200	6200	
Takeoff Weight (lb)									

FIGURE 1: Stage Lengths and representative range.

In order to assign a relevant Reference FL to each flight, the first assumption made is the weight of the aircraft at take-off. BADA and Aircraft Noise and Performance (ANP) data are used to assign a specific weight for each stage of an overall stage length (SL) of a city pair distance for each aircraft type, assuming a fixed load factor. As ANP data uses more weights, based on the Stage Length (SL) or distance of the flight, an interpolation/extrapolation is made from the BADA values, so a table of optimum FLs can be created for each ANP weight, corresponding to each sector length of the SLs defined, for each aircraft type.

With this assumed weight for each SL, a Reference FL can be determined for each stage of an overall stage length (city pair distance) to represent medium/longer-haul flights performing step climbs. This process also provides a fuel burn rate in kg/min and kg/nm (for each aircraft type and stage length) to support fuel burn calculations, from where the optimum fuel burn FL is determined.

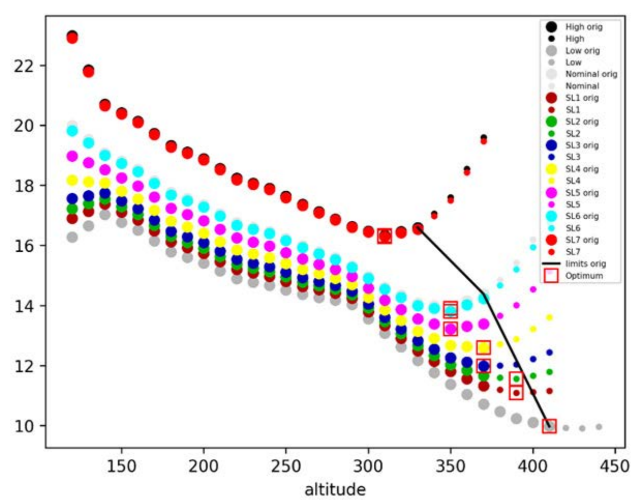


FIGURE 2: Example of using Stage Lengths from ANP and BADA data to identify the lowest fuel burn rates.

Figure 3 demonstrates how the Reference FL (in green) may change over time as an aircraft passes between stage lengths, as the Reference FL gets higher as the aircraft weight decreases. That way, step climbs are allowed at each portion of 1000 NM (which corresponds with Original Equipment Manufacturer (OEM) assumptions on aircraft weight loss over distance).

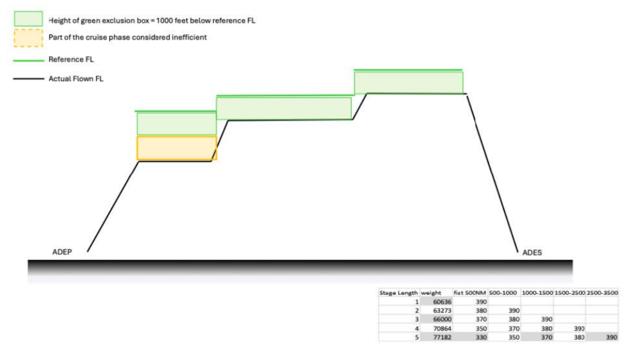


FIGURE 3: Example of step climb flight.

Reference FL2 - Statistical calculation

Flights with sector lengths below 1000 NM are usually flown with the aircraft not fully loaded with its maximum fuel capacity. In such cases, the optimum FL based on fuel consumption (BADA) is likely to be high. However, the sector length may be too short for the flight to reach the BADA optimum FL, or there may be a myriad of other reasons - e.g. operational constraints - that limit the possibility of reaching the optimum level.

All flights with stage length of less than 1000nm were compared with a Reference FL calculated statistically (Figure 4). The Reference FL2 was based on the FLs flown on specific city pairs using a much larger database of flights. For each aircraft type, all flights using that aircraft type, on a certain city pair distance are aggregated in 'bins' of city pair distances. The reference profile is determined for each aircraft type and each city pair distance, considering 50NM bins (i.e. 300NM, 350NM,...1000NM etc.). The reference FL for each aircraft type/city pair 'bin' is obtained from the 80th percentile of the observed planned/actual altitudes of the flights.

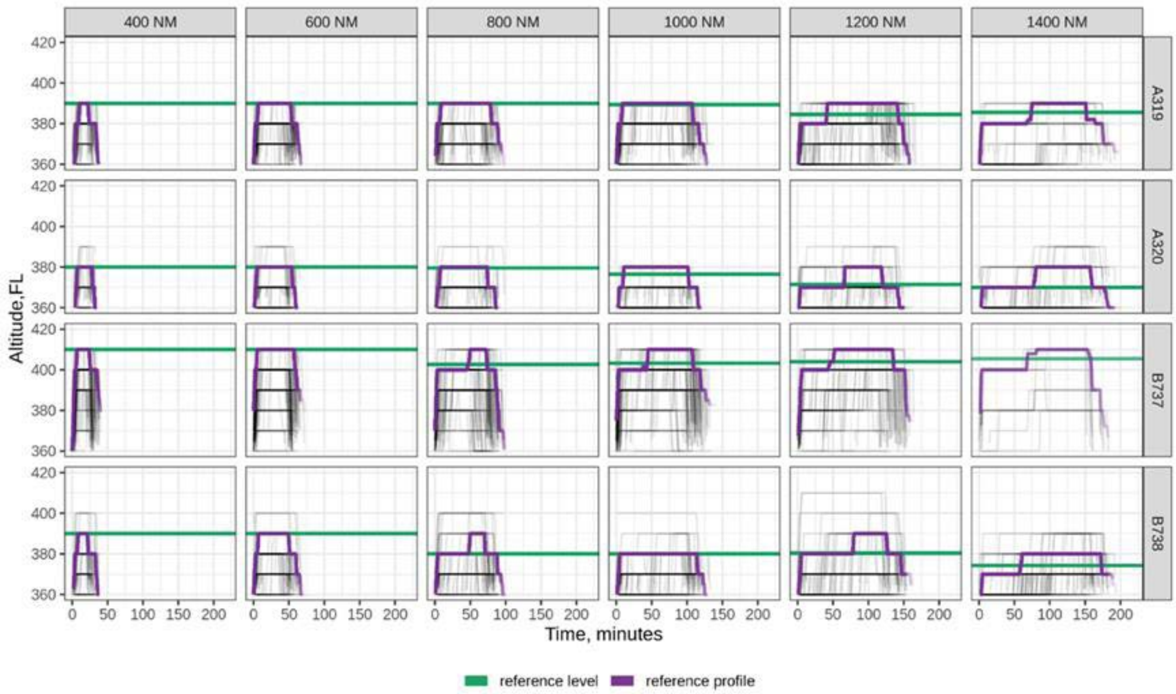


FIGURE 4: Example of statistical Reference FL2 calculation.

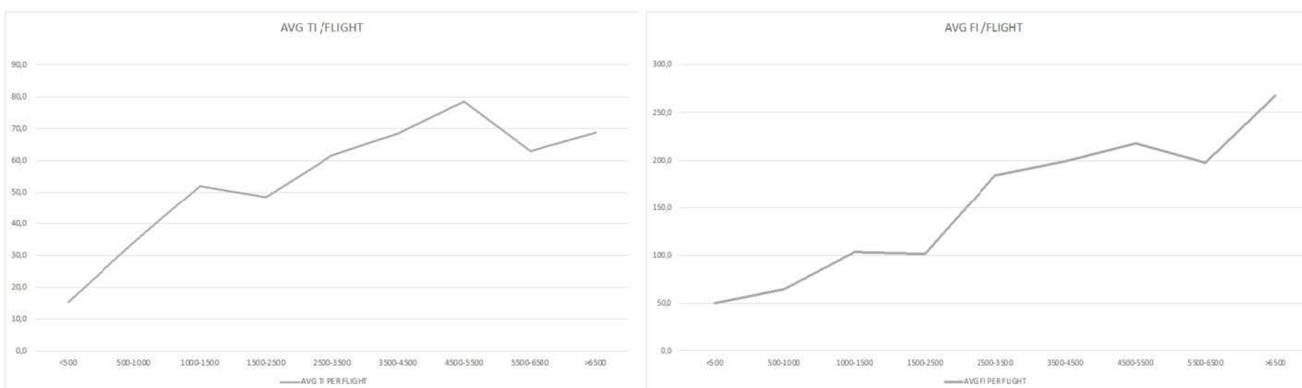


FIGURE 5: Examples of TI (Time Inefficiency) and FI (Fuel Inefficiency) per stage length.

When the statistical Reference FL was above the BADA Reference FL1 for that city pair distance, the BADA Reference is used, as it makes no sense to establish a Reference FL that is above the one that gives the minimum fuel burn per distance flown.

Calculation of the Inefficiency

The analysis of vertical flight inefficiency compares the reference profile of each flight (based on aircraft type and stage length) to the planned or actual flown profile and delivers the amount of Time flown at an inefficient FL (Time Inefficiency TI) and the Fuel Burn difference between the planned/actual and the Reference FL (Fuel Inefficiency FI) see Figure 5.

The main KPI chosen for the result was the Average Time at Inefficient FL per flight. The main reason for this is to align results with the climb and descent phases, where the main KPI is average time in level flight per flight. For the en-route phase the values are expressed in minutes instead of seconds (used for the climb and descent). The secondary KPI is Fuel inefficiency per flight.

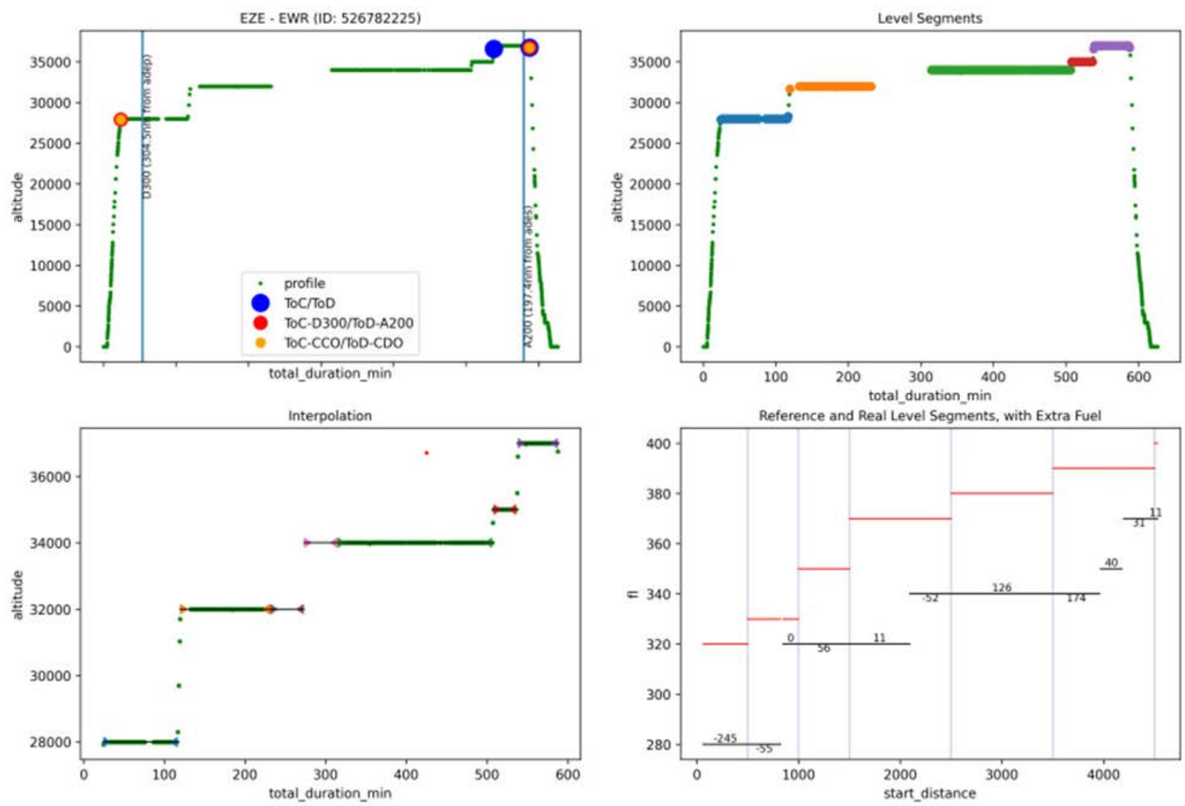


FIGURE 6: visual representation of process to measure fuel inefficiency (clockwise from top-left): identification of ToC/ToD, identification of all level segments, bridging of any gaps in profile, comparison of actual profile with Reference FL with corresponding fuel burn impacts (kgs fuel)

Results

From the total of nearly 4 million flights contained in the ADS-B data sample (4 calendar weeks of global traffic as used in the global VFE climb and descent study), the TI and FI values for each aircraft type and distance bin were used to calculate the total amount of TI and FI contained within each distance bin as part of the overall set of flight lengths (see the table in Figure 7 below). This could then be broken down to the regional level. From the results it is also possible to see how the average inefficiency per flight is skewed towards the shorter flight distances reflecting the shorter flight distances flown by the vast majority of flights.

Stage length distance (NM)	Average FI / flight (kg)	Average TI / flight (mins)	% cruise time flown as inefficient
<500	49.7	15.3	62%
500-1000	64.6	34.1	55%
1000-1500	103.2	52.0	41%
1500-2500	101.1	48.4	23%
2500-3500	184.1	61.6	18%
3500-4500	199.2	68.5	15%
4500-5500	217.9	78.5	13%
5500-6500	197.4	62.9	9%
>6500	267.6	68.7	8%
Average total/flight	**63.2**	**30.4**	**32%**

FIGURE 7: Global average FI / TI results per SL and per flight.

Conclusion

The methodology that has been used for the global VFE en-route analysis, together with its sister methodologies[5], provides a set of methodologies to measure regional and global Horizontal Flight Efficiency (HFE) and VFE in all flight phases. This analysis delivered high level results used for investigating the level of vertical inefficiency in the en-route flight phase compared with other phases of flight or HFE. It is ready and available to be used based on the assumptions made.

When wishing to delve deeper into the root causes of vertical inefficiency, or to assess the contribution of individual stakeholders to the inefficiency, further analysis is required with an accompanying further refinement of the methodology.

The factors that may be further investigated may include:

- Wind: Wind velocity and direction can change the BADA optimum FL. Due to stronger tailwinds, it might be better to fly at a lower FL than the BADA optimal FL which shortens the flight, compensating the extra fuel flow of flying lower. This should not be considered an inefficiency, but a wind optimised FL.
- Weather phenomena along the route: this might suggest flying at a lower flight level (in future, it could include contrail avoidance, if needed). It takes into account mainly forecasted turbulence that makes the AU choose to fly at a lower altitude to avoid it. The selected cruise level is then not considered inefficient, as it is the most convenient for the safety of the flight.
- Delay and other costs: The AU chooses to fly a lower FL – below the BADA optimal FL - or a vertical profile to avoid a specific airspace and reduce the overall cost (due en-route charges) or delay of the flight.
- ATM: ATM vertical inefficiency is the time spent at inefficient FLs due to ATM restrictions. For example, in Europe, RAD (Route Availability Document) restrictions - based on Network Management measures due to Capacity shortage – may define a maximum FL to be planned / flown.

Thanks for supporting the development of the methodology go to:

- US FAA
- Air Services Australia
- Boeing
- EUROCONTROL
- Novair AB (Airline)

5 Global VFE climb and Descent analysis in the 2022 ICAO Environmental Report - https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO ENV Report 2022 F4.pdf
Global HFE analysis in the 2019 ICAO Environmental Report - https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg138-144.pdf

The role of the pilot in climate change mitigation through operations

By Robert Brons (IFALPA)

Introduction

Among the ICAO basket of measures, operational improvements play an important role in reducing the impact on the climate. Every contribution counts toward a net zero future aligned with the long-term aspirational goals. Equally important but often overlooked is the fact that without improvements in flight operations and air traffic management (ATM) infrastructure, the expanding aviation sector cannot be accommodated in the future. Flight and airspace efficiency will decrease rather than improve, leading to increased CO_2 emissions.

Safety Considerations in Operational Improvements

Safety is paramount, as underlined by all stakeholders within ICAO, and it must continue to improve as air traffic increases. For any operational improvement aimed at mitigating the environmental impact of aviation, assessing the potential effects on flight safety and on flight operations is a prerequisite. Before introducing any changes to flight operations at the airport or in the air , it is essential to consult with relevant stakeholders regarding the operational implications, potential benefits, and technical limitations of such changes.[1]

The flight crew may have the overall perspective and plays a role in deciding whether a new flight procedure, cockpit system, or airport design can safely be adopted and is practicable. Conversely, such changes may lack flexibility, robustness, clear instructions, harmonization, or reliability in operations and may increase workload for daily flight operations.

IFALPA

Airline pilots are organized under national pilot associations and, internationally, under the International Federation of Airline Pilot Associations (IFALPA). While safety remains the primary concern of both the pilot and IFALPA, social and environmental sustainability is considered as a fundamental requirement for future growth. To emphasize this commitment, IFALPA has extended its mission "to contribute to the industry's efforts to minimize the environmental impact of commercial aviation." IFALPA believes that pilots can play a crucial role in bridging the gap between science and flight operations. Collaborative efforts are fundamental in any operational improvement initiative.

While IFALPA is committed to advancing environmental sustainability in aviation, the successful implementation of operational improvements requires addressing several critical challenges. The challenges for implementation of operational improvements, as identified by IFALPA, refer to:

- Impact on safety
- Effectiveness of measures
- Practicability of measures
- Economical reasonableness
- Airport Capacity and noise restrictions
- Health issues ground personnel
- Training / awareness issues for operational staff / pilots
- Increased traffic demand

For example, initiatives like contrail management and **Continuous Descent Operations (CDO)** require careful consideration of flight path adjustments and altitude management. **Contrail management**, aimed at reducing the climate impact of condensation trails, and CDO, which optimizes descent profiles for fuel efficiency, demand operational changes that can affect flight efficiency, fuel consumption, and air traffic flow. However, implementation of these measures cannot be effective without considering the operational issues and implications such as increased cockpit workload, required communication protocols and changes to cockpit procedures such as flight path management. These complexities underscore the need for real-world flight testing and close collaboration with the operational actors: the airline operator, the pilot and the air traffic controller. The scale of flight testing should be such to reflect actual flight operation in order to assess the impact on the whole (ATM) system.

Note. IFALPA holds a position as observer in ICAO CAEP for many years. Since 2021, a dedicated IFALPA climate working group of experienced airline pilots has combined operational expertise from the global pilot community to address the many environmental challenges and assist the work within ICAO/CAEP. Several position and information papers have been published to inform pilots and other stakeholders on the pilot's views.[2] [3]

Operational opportunities and the role of the pilot

Several flight techniques and flight management choices are available to the pilot in the daily flight operations to save fuel and optimize flight efficiency. ICAO has compiled these operational opportunities in the ICAO Doc 10013 Operational Opportunities to Reduce Fuel and Emissions. This Manual was developed in close collaboration with CAEP Members and Observers, including IFALPA, to provide meaningful, efficient, and safe options for the reduction of fuel use and emissions.[4] The prerequisite is that these "green" procedures are well embedded in the flight manuals and pilot training.

These opportunities may be adopted during flight operations when considered feasible and safe by the pilot. The decision to implement them depends on the specific situation, including factors such as weather, required equipment and the availability of ATM and airport facilities associated with each flight, aircraft and crew. Examples of these operational measures for the reduction of aviation CO_2 emissions include:

- Flight Planning And Fuel Reserves
- APU Usage
- Delayed Engine Start
- Aircraft Towing
- Optimized Climb Speed
- Continuous Climb Operations
- Cruise Speed Optimisation
- Optimised Flight Routings
- Weather And Wind Updates
- Continuous Descent
- Performance Based Navigation
- Reduced Flap Landing
- Delayed Flap Landing
- Idle Reverse Thrust
- Reduced Engine Taxi-In
- Centre Of Gravity Optimization
- Adjusted Potable Water Uplift
- Catering And Waste Tank Service

Advances in computerized flight planning, flight management systems (FMS), improved in-flight support and increased accuracy of weather forecasts have significantly enhanced pilots' ability to optimize operational efficiency. These improvements offer opportunities to optimize fuel planning (and reduce carrying extra fuel) and the selection of nearby alternate without compromising safety.[5] A fuel consumption monitoring program may reduce or refine the planned taxi fuel and required contingency fuel based on specific aeroplane and route data. **Ultimately,** the pilot-in-command has the authority to determine the final amount of fuel carried on board, and to increase the minimum fuel warranted for a safe flight or for operational reasons.

During the actual flight, the pilot may optimize the flight altitude, routing and cruising speed, depending on operator's needs and the flexibility of the Air Navigation Service Provider(ANSP). Trajectory-based operations (TBO) are expected to streamline this concept in the future. This requires updated enroute weather and wind information, and close collaboration with the operator/dispatchers, the flight crew and the ANSP during flight. For the flight crew to actively manage the flight in a safe and sustainable way, data-communication and on-board flight management systems and an electronic flight bag with flight optimization tools should be available.

Ground operations can be made more fuel-efficient, but they generally require facilitation through by airport equipment and/or proper coordination and communication. For example, the reduced use of the Auxiliary Power Unit (APU) on board, requires suitable external ground equipment at the parking position for electric power and cooling of the aircraft. The implementation of Airport Collaborative Decision Making (A-CDM) and flow management can enable delayed aircraft engine start, but requires extensive communication and collaboration between the airport, ANSP and operator. This may limit the flexibility to accomodate last-minute changes.

One engine-out during taxi-in may be an option for a pilot, when this procedure is clearly outlined in the operating manual. It is then up to the pilot to decide if the circumstances are favorable to apply this procedure - lower aircraft weight, and no crossing runways, slippery apron, tight turns into gate positions, or aircraft technical deficiencies. Engine-out taxi-out procedures, on the other hand, involve more challenges: higher aircraft weight, greater workload for engine starting, the need for engine thermal stabilization, delayed checklists and system checks, and the absence of ground staff assistance.

Typically, the aircraft is certified with more than one standard landing flap setting. Choosing a reduced landing flap selection can decrease fuel consumption and reduce noise exposure during the final approach segment. However, this choice depends on various factors, such as aircraft weight, the runway length and runway conditions and the atmospheric/wind conditions. With reduced landing flaps, the aircraft will approach at higher speeds which will likely impact the runway occupancy time and the use of reverse thrust after landing.

The selection of idle thrust reverse upon landing will increase the landing distance and brake wear but reduces engine noise and fuel consumption. On a long and dry runway, this technique may be safely applied. However, this procedure should never be mandated, and full reverse thrust should be available for safety reasons. The pilot should be trained to use full reverse if circumstances require doing so.

Aircraft maintenance can also impact fuel consumption. The consequences of some aircraft deficiencies may be clear and relatively small – such as a missing fairing, which leads to a slight increase in drag and a clear fuel penalty. Over time, with frequent flights, this can lead to considerable fuel costs. For other deficiencies, operational expertise is required to assess the potential consequences – such as a lack of Reduced Vertical Separation Minima (RVSM) or Performance Based Communication and Surveillance (PBCS) capabilities, which may result in significant fuel penalties due to flight planning constraints.

Note. Future contrail management to avoid the warming non-CO_2 effects of persistent contrails, will entail several scientific and operational challenges. Any operational strategy should be carefully designed to address the uncertainties in forecasting and modeling, while also considering the impact on flight safety and flight efficiency and operational requirements.

Pilot training

Pilot training plays a crucial role in facilitating fuel-efficient operations and raising awareness on the environmental impact of aviation. Both ab-initio training and recurrent training should incorporate the environmental opportunities and relevant operational implications.

Continuous descent operations can be planned efficiently when the aircraft performance characteristics are well-known, and the capabilities of the aircraft automation and flight management are well used, and the flight path, speed and aircraft configuration changes are well managed and anticipated. This requires pilot and air traffic controller training, and situational awareness, specifically of parameters such as distance to go, expected routing, number in traffic and effects of wind patterns.

Specific navigational procedures, based on Required Navigational Performance - Authorization Required (RNP-AR) standards, will enable more direct and efficient departure and arrival routes, especially in congested airspace. These new standards require both pilot training and associated aircraft navigational capabilities.

The feedback of anonymized fuel and flight data statistics can assist in creating awareness among both the pilot and the company, facilitating more efficient fuel and flight planning. For example, the amount of contingency fuel, the amount of fuel required to compensate for unforeseen factors, may be reduced using fuel consumption monitoring data specific to each aircraft and route. This data ensures an appropriate statistical coverage of the deviation from the planned to the actual trip fuel.[6] The use of these statistics should be supported by airline's Flight Data Analysis Program (FDAP) embedded in a fully established just culture.[7]

Future outlook

IFALPA anticipates an enhanced role for the flight crew in the future, flexible and dynamic flight planning aimed at improving airspace capacity and flight efficiency. Especially on longer flights, route re-negotiation and adaptation during flight based on the operator/pilot's requests and updated weather forecasts, could significantly benefit flight efficiency. The Pilot in Command will remain responsible for the safety of the flight even when certain functions are delegated to automation. [8]

Looking ahead, future assessments, should consider the changing aircraft equipage and changing ATM environment. New airspace users will play an important role, such as advanced air mobility (AAM), unmanned aircraft, supersonic transport (SST), commercial space operations and these new users must be accommodated. These emerging technology aircraft may affect flight operations and environmental performance of conventional aircraft if not properly integrated.[9]

[1] ICAO Doc 10031 Guidance on Environmental Assessment of Proposed Air Traffic Management, 2014.

[2] IFALPA Position Paper Safe and Sustainable Aviation, 15POS14

[3] IFALPA Position Paper Long-term Aspirational Goals for CO_2 Reductions, 22POS03

[4] ICAO Doc10013 Operational Opportunities to Reduce Fuel and Emissions, 2014

[5] ICAO Doc 9976, Flight Planning and Fuel Management (FPFM) Manual, 2015

[6] ICAO Doc 9976 Flight Planning and Fuel Management Manual, 2023

[7] IFALPA Position Paper Pilot Self-Assessment Systems, 19POS18

[8] IFALPA Position Paper on Implementation of the Future of Air Traffic Operations, 21POS06

[9] IFALPA Position Paper, Introduction of Emerging Technology Aircraft in Civil Airspace, 25POS10

Operational Opportunities to Reduce Climate Effects of Contrails

By Asuka Boehm (CANSO) and Robert Brons (IFALPA)

Introduction

According to current scientific understanding, the impact of persistent contrails and aircraft-induced cloudiness on the climate is significant as they affect the Earth's radiative balance. These contrails, which form in the immediate wake of an aircraft at cruise altitudes, along with the associated contrail cirrus clouds, are estimated to have a notable radiative forcing (RF) effect and, on balance, contribute to global warming.

However, uncertainty on the magnitude of the contribution is considerable, especially on a smaller scale / locally and for individual flights. The related upper air chemistry and physical processes are complex and not well understood (such as the impact of background aerosols and interaction with existing cirrus). Additionally, missing data on the humidity field in the upper atmosphere and on particulate matter emissions from engines limits understanding of contrail formation and in particular, persistence.

As research on the scientific basis of contrail formation, and the related radiative forcing and climate impacts continues to evolve, it is essential to assess the operational opportunities as well to reduce these impacts. How can we effectively avoid formation of warming aircraft-induced cloudiness in practice, in a safe and efficient way?

This article relates to the findings in the ICAO Committee on Aviation Environmental Protection (CAEP) report on "Operational Opportunities to Reduce Climate Effects of Contrails and other non-CO_2 Emissions" [1], written by operational experts and contrail scientists under leadership of the two authors. The report identifies potential operational measures, which are embedded in various concepts of operations, along with the associated challenges and interdependencies with other aspects of flight, such as flight time and fuel consumption. To address these challenges, future opportunities and enablers have been identified to support the effective and efficient mitigation of contrails.

Trajectory adjustment

Three pathways are available for reduction of warming contrails: 1) through operational measures, 2) through adaptation of engine and aircraft design, and 3) through modification of fuel type and composition.

Note. Experimental evidence is available that low-aromatic sustainable aviation fuels (SAF) may reduce the soot and ice number concentrations, reducing contrails and more importantly the warming potential of contrails, but this needs more research and validation.

The ICAO CAEP report focuses on operational measures, and in particular, trajectory adjustments of flight: horizontally, vertically, or in time, either planned before the flight or applied during flight. The different pathways are not mutually exclusive and could complement and/or impact each other.

1 ICAO CAEP Report on Operational Opportunities to Reduce Climate Effects of Contrails and Other Non-CO_2 Emissions, to be published.

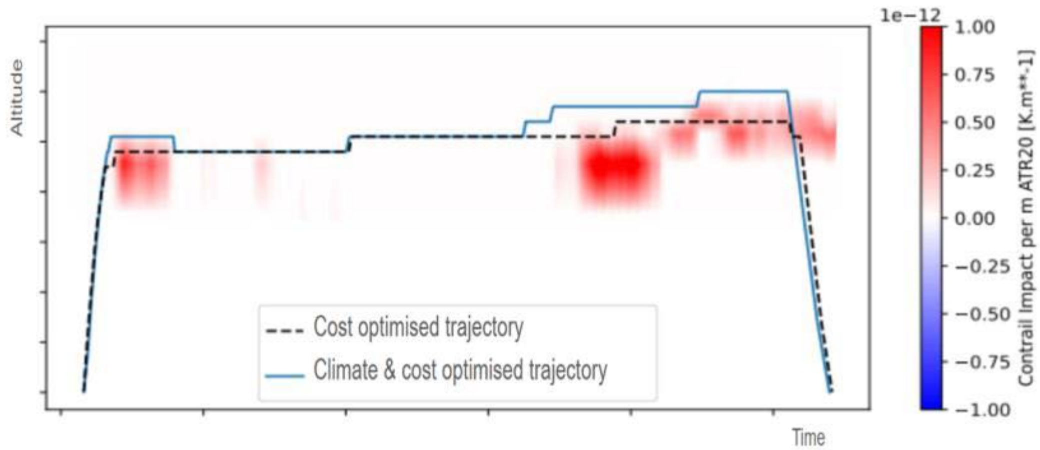


FIGURE 1: Example of vertical trajectory adjustment to reduce climate impact of contrails.

Challenges

Multiple challenges are identified for effective and safe implementation of trajectory adjustment for contrail mitigation. These challenges relate to:

- the availability of relevant meteorological data (especially relative humidity to ice),
- the modeling of persistent contrail formation and calculation of subsequent climate impact,
- the verification of the effectiveness of interventions,
- the flight planning capabilities of the operator
- and the required flexibility of air traffic management (ATM).

The climate impact from contrails is in general quantified with low confidence, compared to that of CO_2. Uncertainties exist for both the spatial and temporal characteristics of individual contrails, as well as the climate impact of individual contrails, multiple contrails and the combined global impact.

A key element is the availability of relevant meteorological data, especially relative humidity with respect to ice (RH_i) at flight altitudes with sufficient accuracy and at sufficient temporal and spatial scales. Other relevant scientific gaps relate to the (unknown) impact of background emissions and the cloud aerosol interaction and the impact of changing fuel composition.[2]

Potential concept of operations

Guidance for operational measures to avoid non-CO_2 climate effects is not yet available. Several operational concepts for trajectory adjustment can be identified. These concepts involve all operational stakeholders (the flight planner, the airline operational control center, the flight crew and the ANSPs). The choice of concept may depend on the mitigation objective, the region of applicability, the timeframe for decision-making, the availability of observations, forecasts, and modeling tools, and on the decision initiator (Figure 2).

The decision and intervention for navigational adjustment can be made pre-flight (during flight planning), strategically in-flight (in anticipation), or tactically in-flight through ATC intervention. Pre-flight interventions may be preferential from a workload and flight planning perspective. On the other hand, tactical interventions may be preferential to reduce the forecasting window. Tactical intervention may reduce the actual regions of the airspace to be avoided and enable verification with real-time observational data.

Flight operations are by essence a multiple stakeholder cooperative effort and given the potential interdependencies between contrails avoidance at scale and for specific flights, the initiative for pre-flight or in-flight trajectory adaptation might be handled by the airline operator, the ANSP or a collaboration between both. The ANSP has the bigger picture and oversees the complete flow of operations in their control area, ensuring that the global flow of

2 ICAO CAEP Impacts and Science Group (ISG), "Contrail Science Workshop Report," [to be published]

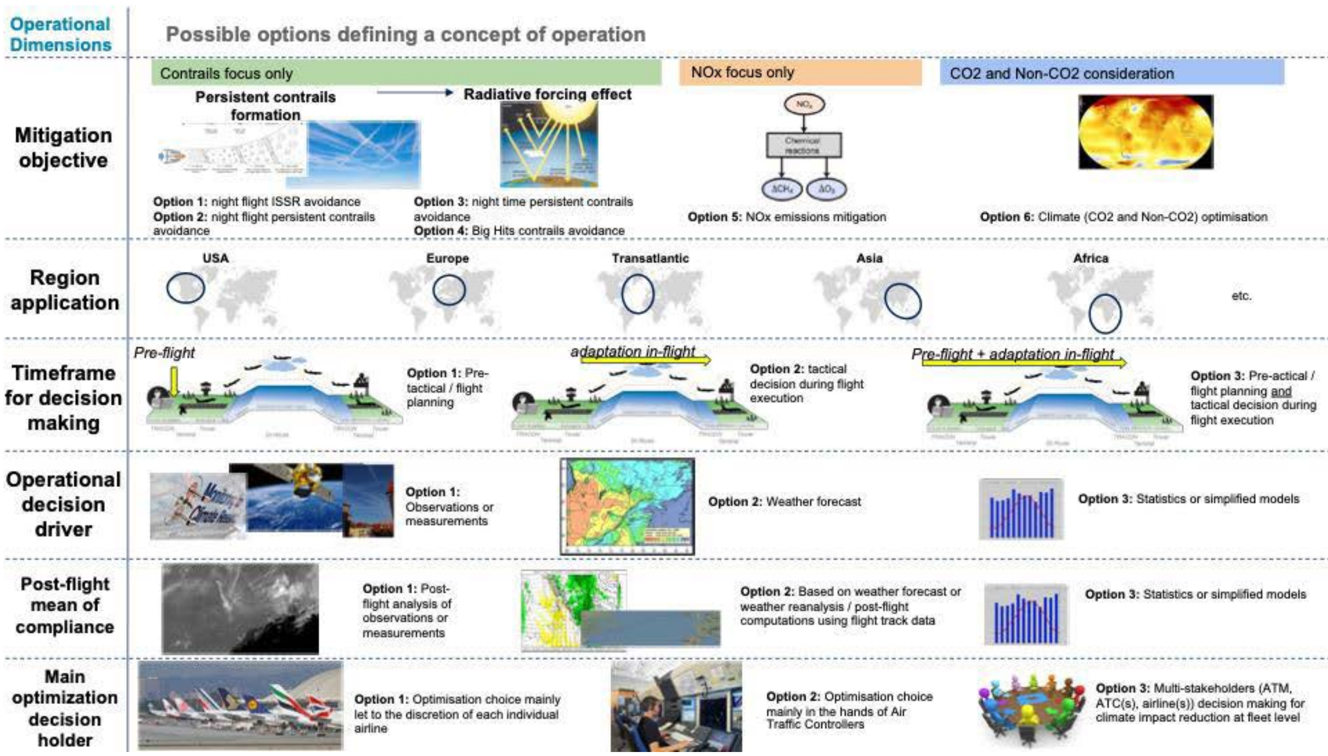


FIGURE 2: Possible options defining a concept of operations (from the EU project Ciconia).

operations matches all the criteria for safe operations. However, the ANSP stakeholders do not necessarily have the knowledge of airlines' strategies in terms of mission or cost management and have less accurate models in terms of aircraft performance or status which may lead to sub-optimal trajectory optimization.

To date, none of these concepts are tested or implemented in practice on a large-scale; however, they may serve as basis for further assessment and research. Large-scale trials and verification action will be required to assess the effectiveness and feasibility of these interventions. Technological and operational enablers will be essential for effective and safe implementation in flight operations and will be discussed further below.

Interdependencies

Current flight paths are mainly designed to minimize flight time or fuel consumption (cost), within the existing airspace and route structure, both which may be impacted with changes in the optimization strategy to include navigational contrail avoidance efforts. Airspace capacity and potential flight efficiency of other airspace users may be affected as well, especially in areas of congested airspace.

Consequently, navigational avoidance may result in increased climate forcing due to increased greenhouse gas emissions (primarily CO_2) associated with the specific flight and potentially other impacted flights. Efforts to balance the net climate impact from various CO_2 and non-CO_2 effects must be considered when implementing operational strategies to reduce contrails.

Crucially, safety must not be negatively impacted. Depending on the capacity of the airspace, the airspace structure and traffic density, ATM may lack flexibility to allocate climate-compatible flights quickly and safely without reducing airspace capacity. Areas prone to contrails formation such as Europe and the northeastern US could be more challenging to address due to high traffic density and congestion.

Targeting only the flights with significant contrail climate forcing might prove to be (partially) effective and less operationally impactful as only a portion of flights are responsible for most of the warming contrail formation.

However, as contrail formation and persistence are dependent on atmospheric conditions, this percentage may vary, and these flights are likely to be co-located in space and time. An initial option could initially be to divert flights only if there is minimal or no fuel penalty, avoiding additional CO_2 emissions.

The multiple trade-offs and interdependencies should be evaluated with respect to airspace, airport, other flights, and network operations. The following aspects should be considered when selecting a strategy for intervention:

- Impact on safety
- Impact on flight time
- Impact on fuel consumption and CO_2 emissions
- Impact on airspace capacity and predictability
- Impact on workload for operational staff
- Impact on schedules and passenger experience
- Overall net climate impact

Enablers

Without an improved scientific understanding of all physical, chemical, and meteorological processes involved and improvements in forecast accuracy, contrail mitigation may prove to be impractical. Uncertainties exist for both the spatial and temporal characteristics of individual contrails, as well as the climate impact of individual contrails, multiple contrails, and the combined global impact.

Enablers have been identified to address these uncertainties:

- *Weather data measurement and weather forecasting*
- *Forecasting of contrails and persistence*
- *Contrail observation*
- *Climate impact modeling*
- *Flight plannings*
- *Airspace Capacity and ATM flexibility*
- *Flight Execution*
- *Verification*
- *Collaboration and continuous improvement efforts*

These enablers, ranging from installation on-board humidity sensors and improved contrail modeling to contrail observation and flight planning tools, will contribute to progress towards feasible and effective operational contrail impact mitigation. See the ICAO CAEP report[3] for more detailed information.

The importance of quantifying the climate impact of persistent contrails, relative to CO_2, cannot be understated. Because of the uncertainties and trade-offs involved, it may be inappropriate to recommend definitive actions on aviation non-CO_2 emissions since they may be of limited effect or have unintended consequences on the global climate. However, the potential climate benefits justify efforts to address scientific gaps and continue studying and testing potential operational concepts.

Looking Ahead

The findings of the ICAO CAEP report establish a basis of understanding of operational opportunities to mitigate non-CO_2 effects. While the scientific understanding of contrail formation, persistence and climate impact and the impact of new fuel composition continues to evolve it is essential to also continue progressing the understanding of operational considerations for the mitigation of adverse climate impacts from contrails.

3 ICAO CAEP Report on Operational Opportunities to Reduce Climate Effects of Contrails and Other Non-CO_2 Emissions, to be published.

Operational opportunities and challenges for addressing air transport's non-CO_2 environmental impacts

By Nellie Elguindi (IATA), Sigrun Matthes (DLR), Gerd Saueressig (Deutsche Lufthansa AG), Christian Grob (Swiss International Air Lines Ltd.)

Introduction

Air transport's total environmental impact results from both its CO_2 and non-CO_2 emissions (e.g., NO_X, PM, SO_X, water vapor and subsequent formation of contrail-cirrus clouds). Most of the non-CO_2 climate warming effects are due to contrails and NO_x emissions and are short-lived compared to CO_2 emissions which accumulates in the atmosphere for hundreds of years (Figure 1). According to the Intergovernmental Panel on Climate Change Sixth Assessment Report[1], the effective radiative forcing from historic non-CO_2 emissions up to 2018 is estimated to account for more than half of the aviation net warming effect. However, the level of uncertainty from the non-CO_2 effects is eight times higher than that of CO_2, in part due to the lack of estimates from Earth System Models (ESMs)[2]. Nevertheless, the climate warming footprint of aviation is larger than its carbon footprint alone, highlighting that non-CO_2 effects are non-negligible and may be a potential mitigation lever to reduce aviation's total short-term environmental impact.

The air transport industry's priority has been and should remain on reducing CO_2 emissions because of their long-term cumulative warming effect. Leveraging non-CO_2 climate drivers (e.g., contrails) may potentially offer a means for the air transportation sector to further advance in decoupling growth from emissions and reduce its total environmental short-term impact as other decarbonization levers have sufficient time to scale up and develop into fully sustainable solutions.

Potential non-CO_2 mitigation solutions include flight trajectory optimization, fuel optimization, and new engine technologies. Here we provide a high-level overview of the main scientific, technological and operational challenges associated with flight optimization and how the air transport industry is working together with researchers and other stakeholders to find solutions.

1 IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, doi:10.1017/9781009157896.

2 Lee, D.S. (2020). "The Contribution of Global Aviation to Anthropogenic Climate Forcing for 2000 to 2018." *Atmospheric Environment*, 244, p.117834, https://doi.org/10.1016/j.atmosenv.2020.117834.

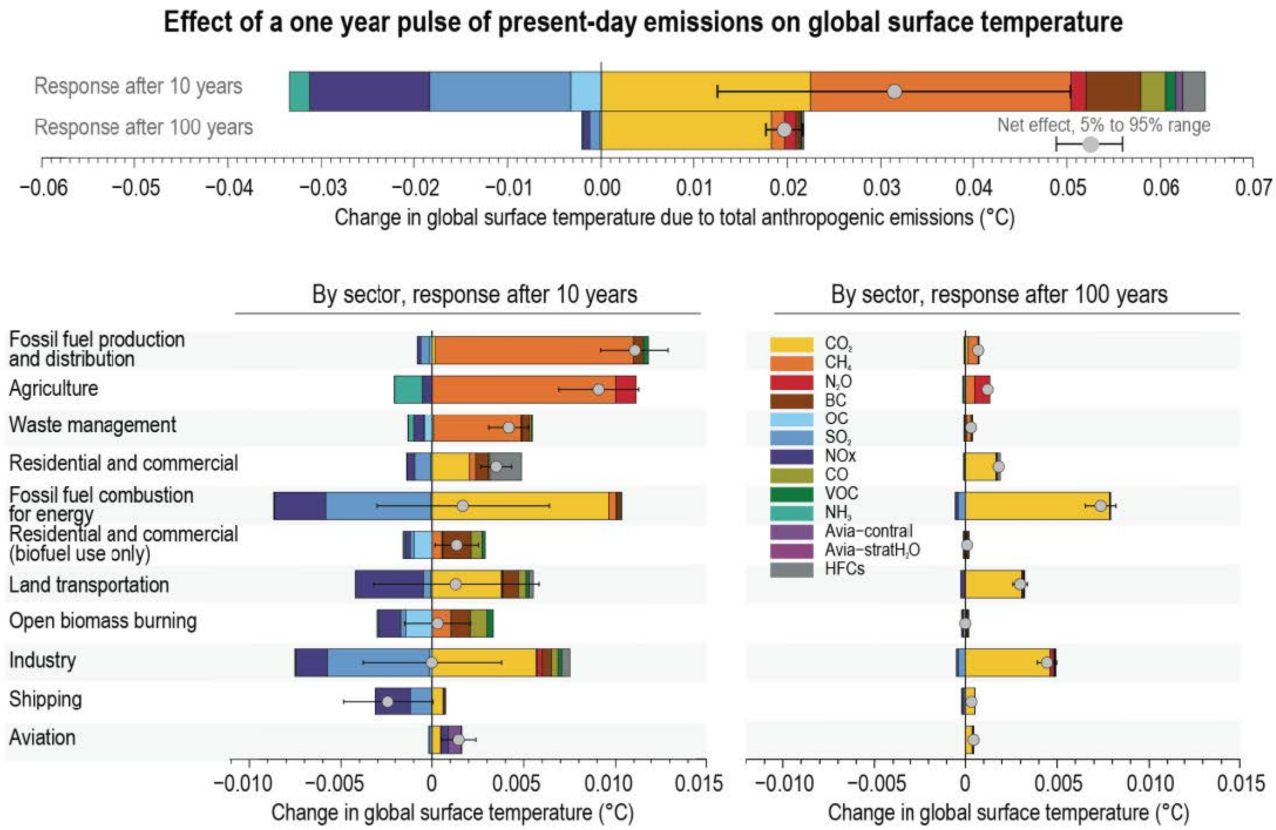


FIGURE 1: Global surface temperature change 10 and 100 years after a one-year pulse of present-day emissions. Non-CO_2 emissions account for more than half of air transportion's short-term climate impact, although the uncertainties are much higher than for CO_2.[1]

Flight trajectory climate-optimization

Operational flight trajectory climate-optimization strategies involve rerouting aircraft either vertically or horizontally to avoid climate-sensitive airspace, for example, where persistent warming contrails are likely to form under favourable atmospheric conditions. Contrails form and persist in cold, humid air where the relative humidity is saturated with respect to ice in so-called Ice Supersaturated Regions (ISSRs). Studies have shown these regions are horizontally quite large (~100 – 250 km), but vertically thin (~1000 – 4000 ft on average), thus, in some cases, deviating flights above or below these regions could be more efficient given the implied CO_2 trade-off (Figure 2). Additionally, studies indicate that only a small fraction of flights contribute to the majority of contrail warming, therefore not all flights would need to be rerouted. However, the challenge lies in the fact that this small percentage of flights may be in the same airspace, rendering operational and safety obstacles.

On the surface, it seems that flight climate-optimization could be implemented easily and cost-effectively, however, there are still significant scientific, technological, and operational issues and challenges that need further investigation, including the crucial question of which flights should be diverted, given the great uncertainty in predicting climate-sensitive regions and estimating the associated climate impacts.

Airlines (e.g., Lufthansa, Delta, American Airlines, Etihad, SWISS, and AirFrance-KLM) are working together with scientists and other stakeholders through various cross-collaborative projects such as the German project D-KULT (led by DLR and funded by the German Federal Aviation Research Programme - LuFo) and the SESAR EU-funded

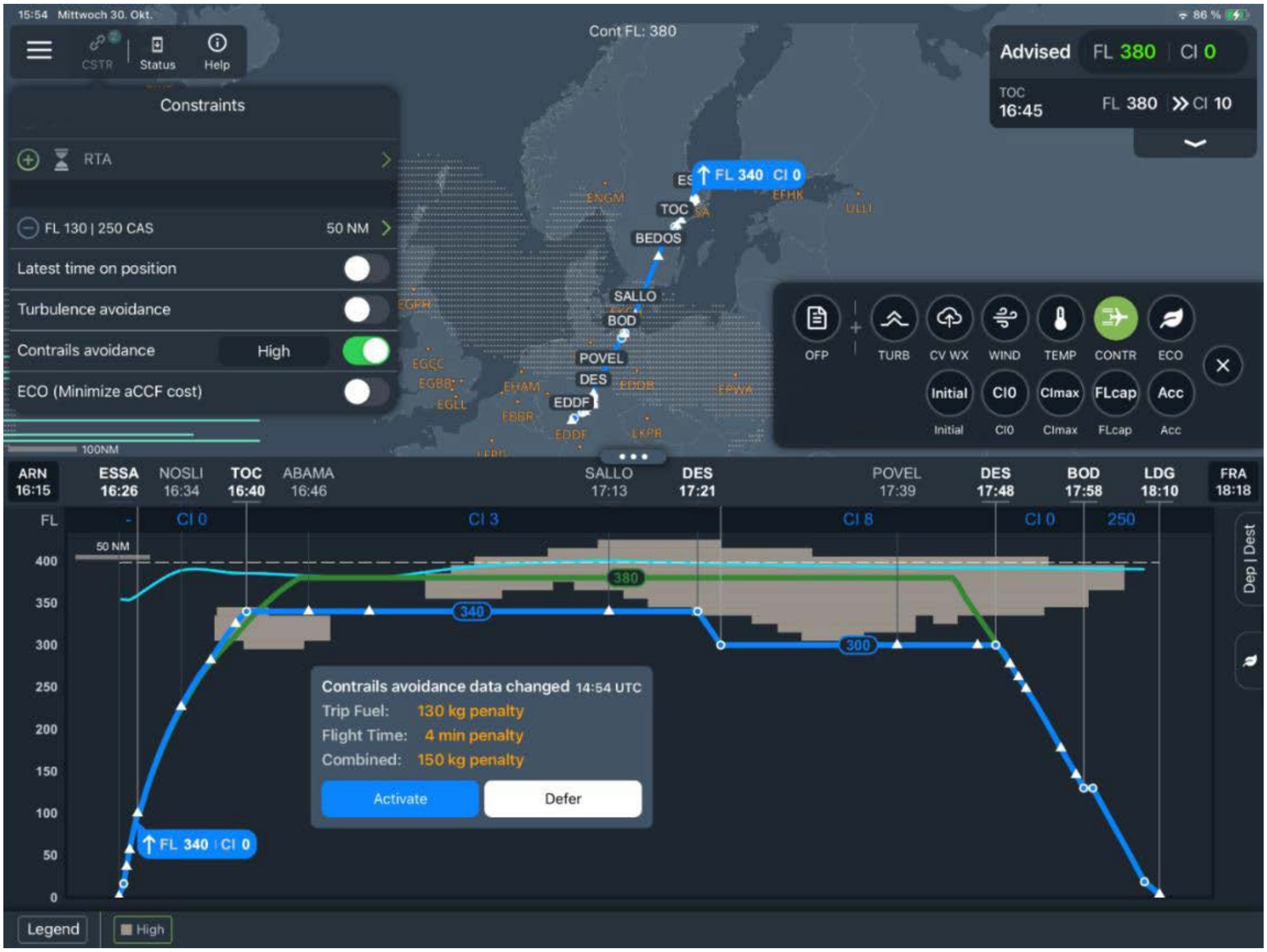


FIGURE 2: A sample flight from Stockholm to Frankfurt was optimized using PACE's FPO-Cloud prototype (see below), resulting in a lower flight profile including a flight level change (step descent) to avoid climate-sensitive regions.

projects (e.g., CICONIA) to investigate the feasibility of navigational avoidance strategies and their impact on flight operations and on the airspace as a whole.

Science and technology

A fundamental requirement of an effective and verifiable navigational avoidance strategies is reliable forecasts of meteorological conditions and accurate predictions of the potential non-CO_2 climate impacts at the strategic (pre-flight) and tactical (in-flight) levels. Today, both are associated with large uncertainties. Contrail-cirrus and climate response models used to estimate non-CO_2 effects are driven by inherent large uncertainties (e.g., meteorological variables, emissions estimates) and are based on highly simplified parameterizations of complex, nonlinear processes. For contrail avoidance, being able to accurately predict when and where contrails will form and persist, as well as how they will evolve over their entire lifetime, is crucial in assessing the CO_2 trade-off due to the extra fuel burn and deciding whether flights should be rerouted.

Because accurate meteorological data and climate response models are essential elements for navigational avoidance decisions, significant improvements have been made in weather forecasting models which have enhanced the forecasting skill of key variables needed to predict potential persistent contrails at cruise altitudes. National weather service providers such as Deutscher Wetterdienst (DWD) and Météo-France have made major upgrades in their forecasting capabilities of ISSRs (i.e., 2-moment ice-scheme), a critical parameter for contrail avoidance.

The work to improve ISSR forecasts is ongoing by developing and integrating new observational data including in-situ measurements and satellite imagery. Towards this end, the DWD has partnered with Lufthansa as part of the MEFKON project (LuFo-funded) to test data assimilation techniques of near real-time humidity measurements taken on-board commercial aircraft to improve ISSR and contrail forecasting and robust verification capabilities.

Using commercial aircraft to collect meteorological and atmospheric composition data in the upper atmosphere is not a new concept. Airlines have been utilizing their aircraft to help collect data for research and operational purposes in this sparse region for decades[3]. The global Aircraft Meteorological Data Relay (AMDAR) program was initiated by the World Meteorological Organization (WMO) with the objective to relay meteorological data in real time from commercial aircraft platforms in support of improved weather forecasts and applications for aviation and the wider community. Since 1994, European scientific institutions, weather services and several commercial air transportation companies have been collaborating through the MOZAIC/IAGOS programs to collect essential data on atmospheric composition and air quality. Since 2015 the IAGOS fleet are also providing near-real time data of ozone and carbon monoxide, and of water vapour (since 2019), for operational users. Boeing, Airbus and government-funded projects (e.g., NASA, US DOE ARPA-E) are working towards developing and commercializing low-cost, higher-accuracy water vapor sensors that can be installed on more commercial aircraft to support contrail avoidance systems and verification.

To complement in-situ measurements, ground-based cameras, satellite imagery and artificial intelligence (AI) are being utilized as additional sources of data for navigational avoidance system validation. In addition, satellite imagery and artificial intelligence technologies are being exploited to improve weather forecasting models through data assimilation.

Operations

From an operational perspective, climate-optimized rerouting has significant implications and can pose numerous challenges for both aircraft operators (AO) and air navigation service providers (ANSPs). Rerouting of flights for climate benefits implies extra fuel burn and can lead to flight schedule modifications, increased workload for pilots, dispatchers and air traffic controllers, potential safety issues and other concerns. To provide actual data and to help identify potential problems, airlines and other industry stakeholders are participating in live contrail avoidance trials.

Coordination, communication, and collaboration among all stakeholders will be essential for navigational avoidance strategies to be implemented. Live trials involving multiple stakeholders are designed to test and evaluate different options for operational management: Airline operator-led and/or ATC-led. Exercises conducted by DFS (Deutsche Flugsicherung) showed that in high traffic areas such as Central Europe, there was a significant reduction in airspace capacity and handling of air traffic. From an airline and an ANSP point of view, navigation avoidance strategies to minimize the impact of warming contrails will involve trade-offs. Concepts such as Flight and Flow Information for a Collaborative Environment (FF-ICE) and Trajectory Based Operators (TBO) provide opportunities to enable airlines and ANSPs to share information and make decisions regarding such trade-offs.

For the selected complex use cases such as when climate-sensitive areas were close to main flight paths, the workload of air traffic controllers increased while at the same time airspace capacity is reduced. In addition, it is important to understand how adverse secondary effects can be avoided and checked (e.g., additional congestion in airspace ending up in slots, high-speed flying, detours around even more congested airspaces). Knock-on effects for neighboring airspaces should also be considered.

Ongoing projects are also investigating the feasibility of integrating available information on weather and climate impacts into existing flight planning and air traffic management (ATM) processes to avoid climate-sensitive

3 https://www.iata.org/contentassets/726b8a2559ad48fe9decb6f2534549a6/aviation-contrails-climate-impact-report.pdf

regions. Lufthansa Systems and PACE have each added a module to their software for flight planning (Lido Flight 4D), pre- and in-flight optimization (FPO cloud) to avoid climate-sensitive regions. The integration of climate-relevant data into operational tools and processes raises the question of the quality of the overall process for calculating climate-optimized flight routes, and requires concepts on further developments, e.g. masking of data. This also includes verifying whether and how often, for example, contrails can be successfully avoided.

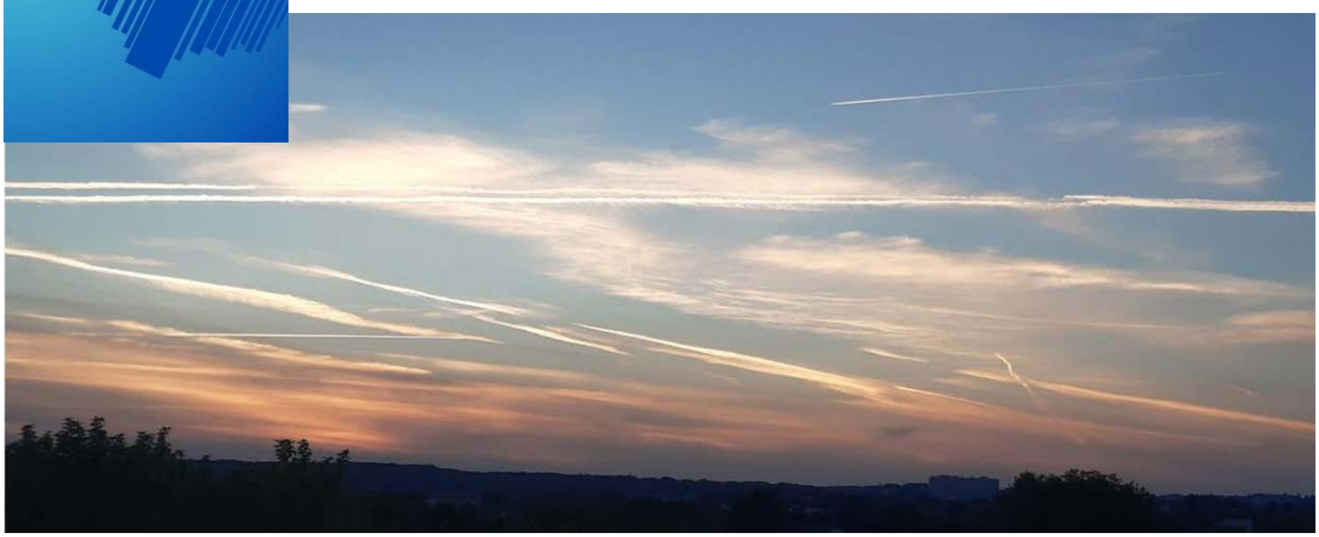
To better understand this, large-scale live trials such as that conducted by five German Airlines as part of the "100-Flights Trial", provide the opportunity to test newly developed prototype tools and meteorological service data for climate-optimized flight planning and execution. Assessing whether a rerouting was successful is a complex task that currently cannot be addressed by any of the existing methods alone. Rather, analysis concepts must be developed, particularly for contrail avoidance, that utilize various climate response model calculations as well as satellite observations for verification. These observations play a crucial role in the analysis of individual diverted flights, as they enable independent verification of contrail formation. The results of the climate models must also be further analyzed to ensure that follow-up measures have a positive impact on the climate. In addition to the ongoing evaluation, concepts for risk analysis and the determination of confidence intervals for the parameters that play a decisive role in the forecast quality are currently being developed to adequately consider the uncertainties in models and input data.

Conclusions

Operational mitigation strategies such as climate-optimized flight rerouting could be a potential lever for the air transport industry to reduce their short-term climate impact if proven viable and reliable verification possible. To assess operational feasibility, trade-offs and interdependencies associated with navigational avoidance such as extra fuel consumption, safety issues especially in crowded airspaces, additional workload for operational staff, flight schedule modifications and passenger experience, etc. must be carefully evaluated and understood before mitigation processes are implemented. Effective exchange of reliable and accurate data and collaborative decision-making among multiple stakeholders will be crucial. Ongoing collaborative efforts between researchers and industry stakeholders are working together to address these issues. To ensure effective outcomes, it's essential that we learn from the ongoing trials before moving forward with any final conclusions or policies.

Leveraging environment footprint reduction in operations, including non-CO_2

By Charles Renard (Airbus)



The state-of-the-art scientific assessment of Lee et al, 2021[1] estimated that aviation represented about 3.5% of total anthropogenic Effective Radiative Forcing (ERF) in 2018, and that non-CO_2 emissions accounted for about two thirds of that aviation-attributable impact. However, it also points out that the uncertainties around the contribution of non-CO_2 emissions on aviation's ERF are around eight times higher than those related to CO_2 emissions.

Optimising individual flight trajectories with a climate objective has long been proposed as a potentially effective way to reduce the climate impact of some non-CO_2 emissions. This is particularly true with respect to contrails, whose formation, evolution into cirrus clouds and ultimately climate impact, depend largely on the local weather conditions and hence on flight trajectory. To a lower extent, this is also true with respect to NO_x, the impact of which varies with time and location of emissions.

1 Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., Doherty, S. J., Freeman, S., Forster, P. M., Fuglestvedt, J., Gettelman, A., De León, R. R., Lim, L. L., Lund, M. T., Millar, R. J., Owen, B., Penner, J. E., Pitari, G., Prather, M. J., Sausen, R. and Wilcox, L. J. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmos. Env., 244, 1–29.

Addressing flight operations is obviously a question of inclusion of all involved stakeholders and collaboration. That is Airbus's ambition with CICONIA, a SESAR3 project launched in 2023 and due to complete in 2026.

CICONIA focuses on improving the understanding of the non-CO_2 effects of aircraft, and in particular of persistent contrails, in real en-route operating conditions, how they can be measured and how they can be considered in more efficient operational schemes, engaging a representative sample of all concerned stakeholders as project partners: universities and research centres (DLR, ONERA, Imperial College of London, UPC, NLR, ENAC, Breakthrough Energy), MET providers (METEO FRANCE, IAGOS), aircraft manufacturers (AIRBUS and BOEING), airlines including their pilots and their dispatchers in Operational Control Centre (OCC) (AIR FRANCE, SWISS, EASYJET), the Network Manager (NM) and Air Navigation Service Providers (ANSP) (NATS, DSNA) and their air traffic controllers.

CICONIA's goal is to support the development of environmentally effective, economically balanced, and operationally viable mitigation measures from the short to medium term. CICONIA aims to develop solutions to prepare the overall ecosystem (including aircraft, ATC systems, weather etc.) to operate in this context.

Our top three challenges are:

1. **To improve weather forecasting capabilities, including persistent contrail regions, tailored for operational mitigation concepts.**

As usual in meteorology, forecast reliability depends on the quality and density of the observations fed into the numerical model. CICONIA is evaluating these observation means, including aircraft measurement with IAGOS and Airbus aircraft, pilot observation reports with the Air France COOP program, and satellite images, lidars and ground based cameras with Airbus Defense and Space, ONERA, Meteo France, EUROCONTROL and Imperial College. The added value and requirements for new and complementary sources of information data like aircraft humidity sensing will be further defined.

An important aspect is to incorporate the level of confidence of the forecast – which can never be absolute – into operational decision-making. This is managed using ensemble forecast methodology, which consists of providing multiple distributions of the calculated forecast, based on variations of the input parameters around their uncertainty range. Sometimes, or in certain areas, the distribution of the ensemble is very narrow, raising the confidence in the forecast, and at other times, the results are less convergent, lowering the probability. Providing that confidence level together with the forecast itself enables a more informed decision making, something that CICONIA is exploring.

2. **To improve climate impact assessments tailored for operational mitigation concepts, at aircraft trajectory level and larger-scale traffic, and define a quality-controlled climate-oriented MET service.**

Predicting where contrails can form and persist is a paramount input, but is not sufficient to determine how strong their warming (or cooling) impact is. Furthermore, a true climate-optimised flight trajectory must take into account all climate forcers: contrails, but also other contributors, including NO_x, H_2O and of course, CO_2 emissions.

To deliver a usable climate impact assessment, a Climate MET service requires several inputs and sub-models, on top of weather forecast. Thanks to simulation work within CICONIA, we are testing their importance and usability, for example:

- Accurate aircraft and engine performance models, and how emissions evolve during the flight (aircraft and engine type, mass, fuel burn, CO_2, H_2O, NO_x, propulsion efficiency, particles) and how the fuel composition may affect some of them. In CICONIA, we are using and evaluating EUROCONTROL BADA and Poll-Schumann models, and comparing the results with Airbus and Boeing Flight Management System (FMS).
- We also need models about how aircraft emissions generate contrails and NO_x effects. To be as complete as possible, we use the CoCiP[2] model (contrail cirrus prediction model that covers the radiative effect of

2 Schumann, U.: A contrail cirrus prediction model, Geosci. Model Dev., 5, 543–580, 2012.

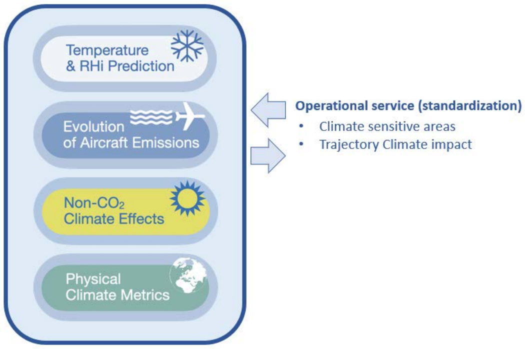


FIGURE 1: Modular definition of a Climate MET service

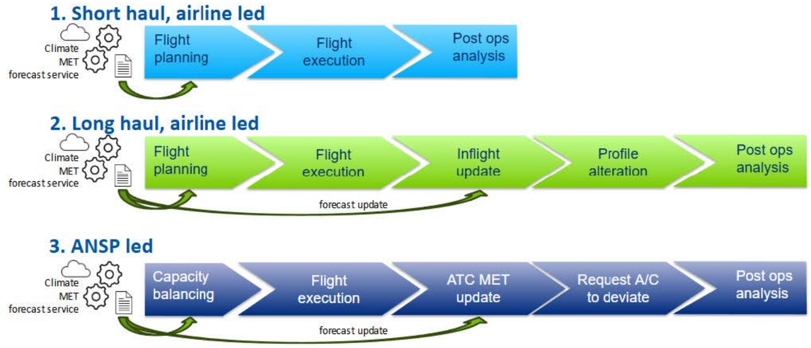


FIGURE 2: CICONIA CONOPS.

individual contrails only) and the aCCFs[3] (algorithmic Climate Change Functions, e.g. mathematical formulation for estimating the temporal and spatial climate effects of both CO_2 and non-CO_2 emissions produced by individual flights and at traffic level). We compare them and identify their convergence and divergence aspects.

- We also need the use of appropriate climate metrics. As each metric weighs the effects of each climate forcer differently, we are testing in CICONIA the use of different metrics and time horizons, and analysing their influence on trajectory optimization and on potential climate benefits. This might be an additional help to operators to better assess the impact of these climate-metric-dependent optimized trajectories on their daily activities (see Figure 1).

An efficient Climate MET service must feature these two key characteristics:

- **Standardized interfaces**: its inputs, calculation time and outputs must be designed so that the service can be incorporated into flight planning by Airlines or ANSP tools. For that purpose, a level of standardisation will be required.
- **Modularity**: as science progresses, better models will be developed. The Climate MET service must be able to substitute them without changing the interfaces. This can be achieved with a modular architecture.

3. To define and assess potential Concepts of Operations, in order to provide policy makers with widely agreed recommendations.

The operational analysis covers the full trajectory-based operations (TBO) cycle envisaged by SESAR from planning to execution. The proposed assessment of the CONOPS (Figure 2) impact will integrate climate impacts (due to both CO_2 and non-CO_2 emissions in operations), economics (re-routing costs, training, equipment), and impact on operations.

Three main concepts have now been selected for further evaluations through simulations and live trials during winter 2025-2026:

- First, for short haul flights, the airline dispatcher will use the climate MET Service to optimise the flight plan with the climate aspect. The forecast service is intended to provide data that is stable enough to avoid having to take into account updates during the short flight.

  The dispatch process is often automated for short haul, and we still have to further assess how this use case can be integrated and automated in legacy operations. Additionally, impacts of numerous simultaneous re-routing demands might introduce congestion. This is currently under work in CICONIA.

3 Dietmüller, S., Matthes, S., Dahlmann, K., Yamashita, H., Simorgh, A., Soler, M., Linke, F., Lührs, B., Meuser, M.M., Weder, C., Grewe, V., Yin, F. and Castino, F.: A python library for computing individual and merged non-CO_2 algorithmic climate change functions: CLIMaCCF V1.0. – Geoscientific Model Development Discussions, 1–33, DOI: 10.5194/gmd-2022-203, 2023.

At this moment, this use case is seen as promising, because of its simplicity and anticipation aspect that gives time for operational coordination.

- Secondly, an extension of this first use case for long haul flight, is to consider that the meteorological conditions can evolve during the flight. It is therefore envisaged that the airline proposes a change in the flight path during the flight to maintain climate benefits. The order of magnitude of the possible updates is under analysis. The aircraft is airborne, and the re-routing has to take into account a stronger constraint with onboard fuel. The collaborative decision making between airline, pilot, and ATC needed to validate the re-routing proposal is under consolidation.

- And finally, the Climate MET service can as well bring capabilities at network and ATC levels.

  In pre-tactical, the network operators could as well benefit from their full knowledge of the existing airspace capacity to influence the traffic flows toward climate optimized re-routing that could be proposed to airlines in pre-tactical.

  As well, during the flight, ANSPs and especially FMP (Flow Management Position) could propose climate-optimized re-routing options.

Progress to date is encouraging, collaborations need to continue

CICONIA believes that airline-led trajectory optimization is the most promising short term approach to non-CO_2 climate impact mitigation, based on reliable forecast tools, and on the consideration that the most anticipated trajectory is the easiest to integrate for ATC.

The collaboration between individual airlines optimizing their flight, and the ATC and Network, will help solve forecasted traffic congestion, which are only considered at the moment as induced capacity reductions.

Provisions for inflight re-routings require consideration, due to intrinsic instability of meteorological conditions, involving a more complex, real time collaborative decision making between pilots and ATC, Airline Operational Centres, with Network considerations.

A harmonized understanding of the climate response of flights is a key enabler for all our operational stakeholders. For coherent operational decisions, we need a standardized Climate MET service, providing meteorological and climate forecasts and nowcasts with their level of confidence. Additional evaluations and trials need to be further developed to reach as soon as possible an introduction into daily operations.

ICAO

CHAPTER FIVE

Climate Change Mitigation – Aviation Cleaner Energies

ICAO Global Framework for SAF, LCAF and other aviation cleaner energies

By ICAO Secretariat

FIGURE 1: CAAF/3 meeting in Dubai, November 2023.

Introduction

During the Third ICAO Conference on Aviation and Alternative Fuels (CAAF/3), held in Dubai, United Arab Emirates, from 20 to 24 November 2023, the international aviation sector took a significant leap to accelerate its decarbonization efforts.

By adopting the ICAO Global Framework for SAF, Lower Carbon Aviation Fuels (LCAF), and other Aviation Cleaner Energies[1], ICAO and its Member States agreed to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 percent by 2030, compared to zero cleaner energy use. In pursuing the Vision, each State's special circumstances and respective capabilities will inform their ability to contribute to the Vision within their own national timeframes, without attributing specific obligations or commitments in the form of emissions reduction goals.

Key elements of this Framework has been set out in four interdependent Building Blocks – 1) Policy and Planning; 2) Regulatory Framework; 3) Implementation Support; and 4) Financing. The Framework sends a clear signal that the sector is firmly committed towards decarbonization, in a way that provides clarity, consistency, and predictability to governments, public/private investors, industry, and fuel producers, supporting and unlocking the full potential of the sector's global energy transition efforts.

1 https://www.icao.int/Meetings/CAAF3/Pages/default.aspx

Building Block 1 – Policy and Planning

This foundational Building Block establishes the collective Vision to reduce CO_2 emissions in international aviation. ICAO and its Member States will work together to strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030 through the use of SAF, LCAF and other aviation cleaner energies (compared to zero cleaner energy use).

The Vision and global framework will be continually monitored and periodically reviewed on the progress of emissions reductions and means of implementation support, aspiring to have production sites in all regions before the convening of CAAF/4 no later than 2028, with a view to updating the ambition on the basis of market developments.

Achieving the Vision will rely on means of implementation including financing, technology transfer and capacity building, and the Vision should follow other points, e.g., contributing to a level playing field among all States and avoiding market distortion.

This Building Block also addresses the development and implementation of aviation cleaner energy policies and State Action Plans in accordance with their special circumstances and respective capabilities, as well as related actions by aviation and fuel stakeholders, in support of the Vision. More information on aviation cleaner energy policies is available in other articles in this Chapter. More information on ICAO State Action Plans initiative is available in Chapter 7.

Building Block 2 – Regulatory Framework

This Building Block defines the technical and institutional architecture needed to ensure SAF, LCAF, and other aviation cleaner energies meet recognized sustainability standards and can be credibly accounted for in international aviation emissions reductions.

For that, the Framework states that the CORSIA sustainability criteria, sustainability certification, and the methodology for the assessment of life cycle emissions should be used as the accepted basis for the eligibility of SAF, LCAF and other aviation cleaner energies used in international aviation.

The Framework supports accelerating the development and approval of new Sustainability Certification Schemes (SCS) for aviation cleaner energies, analysis and approval of life cycle values for new fuel sources and pathways, and certification of additional fuel production pathways, without excluding any particular fuel source, pathway, feedstock or technology.

More information on ICAO CORSIA regulatory frameworks related to SAF and LCA is available in other Articles in this Chapter and in Chapter 6.

The Framework also seeks to promote transparency, accuracy, consistency, comparability and completeness of fuel accounting methodologies. In support of that, the Framework requests ICAO to conduct a study of fuel accounting systems, including preliminary exploration of the so-called ‘book and claim’ concept to assess its relevancy and applicability, in order to determine any possible role of ICAO to facilitate access to environmental benefits of cleaner energies for international aviation, with a view to fostering the global production, in particular in developing countries. More information on related to fuel accounting methodologies is covered in other Articles in this Chapter, as well as in Chapter 6 on CORSIA-related accounting and reporting requirements.

Building Block 3 – Implementation Support

On this Building Block, the Framework encourages ICAO and aviation stakeholders to deliver a robust and substantial capacity-building and implementation support, taking into account various stages of readiness in different States and regions, and building upon the success of ICAO ACT-CORSIA and ACT-SAF programmes, with the contributions of resources by States and the industry.

The implementation support should facilitate partnerships, alliances and cooperation between States and all relevant stakeholders, including regional collaborations, as well as the exchange of information, sharing of best practices under the ICAO's platform. This includes the support for feasibility studies, pilot projects, and proof of concept plans, which may facilitate access to investment, including training on financial aspects of project development, financial planning and investment promotion, as well as support for State Action Plans and roadmaps which may also facilitate access to investment.

Finally, the Framework promotes transfer of technology, in particular to developing countries and States with particular needs, in line with the No Country Left Behind (NCLB) initiative, through comprehensive technical skills, manufacturing, processing and equipment, noting the global benefits that come from increasing the supply of cleaner energy.

More information on capacity-building and implementation support is available in Chapter 8.

Building Block 4 – Financing

This Building Block recognizes that the primary objective for ICAO and its Member States on financing is to support developing countries and States with particular needs, to improve access to low-cost financing and funding, and further de-risking of projects to develop and deploy SAF, LCAF and other aviation cleaner energies. ICAO, States and the industry should advocate and outreach for greater investment in SAF, LCAF and other aviation cleaner energy projects, by increasing understanding amongst the international finance community, regarding the collective commitment of States and the industry, environmental and other benefits of aviation cleaner energies, and opportunities for potential investment.

The Framework also welcomes the ICAO Finvest Hub initiative to facilitate enhanced access to public and private investment capacities and funding from financial institutions, as well as encourage new and additional funding for this purpose. It also set out how ICAO should urgently put in place the necessary structure and capability, toward its operationalization, while identifying how it complements broader aviation decarbonization capacity building and implementation efforts, including the ACT-SAF programme.

More information on climate financing is available in Chapter 9.

Integration into ICAO Implementation Roadmap

In June 2024, the ICAO Council during its 232nd Session approved the ICAO Roadmap for the implementation of the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies, including the planned actions, roles and responsibilities, timeframe, required resources, and the relationship with related ICAO work, such as the Long-term Aspirational Goal (LTAG) implementation, leading to the 42nd Session of the Assembly in 2025, and until the convening of CAAF/4 by no later than 2028.

The ICAO Roadmap is a living document, to be regularly updated to reflect the progress of implementation and elaborate on further actions. It also outlines the additional resources required to implement the Global Framework and the LTAG, informing resource mobilization efforts. The ICAO Roadmap will progress in a balanced manner across the four interdependent Building Blocks, giving immediate focus on the need to accelerate the level of capacity-building and implementation support, financing, and other critical enabling and monitoring elements, so that it may foster swift production and deployment of aviation cleaner energies in all regions.

ICAO Cleaner Energy Tracker Tools

The ICAO Cleaner Energy Trackers[2] monitor progress under the ICAO Global Framework, comprising various indicators, such as airports distributing SAF, policies adopted or under development, SAF volumes under offtake agreements, latest news on SAF developments, etc, outlined under the four Building Blocks, as illustrated in Figure 2.

2 https://www.icao.int/environmental-protection/pages/SAF.aspx.

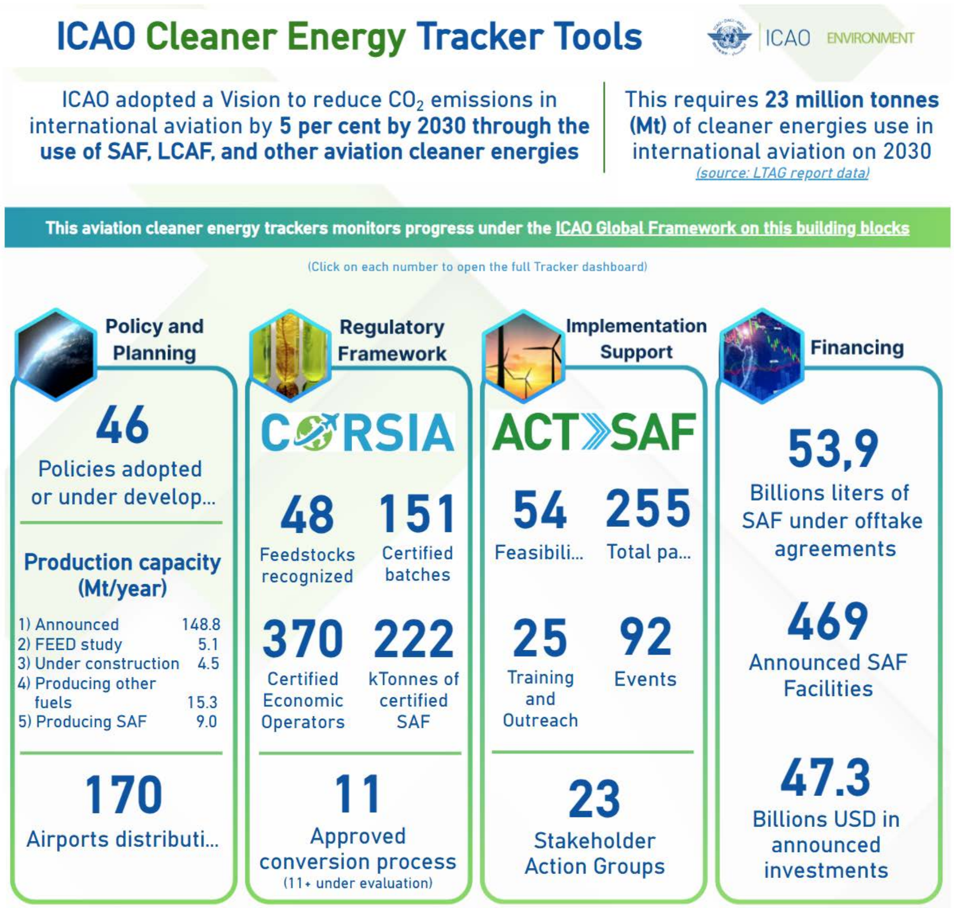


FIGURE 2: ICAO Cleaner Energy Tracker Tools (as of May 2025).

Policy and Planning, and Regulatory Framework Foundations for Aviation Cleaner Energies

SAF Policy Guidance and the CORSIA Eligibility Framework

By ICAO Secretariat

Introduction

Sustainable aviation fuel (SAF) is being pursued globally as a cornerstone measure in the broader framework of climate change mitigation for international aviation. SAF is defined as renewable or waste-derived aviation fuels that meets the ICAO sustainability criteria established under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) . The drop-in nature of SAF means its full compatibility with existing aircraft engines and airport fueling infrastructure. It offers significant life-cycle reductions in greenhouse gas (GHG) emissions compared to conventional jet fuel, and its deployment also contributes to reducing non-CO_2 drivers, which can improve local air quality.

The ICAO Committee on Aviation Environmental Protection (CAEP) has recognized that despite SAF's technical viability, multiple systemic barriers continue to hinder its widespread adoption, including high production costs, feedstock availability, infrastructure constraints, and financing challenges. In response, CAEP developed a policy guidance framework for supporting States to stimulate SAF development and deployment through a combination of fiscal instruments, regulatory actions, and enabling market conditions. Furthermore, CAEP supports the development of a comprehensive and harmonized ICAO regulatory framework for the sustainability criteria and certification mechanisms under the CORSIA, ensuring that SAF and other cleaner aviation fuels contribute meaningfully to the achievement of ICAO's Long-Term Global Aspirational Goal (LTAG)

As part of the ICAO Global Framework for SAF, Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, adopted by CAAF/3 in November 2023, ICAO and its Member States strive to achieve a collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030 through the use of SAF, LCAF and other aviation cleaner energies (compared to zero cleaner energy use). In support to achieving this Vision, **policy support is a key component of Global Framework's Building Block 1 (Policy and Planning)**, as illustrated in Figure 1, together with all other Building Blocks already mentioned in the previous ICAO Secretariat Article. It promotes national action through planning, target-setting, and the development of State policies and roadmaps.

As another key pillar, the CORSIA sustainability criteria and the broader CORSIA framework serve as fundamental elements of Building Block 2 (Regulatory Framework), anchoring environmental integrity, eligibility assurance, and emissions accounting mechanisms essential for the deployment of cleaner aviation energies.

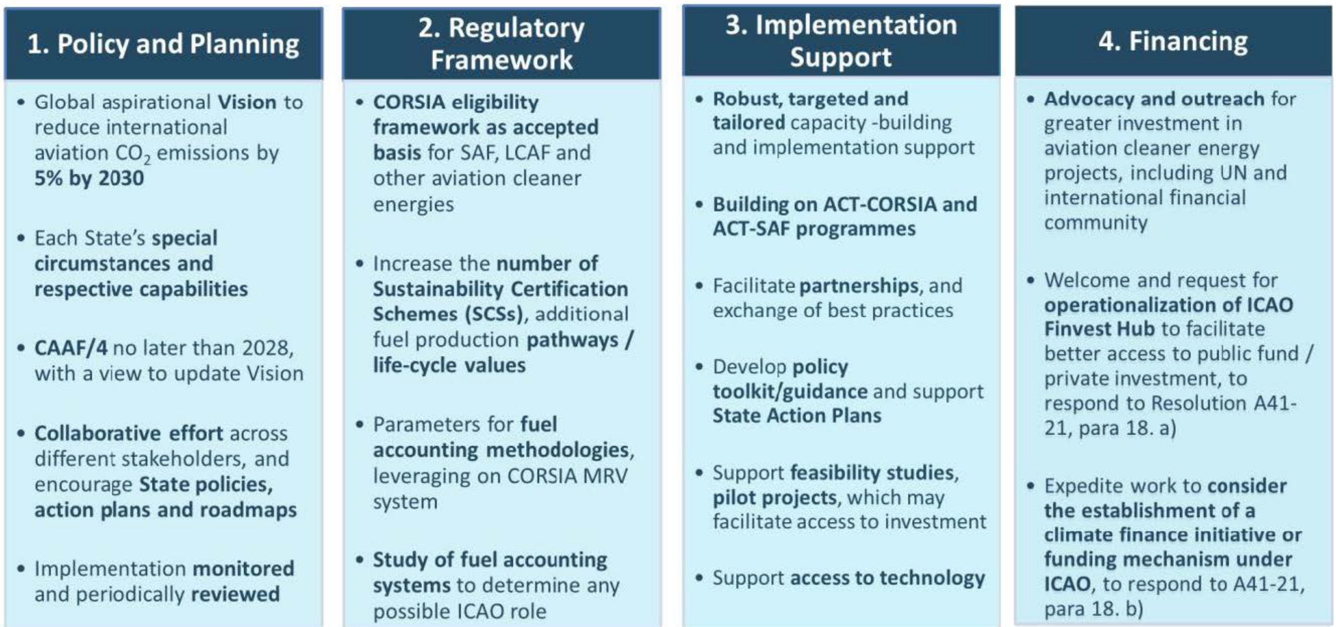


FIGURE 1: ICAO Global Framework Building Blocks.

This article focuses in greater detail on these two key pillars of ICAO's work as they relate to the topics addressed in this Chapter. Meanwhile, **Building Block 3 – Implementation Support** is explored in **Chapter 8 – Capacity Building and Implementation Support**, and **Building Block 4 – Financing** is addressed in the dedicated **Chapter 9 – Climate Financing**.

ICAO Policy Guidance on SAF Development and Deployment[1]

The policy guidance developed by CAEP is based on detailed analytical work carried out since 2016, including techno-economic assessments and policy reviews. The objective is to offer ICAO Member States a practical toolbox of policy options that can be tailored to their national circumstances, economic profiles, and development goals.

The guidance identifies three main policy functions: stimulating the growth of SAF supply, creating demand, and enabling SAF markets. One approach to stimulate supply is through public funding of research, development, demonstration, and deployment (RDD&D). For example, governments may allocate funds to support SAF-specific R&D, particularly for new feedstock conversion technologies or to improve yields in existing pathways. Demonstration projects are also critical to derisk investment; they may involve funding pilot plants or test flights using SAF blends. In the European Union, the Horizon Europe programme financed 119 SAF-related projects between 2014 and 2023 with a total investment of €493 million, showcasing the type of long-term commitment that can foster innovation and learning-by-doing.

Another category focuses on targeted incentives to expand SAF production capacity and infrastructure. Tax relief and financial instruments such as loan guarantees, grants, and production subsidies can make SAF production economically viable in its early stages. For example, tax credits could reduce the operational costs of SAF producers, while capital expenditure grants might lower the upfront costs of building new biorefineries.

Mandates play a key role in creating demand for SAF. These can be structured as blending quotas that

1 https://www.icao.int/environmental-protection/Pages/saf_guidance_potential_policies.aspx

require fuel suppliers to include a minimum percentage of SAF in their jet fuel mix. The establishment of binding targets, such as the European Union's ReFuelEU Aviation initiative, compels market actors to integrate SAF into their operations, thus driving demand. In countries where mandates may not yet be feasible, updating existing renewable energy legislation or emissions trading schemes to include aviation SAF can indirectly encourage uptake.

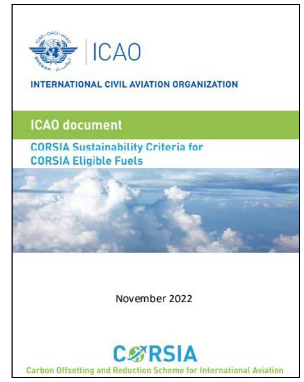
Government leadership can further amplify market confidence. When States incorporate SAF into their own public procurement or military aviation operations, they send a strong demand signal to the private sector. These actions also demonstrate a commitment to broader decarbonization objectives and may facilitate public-private partnerships that reduce investment risks for new entrants.

Finally, enabling SAF markets requires action on institutional and infrastructural fronts. Developing standards for SAF quality, certification systems for emissions performance, and traceability protocols ensures interoperability and environmental integrity. Public authorities may also support the formation of industrial alliances and value-chain consortia, which are essential for coordinating stakeholders from feedstock suppliers to airport fuel handlers.

An effective SAF policy, according to CAEP guidance, should be: predictable, stable, and of long enough duration to support long-term investment; feasible and practical in implementation, with minimal administrative burden; technology-neutral, allowing diverse feedstock and conversion pathways; and stackable with other incentives, including those in other sectors. It should also reflect national or regional contexts, leveraging local advantages while mitigating barriers. To assist with decision-making, the guidance includes a qualitative metrics framework that allows policymakers to evaluate potential measures based on factors such as flexibility, certainty, cost-effectiveness, unintended consequences, and contribution to GHG reduction and SAF deployment.

CORSIA Sustainability Criteria and Linkages to the Broader CORSIA Framework

The "CORSIA Sustainability Criteria for CORSIA Eligible Fuels[2]" is a foundational document referenced in Annex 16, Volume IV – *Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*. It sets out the various sustainability requirements relating to carbon reduction, environmental, and socio-economic aspects that fuels must meet to qualify as CORSIA eligible fuels (SAF or LCAF).



The CORSIA sustainability criteria is organized into the following themes and associated principles:

- **Greenhouse Gases (GHG)**: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis. Criterion 1.1 states that CORSIA eligible fuel will achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
- **Carbon Stock**: CORSIA SAF should not be made from biomass (feedstock for CORSIA LCAF) obtained from land/aquatic systems with high biogenic carbon stock.
- **Greenhouse Gas Emissions Reduction Permanence**: Emissions reductions attributed to CORSIA eligible fuel should be permanent.
- **Water**: Production of CORSIA eligible fuel should maintain or enhance water quality and availability.
- **Soil**: Production of CORSIA eligible fuel should maintain or enhance soil health.
- **Air**: Production of CORSIA eligible fuel fuel should minimize negative effects on air quality.
- **Conservation**: Production of CORSIA eligible fuel should maintain biodiversity, conservation value, and ecosystem services.
- **Waste and Chemicals**: Production of CORSIA eligible fuel should promote responsible management of waste and use of chemicals.

2 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

- **Seismic and Vibrational Impacts**: (Applicable for CORSIA LCAF only) Production of CORSIA LCAF should minimize seismic, acoustic and vibrational impacts.
- **Human and Labour Rights**: Production of CORSIA eligible fuel should respect human and labour rights.
- **Land Use Rights and Land Use**: Production of CORSIA eligible fuel should respect land rights and land use rights including indigenous and/or customary rights.
- **Water Use Rights**: Production of CORSIA eligible fuel should respect prior formal or customary water use rights.
- **Local and Social Development**: Production of CORSIA eligible fuel should contribute to social and economic development in regions of poverty.
- **Food Security**: Production of CORSIA eligible fuel should promote food security in food insecure regions.

Along with the above document, additional ICAO documents (described below) are also essential to ensure robust monitoring, reporting, and verification of CORSIA eligible fuels, as well as accounting for its emissions reductions.

The suite of interlinked ICAO documents[3] under the CORSIA framework includes:

- **CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes:** Outlines criteria that SCSs must meet to certify CORSIA eligible fuels. They encompass documentation management, risk assessment, transparency in greenhouse gas reporting, and adherence to approved sustainability standards, ensuring that certified fuels contribute effectively to emission reduction goals;
- **CORSIA Approved Sustainability Certification Schemes:** Lists the SCSs approved by the ICAO Council.;
- **CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels**: Provides default life cycle assessment values for various SAF pathways to enable operators to claim emissions reductions under CORSIA without the need to establish actual life cycle assessment values, provided they adhere to specified documentation and compliance requirements;
- **CORSIA Methodology for Calculating Actual Life Cycle Emissions Values:** Provides detailed procedures for determining the life cycle greenhouse gas (GHG) emissions of CORSIA-eligible fuels. It outlines methodologies for calculating emissions across various stages of the fuel supply chain, including feedstock production, transportation, conversion, and combustion, ensuring compliance with CORSIA's sustainability criteria.

These documents collectively ensure the environmental integrity, credibility, and traceability of fuels used under CORSIA. For example, a fuel producer must be certified under an approved SCS to claim compliance with CORSIA sustainability criteria. If actual life cycle emissions values are used, the calculations must follow ICAO's approved methodology, and data must be verified by the SCS and transmitted through a recognized chain-of-custody.

This robust framework allows ICAO to monitor and validate climate benefits from CORSIA SAF and LCAF use, ensure comparability across operators and States, and support global climate transparency and accountability. This architecture supports global harmonization, environmental credibility, and the scaling up of cleaner energies for international aviation. The rest of this Chapter builds on this foundation to explore implementation pathways, regional strategies, innovation in production technologies, and investment mechanisms for scaling cleaner energy in aviation.

3 https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx

Advancing CORSIA-Eligible Fuels (CEFs)

Methodological Enhancements for the CORSIA framework on fuels

By ICAO Secretariat and Daniel Brousse Rivas (EASA)[1]

Delivering meaningful climate progress in international aviation requires more than ambition: it requires the tools to measure, validate, and certify the decarbonization efforts. Since its adoption, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) has continued to evolve, particularly around CORSIA-Eligible Fuels (CEF), which are central to decarbonizing the sector as seen in the results of the ICAO LTAG Report in 2022[2].

The latest developments under the Committee on Aviation Environmental Protection (CAEP) during CAEP/13 cycle (2023-2025) include a comprehensive package of amendments to strengthen the methodological backbone that enables fuels to qualify under CORSIA, reflecting both scientific advancements and practical implementation experience. CAEP also have developed new sample calculations to improve transparency and facilitate the verification of the life cycle values associated with CORSIA eligible fuels. Below, we unpack the key areas of enhancement recommended by CAEP, which will be incorporated into the CORSIA framework pending Council approval.

Clarifying the Role of Sustainability Certification Schemes (SCSs)

One of the cornerstones of CORSIA's sustainability assurance is its reliance on independent Sustainability Certification Schemes (SCSs). To enhance consistency and clarity, CAEP has proposed amendments to the document *CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes*[3].

A key clarification made was on the role of SCSs in verifying whether a material qualifies as a waste, residue, or by-product. The revised approach removes the burden from SCSs to interpret definitions; instead, SCSs must ensure the feedstock used by an economic operator aligns with ICAO's positive list and associated specifications. These definitions—"unintentional" and "unavoidable" production—help prevent deliberate misclassification and preserve environmental integrity. ICAO remains responsible for evaluating new feedstock classification proposals, thereby maintaining a centralized, consistent and inclusive review process.

Enhancing Life Cycle Assessment (LCA) Methodologies for Actual LCA Values

The document *CORSIA Methodology for Calculating Actual Life Cycle Emissions Values*[4] has undergone substantial updates. Several new components are now included to ensure more accurate greenhouse gas (GHG) assessments:

- **Electricity Sourcing Criteria for High-Electricity Input CEFs (HEI-CEFs):** For fuels like Power-to-Liquids, where electricity is a major input, new sourcing, deliverability,

1 Co-Rapporteur of ICAO's CAEP Fuel Task Group (FTG) (actual Working Group 5 – WG5)
2 https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx
3 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
4 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

temporal matching, and additionality criteria have been recommended by CAEP, providing a robust methodology to assess the benefits of low carbon electricity used in CEF production. For more details on this, please refer to the additional article "The Increasing Importance and Potential of Electricity for CORSIA Eligible Fuel Production" in this Chapter.

- **Soil Carbon Accumulation (SCA):** The new methodologies developed by CAEP will allow the consideration of emission savings associated with sustainable agricultural practices (e.g., reduced tillage, compost use, biochar use) can lead to meaningful soil carbon storage.
- **Carbon Capture and Sequestration (CCS):** Fuels produced with captured CO_2 will now be allowed to integrate GHG reductions from geological CCS into their lifecycle values. Requirements cover monitoring and permanence of the carbon storage, including a reserve inventory mechanism to offset any possible leakage events.
- **Feedstocks from Waste and Residue Gases:** New methodologies have been developed to calculate the GHG benefits of fuels produced from waste and residue gas streams, considering both baseline emissions and avoided releases. Additionally, specifications have been developed to clarify the conditions for a gas stream to qualify as a waste or residue gas stream.

Together, these updates enable a more complete accounting of environmental benefits across a broad range of SAF pathways.

Updating Default Values and ILUC Calculations

The document *Default Life Cycle Emissions Values for CORSIA Eligible Fuels*[3] was also revised, with significant changes that reflect newer datasets and improved modeling:

- **Core LCA Values:** Most core LCA values have been updated using the latest life cycle databases, improving precision across multiple fuel pathways.
- **ILUC (Induced Land Use Change) Values:** All ILUC values have been revised to reflect most up to date information (e.g., inclusion of IPCC 2019 guidelines on the ILUC Models), with special attention to removing soil carbon benefits to avoid double-counting when SCA credits are separately claimed.
- **Co-Processing Methodologies:** New equations now account for the GHG intensity of both fossil and renewable portions of SAF produced in LCAF-certified refinery units, enabling SAF/LCAF co-processing compatibility.
- **Weighted Average Approach for Multicropping:** A "weighted average approach" has been developed to obtain ILUC values for cases of significant multicropping, using region-specific crop data.

Providing Transparency through Sample Calculations

To promote transparency and consistency in the application and verification of the methodologies, CAEP has recommended two sample calculation cases:

- **Core LCA Calculation Example:** Using the corn grain alcohol-to-jet pathway, the sample walks through each step of LCA computation—highlighting differences between default and actual values, and clarifying data source requirements.
- **Direct Land Use Change (DLUC):** Historic case studies of land conversion (e.g., sparsely forested land to crop plantations) are used to illustrate the application of the CORSIA DLUC methodology, facilitating the verification of the use of this methodology.

Moving Forward

These methodological refinements mark a milestone in ICAO's ongoing commitment to credible, science-based aviation climate action. With the continuous update of the methodologies underpinning CORSIA-Eligible Fuels, ICAO ensures the environmental integrity of its flagship decarbonization scheme while addressing regional realities and new technologies in a timely manner.

The work ahead will continue under the CAEP/14 cycle, particularly on refining the ILUC modeling, expanding CCS methodologies and related guidance and continue refining the methodologies for electricity sourcing and sustainability certification. Together with States and stakeholders, ICAO remains committed to driving forward aviation's clean energy transition with the best available scientific information.

Emerging Technologies and processes for an increased SAF production

By Dan Bergels, Alyson Fick and Mark Rumizen (ASTM International)

ASTM International is a 127-year-old mission-oriented, non-profit organization that provides an open, transparent process for individual members around the world to collaborate in the development of global technical standards. At present, our 30,000 volunteer technical members representing 150 countries create standards that underpin the safety and performance of more than 90 industry sectors, including the energy industry. These standards help ensure safety, foster trust, promote innovation and address sustainability concerns while enabling global trade.

ASTM's individual membership model and consensus standards development process ensure every voice is valued, and the voting power of stakeholder groups is balanced. Through the ASTM process of classification and voting rights assignments, a large organization has the same voting power as an individual. We believe this approach ensures the process is free of undue influence while creating the strongest technical specifications required of a given industry. A 2021 report from the Paris-based Organization for Economic Co-operation and Development (OECD)[1], highlighted the unique features and benefits of ASTM's agile, independent process for developing global standards.

A section of the OECD case study specifically covered ASTM's role in the standards setting activities around sustainable aviation fuels (or synthetic aviation turbine fuels (SATF), noting "ASTM International standards in sustainable aviation fuels encompass the entire life-cycle of the production process."

The ASTM standards that support SATFs are created to specifically address the technical quality and performance of the fuels to ensure safety of flight. By focusing on flight safety for new and emerging fuels, ASTM standards accommodate sustainability in the varied contexts of regions, countries, and municipalities, and can serve as a helpful tool when addressing the European carbon emission mandates that require a reduction of at least 55% in net greenhouse gas emissions by 2030.

Additionally, the OECD report acknowledged that "the international standards produced by ASTM International support the scalability of this market and, by extension, help to drive down the costs of SAFs."

The ASTM standards for this industry are managed by ASTM's subcommittee on aviation fuels (D02.J), a diverse group of more than 800 members from around the world, representing a wide-variety of stakeholders including major engine and aircraft manufacturers, testing labs, fuel producers, airlines and regulators. The subcommittee strives for the broadest participation and inclusion possible in its standards development activities due to the critical nature and global applicability of standards related to aviation Fuels. The subcommittee develops standards, including specifications, test methods, and practices, to help ensure that aviation fuels are fit for purpose and remain clean and dry before use. The subcommittee creates and maintains specifications for Jet A and Jet A-1 fuel and synthetic alternative drop-in fuels.

1 https://web-archive.oecd.org/2021-09-10/597825-irc-astm-case-study.pdf

This task has taken on more significance with the current widespread focus on reducing carbon emissions from aviation fuels, along with efforts to eliminate the use of lead in aviation gasoline. There is now much greater global interest in the ASTM standards development process. This interest is especially true in Europe, where pending environmental mandates for increased use of Sustainable Aviation Fuels (SAF) and proposed regulatory constraints on the use of leaded aviation gasoline have given new urgency to develop alternative fuels, along with the specifications that control and define those fuels. The rigor of the ASTM consensus process has led most of the global aviation expertise to coalesce around ASTM Subcommittee D02.J and associated standards. Air worthiness authorities rely on these same ASTM standards, and other national standards bodies align their aviation fuel standards with these ASTM standards. The open, consensus-based approach utilized by ASTM accommodates the technical deliberations necessary for industry to continue to provide safe, fit-for-purpose aviation fuel that supports this global industry.

In April 2025, ASTM D02.J held a week of aviation fuel related events in Brussels, Belgium. More than 250 members and interested stakeholders from around the world took part in a full-day seminar on SAF. The seminar included a robust overview of the SATF process, an in-depth review of each of the key standards for the industry, a question-and-answer session about clearinghouses established by the United States, United Kingdom, and the EU, presentations from EASA and the FAA, and an OEM panel discussion.

The three key standards that support this industry include:

1) **Standard Specification for Aviation Turbine Fuels** (D1655)
2) **Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons** (D7566)
3) **Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives** (D4054)

D1655 defines the minimum property requirements for Jet A and Jet A-1 aviation turbine fuel and lists acceptable additives for use in civil and military-operated engines and aircraft. D7566 covers the manufacture of aviation turbine fuel that consists of conventional and synthetic blending components, also known as synthetic aviation turbine fuel (SATF). The specification is designed and structured to control the alternative raw materials, processes and final blending used to make alternative jet fuels. The specification supplies criteria for new synthetic aviation jet fuels to allow these new fuels to fit within the existing jet fuel supply and operational infrastructure.

D4054 provides procedures to develop data for use in research reports for new aviation turbine fuels, changes to existing aviation turbine fuels, or new aviation turbine fuel additives. These research reports are intended to support the development and issuance of new specifications or specification revisions for these products. It describes the evaluation process and data required to develop specification criteria for new drop-in alternative jet fuels. It is a key element of the process to validate that a new alternative jet fuel is safe to use on aircraft and can be qualified as a 'drop-in' fuel, i.e. a fuel equivalent to conventional petroleum-derived aviation turbine fuel.

D4054 is a rigorous technical evaluation that facilitates the broad industry review required to evaluate proposed fuels. Ultimate approval to use any fuel or additive on an aircraft or engine is the responsibility of the original equipment manufacturers (OEM), working with aviation regulatory authorities. New fuels, or pathways of fuel production, require review to ensure safety and operability (fit-for-purpose). OEMs need technical data to conduct review and provide a basis for approval decisions. D4054 provides guidance to the fuel producer on the procedures to develop the necessary data package for the OEMs and, subsequently, the full range of stakeholders to review and develop consensus.

At present, there are multiple D4054 evaluations in process from organizations around the world, including in Japan, India, Austria, Finland, Denmark, and several in the United States. To assist in this process, SAF Clearing Houses have recently been established in the EU and in the UK to coordinate with the previously existing US Clearing House. They aim to support SAF producers in bringing their products to market and negotiate the process, including applying the ASTM standards and enabling OEM technical review. All three clearinghouses work closely to support the industry in deploying sustainable aviation fuels. The ASTM D4054 practice is acknowledged as the appropriate procedure for evaluation of new synthetic aviation turbine fuels (SATF) and fuel additives. The standard practice details the expected participation from stakeholders and their interaction with global airworthiness authorities.

Currently, D7566 includes eight annexes, or pathways, for creating a synthetic blend component to add to conventional jet fuel. Within each of these pathways, there is a definition of acceptable feedstocks, the conversion process, the blending component makeup, and the actual blending criteria. The approved pathway results in a fuel that complies with the requirements of the ASTM standard specification for aviation turbine fuels (D1655). If the new alternative jet fuel is added to ASTM D7566, it will now have met the minimum standard to be considered a Jet A/A-1 fuel and meet the certificated aviation fuel operating limitations of virtually all jet-powered aircraft. The open, consensus-based ASTM process facilitates collaborative and thorough OEM engagement with aviation fuel producers and other stakeholders. ASTM evaluates SATF by issuing specification criteria after making a technical determination that the synthetically derived material, when blended with conventional blending material, produces Jet A/A-1 fuel. The fuel now fits the existing approval requirements by air worthiness authorities and can be used without any limitations, restrictions, or special handling provisions. It can seamlessly enter the jet fuel supply chain without any additional approvals.

An additional consideration for addressing carbon emission mandates is through co-processing. Co-processing, the combination of conventional and synthetic feedstocks, is also included in D1655. In the recent ASTM Aviation Fuel Seminar, speakers discussed the impact of co-processing because of its potential to support the growing demand for SAF in a shorter timeframe, with lower capital expenditures. It allows fuel producers with years of experience to introduce SATF into the market, while new specialized processing units, that require significant investments and long lead times, work to become commercially viable. There are several benefits to co-processing, including the ability to use existing facilities, and a shorter timeframe with lower capital expenditures. The standard lists three co-processing feedstocks, which include mono, di-, and triglycerides, free fatty acids, fatty acid esters such as animal fats, plant oils and greases, certain synthetic hydrocarbons made from carbon monoxide and hydrogen gas. There are several co-processing feedstocks that are currently under ballot or evaluation by several ASTM task forces. These include pyrolysis oil from recycled rubber tires, mixed waste plastics, and generic feedstocks from any source.

Due to the global nature and requirements of the industry, aviation fuel must be an internationally uniform product. Unlike other transportation fuels, which have significant regional and country variations, jet fuel must be consistent worldwide. Aviation fuel quality control relies on industry oversight, and industry relies on fuel specifications. The open, consensus-based ASTM process facilitates collaborative and thorough OEM engagement with aviation fuel producers, air worthiness authorities, and other stakeholders. Using the ASTM rigorous consensus process, the aviation fuel industry can confidently evaluate SATFs through the development of specification criteria arrived at through technical deliberation and data. The approach utilized by ASTM accommodates the unbounded technical deliberations necessary to maintain the outstanding safety record of aviation fuel. ASTM's subcommittee on aviation fuels seeks to address environmental, sustainability, and supply security concerns through the focus on safe, fully vetted synthetic alternative jet fuels that integrate seamlessly into the existing fleet and supply infrastructure, while constantly looking toward the future. ASTM International remains committed to serving as a valuable resource for the global aerospace community and encourages participation from all interested parties — being at the table means having a direct hand in shaping the standards for the jet fuel of tomorrow.

The Increasing Importance and Potential of Electricity for CORSIA Eligible Fuel Production

By Daniel Brousse Rivas (EASA)[1], Boris Stolz (BAZL)[2], Matteo Prussi (Politecnico di Torino)[2], Robert Malina (Hasselt University)[2], Florian Allroggen (MIT)[2]

Introduction

In an era marked by increasing awareness of climate change and the urgent need for sustainable practices, the aviation industry faces significant challenges in reducing its carbon footprint. Traditional jet fuels necessitate the exploration of alternative and less carbon-intense fuel options.

One of the most innovative and environmentally friendly methods for producing Sustainable Aviation Fuels (SAF) is through the use of decarbonized electricity. This approach, often referred to as Power-to-Liquid (PtL), leverages renewable electricity to convert carbon dioxide (CO_2) and water (H_2O) into synthetic fuels. By integrating electricity generated from renewable sources such as wind, solar, and hydro, this process mitigates the reliance on fossil fuels and creates a virtuous circle where CO_2 is recycled rather than added to the atmosphere.

Another critical application of decarbonized electricity in traditional fuel production facilities is the production of green hydrogen to produce Lower Carbon Aviation Fuels (LCAF) and/or lower the carbon intensity of SAF. Green hydrogen can be produced through the electrolysis of water using renewable electricity, resulting in a low carbon-intense hydrogen source. This green hydrogen can then be used in refinery processes, such as hydrocracking and hydrotreating, which traditionally rely on hydrogen derived from natural gas.

This article delves into the recent developments at ICAO to integrate electricity sourcing considerations for the production of CORSIA Eligible Fuels (CEF), exploring their environmental benefits.

Benefits of using decarbonized electricity as an energy source for CEF production

There are multiple benefits to promoting the scale-up of decarbonized electricity as an energy source for CEF production.

1. Reduced Land Use

One of the most significant environmental advantages of electricity-based Sustainable Aviation Fuels (SAFs) is their reduced land use requirement. Unlike biofuels, Power-to-Liquid (PtL) fuels are produced through a process that converts CO_2 and H_2O into synthetic hydrocarbons using renewable electricity.

Renewable electricity can be generated from various sources, including wind turbines and solar panels, which

1 Co-Rapporteur of ICAO's CAEP Fuel Task Group (FTG) (actual Working Group 5 – WG5)
2 Member of ICAO's CAEP Fuel Task Group (FTG) (actual Working Group 5 – WG5)

can be installed in areas with low environmental impact, such as deserts, marginal lands, offshore locations, or even on rooftops. This flexibility in energy sourcing can minimize the land footprint of PtL fuels compared to traditional biofuels.

2. Decarbonization Potential

SAFs with a significant renewable electricity input offer substantial decarbonization potential, making them a crucial component in the aviation industry's efforts to reduce greenhouse gas emissions. The PtL process utilizes renewable electricity to power the conversion of CO_2 and H_2O into synthetic fuels, effectively recycling atmospheric carbon. This closed-loop system can achieve significant reductions in emissions, with some studies from the World Economic Forum suggesting that PtL fuels could reduce greenhouse gas emissions between 85-100% compared to conventional jet fuels[3].

3. Complementarity with Carbon Capture and Storage (CCS) Technologies

Electricity-based SAFs are highly complementary with Carbon Capture (CC) technologies, creating a synergistic system that optimizes resource use and enhances emission reductions (often referred as Carbon Capture and Utilisation - CCU). The PtL process can utilize CO_2 captured from industrial sources, such as cement plants or steel mills, or directly from the air through Direct Air Capture (DAC) technologies. By integrating CC with PtL, the aviation industry can promote a circular economy where captured carbon is converted into valuable fuels, thereby reducing overall emissions and contributing to a more sustainable future.

Leveraging on a more abundant and cheaper renewable energy

The transition to electricity-based Sustainable Aviation Fuels (SAFs) is closely tied to the availability and cost-effectiveness of renewable energy sources. As the world increasingly shifts towards cleaner and more sustainable energy solutions, the abundance and affordability of renewable energy present a significant opportunity for the aviation industry to reduce its carbon footprint.

According to the International Energy Agency (IEA), renewables accounted for nearly three-quarters of the total increase in power generation in 2024 (Figure 1). Solar PV was the leading contributor, with an increase of approximately 480 TWh—the highest of any source and significantly surpassing the previous year's growth. Globally, solar PV generation has been doubling roughly every three years since 2016.

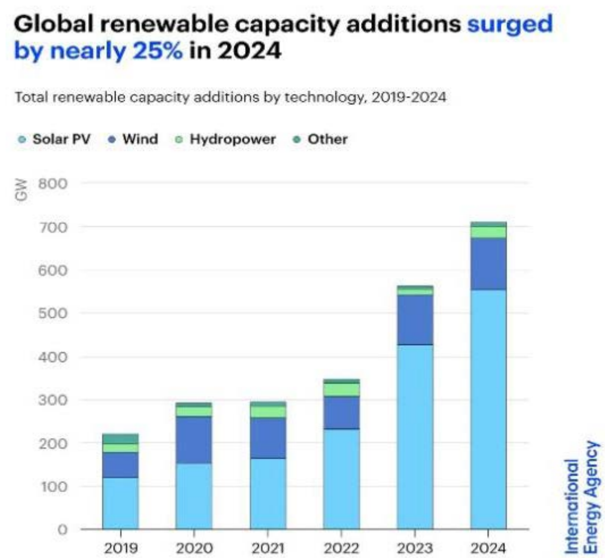


FIGURE 1: Total renewable capacity additions by technology, 2019-2024 (IEA, 2024)[4]

In 2023, 81% of newly added renewable energy capacity was more cost-effective than fossil fuel alternatives, according to a report by the International Renewable Energy Agency (IRENA). This trend, driven by decades of cost reductions and technological improvements in solar and wind energy, underscores another compelling economic and environmental benefit of renewable energy.

For the aviation industry, leveraging on this abundant and cheaper renewable energy would help promoting the production of electricity-based CEFs. Moreover, the integration of renewable energy with aviation fuel

3 https://www.weforum.org/publications/clean-skies-for-tomorrow-delivering-on-the-global-power-to-liquid-ambition/
4 https://www.iea.org/data-and-statistics/charts/total-renewable-capacity-additions-by-technology-2019-2024

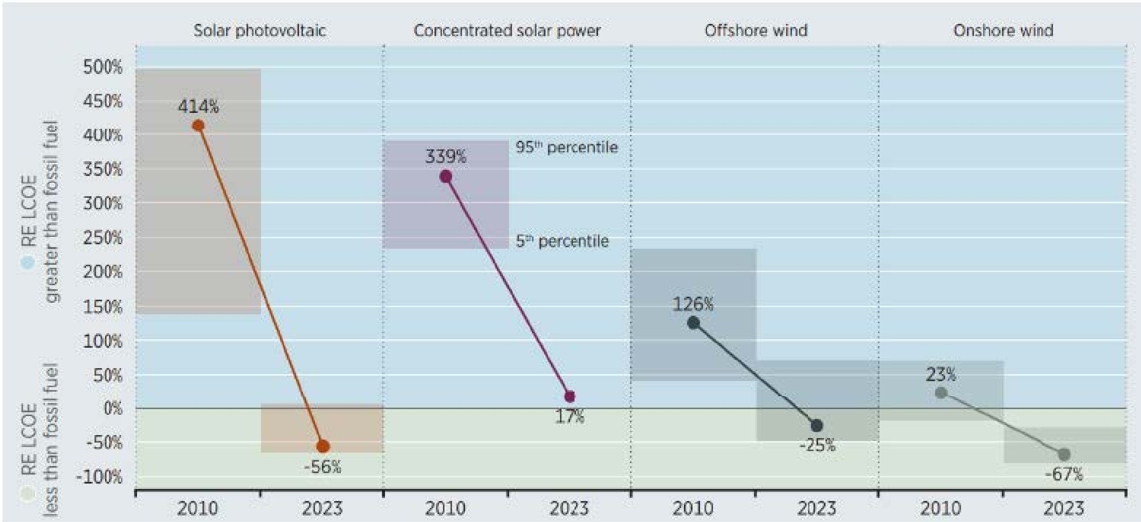


FIGURE 2: Change in global weighted average LCOE for solar and wind compared to fossil fuels, 2010-2023 (IRENA)

production processes can create a more resilient and sustainable energy system. By utilizing excess renewable electricity during periods of high generation and low demand, the aviation industry can help balance the grid and optimize the use of renewable energy resources. This synergy not only supports the decarbonization of the aviation sector but also contributes to the broader transition towards a low-carbon economy.

Why environmental integrity is important when considering a significant use of electricity for CEF production

Knowing the source of electricity is crucial when considering a significant use for CEF production.

The primary goal of using electricity as an energy source for sustainable aviation fuel production is to leverage on its decarbonization potential. If the electricity comes from non-renewable sources, such as coal or natural gas, the environmental benefits are negated. Ensuring that the electricity is sourced from renewable energy, like wind, solar, or hydro, is essential to achieve genuine decarbonization.

Moreover, If the electricity is sourced from areas where renewable energy projects have led to deforestation, the overall environmental impact can be severely negative. Deforestation not only releases stored carbon into the atmosphere but also destroys habitats and reduces biodiversity.

All those considerations have led the ICAO Committee on Aviation Environmental Protection (CAEP) during the CAEP/13 cycle to develop a set of electricity sourcing criteria to avoid unintended consequences when considering a significant use of electricity for CEF production.

Recent developments in the CORSIA framework

For electricity, it is not feasible to physically track the electricity procured for CEF production from a specific electricity generator to CEF production. As such, CORSIA's chain of custody consideration cannot be applied. A set of electricity sourcing criteria has therefore been developed to replicate chain of custody considerations. They are to be applied to all CEF to the extent necessary to (1) obtain a technology-neutral assessment method, and (2) to avoid untenable system-level impacts, e.g. for grid stability or grid-wide emissions. This approach will apply to CEF production processes with increased levels of electrification and has five pillars:

1. **Sourcing arrangements**. Contractual arrangements to identify source of electricity when CEF production is not powered via a direct connection to the electricity generator.
2. **Deliverability**. Defines the sourcing points (facilities) from which the procurement of electricity is possible (ensures connection and addresses grid congestion issues).
3. **Temporal matching**. Timescale over which the generated electricity must match the electricity consumed by the CEF producer (addresses temporal electricity availability).
4. **Additionality**. The degree to which electricity generation capacity is added to a grid in response to demand for CEF production (addresses potential displacement effects in the grid).
5. **Sustainability Requirements**. They aim at avoiding negative sustainability impacts such as deforestation or Induced Land Use Change (ILUC).

The introduction of this comprehensive set of electricity sourcing criteria should represent a significant step forward in enhancing the robustness of the CORSIA framework. By addressing the challenges associated with physically tracking electricity, these criteria would ensure that the environmental and operational integrity of CEF production is maintained. Finally, it will help avoid potential displacement effects within the grid and ensure that the addition of new electricity generation capacity is responsive to the demand for CEF production.

Japan's Efforts to Introduce SAF

By Osamu Nakamura (JCAB), Yuki Nishimura (JGC), Miya Tobioka (ANA), Hideki Ochiai (JAL), Yuhei Sato (COSMO Oil) and Mika Kasagawa (ENEOS)

Introduction

With carbon neutrality by 2050 becoming a world trend in global warming countermeasures, Japan has also declared its commitment to achieve carbon neutrality by 2050 and adopted new greenhouse gas (GHG) reduction targets.

To achieve that, Japan is taking action on various fronts: Japan has participated CORSIA from the beginning and is currently working on measures to further reduce aviation CO_2 emissions.

In addition, Japan chaired a Long-term global aspirational goal Task Group working to develop ICAO's Long-term global aspirational goal (LTAG) for international aviation, which was adopted at the 41st ICAO Assembly as the LTAG aiming for carbon neutrality by 2050.

Japan has set a goal of using 10% SAF of its aviation fuel consumption by 2030, and will continue to steadily work toward this goal, while at the same time striving to foster public understanding and promote international cooperation.

Air Transportation Business Decarbonization Promotion Plan

In order to decarbonize aviation, it is important to support airlines' proactive and planned decarbonization efforts, and JCAB is working to certify an "Air Transportation Business Decarbonization Promotion Plan" based on the Civil Aeronautics Act and other laws.

In January 2024, the two plans of the ANA Group and the JAL Group were first certified, followed by the plans of AIRDO and SKYMARK in November 2024 and March 2025, respectively. The certification process for other airlines is being gradually advanced.

JCAB will support the preparation of plans by airlines to promote the decarbonization of the air transport industry, follow up on the progress of the plans, and steadily promote initiatives to promote the introduction of SAF.

The Public-Private Council for Promoting the Introduction of SAF

In the efforts to reduce CO_2 emissions in the aircraft operation sector, the need to comprehensively and multilaterally examine the direction of Japan's efforts in the aircraft operation sector from the perspective of green recovery, with a view to the future introduction of various technologies and energy sources.

Accordingly, Japan established a study group on CO_2 reduction in the aircraft operation sector. This study group has been analysing the direction of medium to long-term efforts to reduce CO_2 emissions through three approaches:

1. Introduction of new technologies in aircraft and equipment
2. Improvement of flight operation methods by upgrading air traffic control procedures
3. Promotion of the introduction of SAF

To further discussion on promotion of the introduction of SAF, the Public-Private Council for Promoting the Introduction of SAF was established in April 2022. The council is working with private sector such as airlines and oil companies, to discuss ways to promote the introduction of SAF.

Consideration of support and regulations to expand the supply of domestic SAF

In the "Sector-Specific Investment Strategies" developed in December 2023, an investment strategy for SAF was also outlined. The strategy identifies two key directions:

4. Establish a system capable of ensuring sufficient SAF production capacity and a reliable supply chain for feedstocks (including "development import"), enabling the stable supply of SAF at internationally competitive prices.
5. Develop technologies that enable SAF supply, avoiding limitations on feedstocks and technologies, and maximizing the use of domestic and international resources in consideration of feedstock constraints and other factors.

In order to increase the use and supply of SAF, efforts have been made to develop "support measures" through capital investment subsidies using Japan Climate Transition Bonds and tax credits for SAF manufacturers, and "regulations and systems" for the supply side, such as setting supply target volumes in the Act on the Sophisticated Methods of Energy Supply Structures.

A variety of initiatives for promoting SAF

To achieve the goal of replacing 10% of fuel used by domestic airlines with SAF by 2030, JCAB is engaged in a variety of initiatives.

JCAB provided support for the registration and certification of CORSIA-eligible fuel feedstocks, and in 2024, based on a proposal from Japan, non-standard coconut was officially incorporated in ICAO documentation as a new feedstock in the CORSIA framework.

In addition, the General Incorporated Foundation Nippon Kaiji Kyokai (ClassNK) has been approved by ICAO as the third body in the world and the first in Japan to certify sustainability for CORSIA-eligible fuels.

Besides, JCAB worked on developing guidelines to visualize CO_2 emission reductions through the use of SAF for aviation users such as passengers and shippers, and on promoting understanding of efforts to decarbonize aviation among aviation users and others by holding symposiums.

FIGURE 1: ACT FOR SKY partners.

Private sector initiatives

- **Voluntary Organization to Promote SAF in Japan**

  ACT FOR SKY was established in 2022 as a voluntary organization by private sector. Purpose of ACT FOR SKY is to establish SAF entire supply chain in JAPAN including feedstocks, production and off-take.

  Initial members were 16 companies such as airlines, engineering firms, oil companies and various kinds of sector. Membership has been increased to 45 companies and Tokyo metropolitan government as of April 2025.

  ACT FOR SKY members (Figure 1) meet regularly to share the latest information about SAF with inviting experts in various fields. In December 2024, ACT FOR SKY organized the first symposium to announce the activities of ACT FOR SKY members. More than 650 people attended, including online.

In 2025, ACT FOR SKY has achieved a great milestone: members of ACT FOR SKY have started SAF production and completed a SAF supply chain in Japan.

ACT FOR SKY continues to expand SAF supply chain in JAPAN in order to contribute decarbonization of the aviation industry. For more detail information, see ACT FOR SKY's website.[1]

FIGURE 2: Cargo transported under the SAF Flight Initiative being loaded onto an ANA freighter.

- **ANA Group initiatives to decarbonize aviation**

ANA is promoting a variety of initiatives to decarbonize its operations. In recent years, ANA has especially been focusing on taking a pioneering approach to the use of SAF.

One example is the SAF Flight Initiative (Figure 2), the first program of its kind in Asia.

This program responds to requests from companies seeking decarbonized logistics and travel solutions, and aims to reduce CO_2 emissions by collaborating with other entities sharing this goal.

ANA is also working with other airlines, in order to build momentum for decarbonization in the airline industry, and to send a strong signal about the demand for SAF. In October 2021, ANA took initiative and released a joint report with JAL entitled "Toward Virtually Zero CO_2 Emissions from Air Transportation in 2050" to raise awareness and promote the understanding of SAF.

Achieving future decarbonization of aircraft will require understanding and cooperation, not only through public-private partnerships, but also through the active use of decarbonization services by aircraft users. ANA is committed to supporting the growth of both the aviation industry and decarbonization, and to contributing to the growth of society as a whole.

- **JAL Group initiatives to decarbonize aviation**

SAF is the key to incorporate carbon neutral in the aviation industry. Airlines are also making efforts to procure SAF, however, the volume and price are major hurdles for SAF enhancement.

In order to clarify the responsibility of the aviation transport provider and user, the GHG Protocol defines Scope1 and Scope 3 emissions.

This means that aviation carbon reduction should be incorporated not only by Scope 1 emitters, but also together with Scope 3 users (by all the related stakeholder's cooperation (Figure3).

Some mandatory authorities and private initiatives (Task Force on Climate-related Financial Disclosures (TCFD), International Sustainability Standards Board (ISSB), Science Based Targets initiative (SBTi), etc.) are requesting disclosure of those emissions. Additionally, there are requests from aviation users to identify their emission and proof of their contribution to carbon reduction.

FIGURE 3: JAL Sustainable Challenge Flight.

1 https://actforsky.jp/

To comply with those users' requests, JAL started a program to issue "Certificates" to those customers who use aviation transport and contribute CO_2 reduction by SAF, to recognize and prove their contribution to CO_2 reduction, which also works to share SAF cost with customers.

So far, more than 10 companies, mainly freight forwarders, are participating in the program. Airlines continue to work together with society to reduce aviation's carbon emissions.

- **Introduction of SAF at Cosmo Oil**

In December 2024, Cosmo Oil, together with JGC Holdings and REVO International, completed the construction of a SAF plant at the premise of Cosmo Oil Sakai Refinery. This project is Japan's first SAF large-scale project and is subsidized by the New Energy and Industrial Technology Development Organization (NEDO).

Large-scale production will begin in the spring of 2025, and SAF will be supplied to consumers, mainly airlines. This has realized the building of a domestic SAF supply chain.

Also, Cosmo Oil also set a goal of supplying 300,000 kiloliters of SAF annually by 2030. As the next SAF production project, Cosmo Oil, together with Mitsui & Co., Ltd., is planning to commercialize SAF production using bioethanol (Alcohol to Jet) as feedstock at the premise of Cosmo Oil's Sakaide Distribution Terminal, aiming for an annual production of 150,000 kiloliters annually. This project was also selected for a government subsidy in February 2025.

Furthermore, Cosmo Oil is considering importing SAF from overseas in order to establish a stable SAF supply system in the future.

- **The development of SAF supply chain at ENEOS**

ENEOS is taking a great initiative of establishment of both a stable energy supply system and of a carbon-neutral society. As a part of the challenges, ENEOS is developing an integrated SAF supplying system, from feedstock procurement to in-house refining and sales.

In concrete, ENEOS is planning to convert a SAF refinery from an existing refinery in Wakayama. ENEOS especially recognize the collection of feedstock as the most important challenge, so ENEOS is collaborating with the local governments and used cooking oil (UCO) suppliers to establish a collecting network.

ENEOS had also already imported SAF molecule (Figure 4) and started SAF supply for demonstration and pre-marketing purpose in 2024. ENEOS supplied not only physical SAF to airlines but also environmental attributes of Scope 3 emissions to airline users.

Through these activities, ENEOS is doing the best to promote of SAF and contribute to the acceleration in decarbonization of the aviation industry.

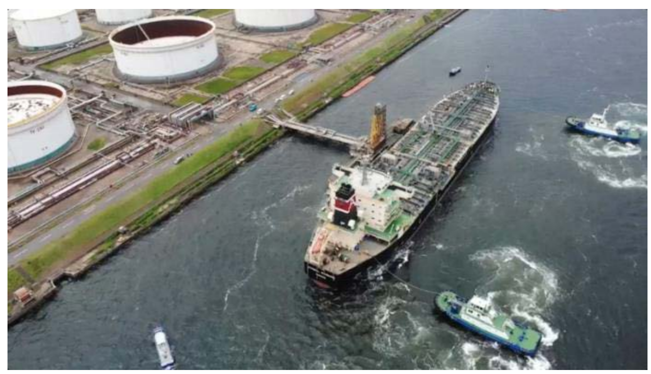


FIGURE 4: The arrival of the SAF import vessel at the ENEOS Kashima Refinery dock.

Conclusion

CORSIA is the only decarbonization scheme in international aviation, and Japan will continue to take measures in accordance with the ICAO framework, including CORSIA.

In addition, toward to increase the use and supply of SAF, JAPAN will work to ensure international collaboration and promote international cooperation.

Fueling the future: Brazil's strategy on SAF and aviation energy transition

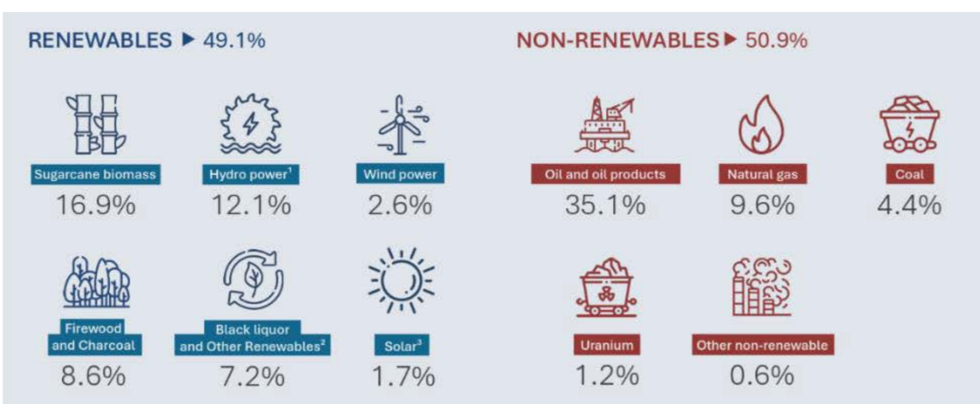
By Marcela Anselmi and Ricardo Dupont (ANAC, Brazil)

Brazil has a well-recognized potential to be one of the most important SAF producers in the world, and this comes from a longstanding tradition. Since the 1970's, the country has made substantial investments in the decarbonization of its energy matrix, starting from the building up of hydropower plants and the establishment of a robust biofuels – ethanol as a first - industry.

As time moved on since then, several and different programs and policies have been implemented in Brazil to foster the deployment of renewable and sustainable energy sources. The result of these policies is that the energy mix in Brazil is currently (2023) about 49% renewable, in which sugarcane biomass by itself comprises 16,9% of the whole energy consumed in the country.[1] Wind power (+17,4% YoY[2]) and solar power (+51,1% YoY) have been growing at an accelerated pace, while non-renewable sources are declining over time.

As examples of these policies, we can note that Brazil has mandatory blending mandates established for ground transportation, which can reach up to 35% of ethanol blended in gasoline – currently moving up to 30% - and provisions for increasing t up to 25% of biodiesel blended into diesel – currently at 14% of biodiesel, apart provisions for up to 3% of additional green diesel. The RenovaBio Policy e put in place procedures to ensure that biofuels produced in Brazil meet high levels of sustainability criteria while ensuring the continuous reduction in the carbon intensity of fuels over time.

Given this renewable energy friendly environment, which includes consolidated infrastructure to produce and distribute renewable fuels, the availability and continuing increase in renewable electricity production, and the potential to produce biomass meeting all sustainability criteria, Brazil had to take the next step: the Fuels of the Future law and the SAF National Program.



1 National Energy Report 2024. Available at: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-819/topico-715/BEB_Summary_Report_2024.pdf
2 Year over year (YoY).

The SAF National Program in Brazil

On 8 October 2024, Brazil enacted the law called *Fuels of the Future* (Combustível do Futuro, in Portuguese), which, among other provisions, established the Sustainable Aviation Fuel's National Program, aiming at fostering the research, production, commercialization and use of SAF in the Brazilian energy matrix.

The SAF National Program was developed via a thorough regulatory process, which included collaborative discussions among regulatory agencies – both civil aviation and biofuels authorities, the aviation industry, fuel producers and distributors, academia and civil society. From this process, several pillars founded the establishment of the SAF National Program, including the establishment of a mandate, financing, taxation, fuel qualification, research, among others.

In this entire process, the guiding principle was that SAF is the principal means for the decarbonization of the aviation sector. This principle was considered in every step of the process and led to a major regulatory innovation not only for Brazil, but a first-of-its-kind in the world: a SAF use mandate directly based on CO_2 emissions reductions, applied to the final users of SAF, the airlines. In order words, Brazil was a pioneer in moving away from a blending mandate, but rather established a decarbonization mandate in which SAF plays a pivotal role. The Brazilian mandate means that the airlines that operate domestic flights shall reduce a percentage of their CO_2 emissions each year by replacing fossil fuels by SAF, starting at 1% CO_2 reduction in 2027 and continuously increasing this percentage to 10% from 2037 onwards. One important aspect of the Brazilian mandate is that it fosters the energy efficiency of SAF production and deployment. Comparing it with a traditional fuel blending mandate, in which the environmental benefits are a secondary aspect, a CO_2-emissions reductions mandate by the use of SAF brings the environmental attribute of SAF to the core of the legislation, taken on an agnostic approach, and has some significant advantages:

- It incentivizes CO_2 efficient pathways, as the CO_2 emissions abatement cost will be the major player in the choice of SAF options by the airlines;
- It empowers the airlines – the final consumers of the product – to push for feedstocks and conversion processes that have lower CO_2 emissions per unit of fuel energy content (gCO_2/MJ);
- It is agnostic on feedstock and conversion processes: what matters is emissions reductions and the compliance with sustainability criteria.
- It avoids logistical difficulties associated with SAF distribution, as the fuel uplift can be concentrated on airports nearby production facilities and feedstock sources, avoiding the CO_2 emissions and costs associated with transportation of the SAF to all airports, which could be a major constrain in a country such as Brazil;
- It does not penalize the growth of the sector, as the emissions reductions are proportional to the market share of the aeroplane operators.

In order to ensure the effective implementation of the mandate, the national policy encompasses provisions to promote market-based mechanisms, such as the so-called book-and-claim system. Allowing this kind of system is a way to promote a more efficient deployment of SAF – the availability can be concentrated in major hubs closer to production while, at same time, ensuring that all airlines – even those that do to have operations in those airports, can have access to the environmental benefit coming from SAF. For sure, the implementation of such a system entails the definition of sustainability criteria to ensure the traceability of the custody chain and that no double claiming happens.

Another important element of the Brazilian SAF National Program is that it aims for alignment with the CORSIA framework. Once again, Brazil has taken the lead in recognizing the need for avoiding a patchwork of different regulations when it comes to assessing the sustainability and eligibility of SAF in its own national regulation. Also, this approach, if implemented by ICAO Members States in their own legislation, allows for the constitution of a global market in which SAF produced in any part of the world meets a set of sustainability requirements that can be accepted for all countries and, therefore, deployed by all airlines in their decarbonization measures.

Mechanisms to promote the development of the SAF industry in Brazil

The establishment of a mandate for the deployment of SAF by the airlines was just a first step in the pathway for incentivizing SAF production in Brazil. It has provided the regulatory framework that has secured a relatively stable domestic demand for SAF, which was seen as an important measure to incentivize investments. Nevertheless, the National SAF policy has also envisaged other complementary steps needed to create a business-friendly environment for this nascent industry to flourish. In that regard, several actions have been deployed in Brazil in order to identify additional actions to put in place the right incentives for SAF production.

a) SAF Connection

The development of SAF industry in Brazil relies mainly on private investment and initiatives. The Brazilian government has very limited resources in its national budget to provide subsidies or direct incentives for this industry to flourish. Therefore, a close collaboration between the public and the private sector is needed to provide the right incentives and policies to incentivize, in the most effective way, the private sector to ramp up their investment in the production of SAF.

In addition, the air transport sector in Brazil is already constrained by a very high costs structure in which fuels account for up to 40% of their overall operational costs. Given that, in this moment, SAF is more expensive than conventional fuel, the costs for the aviation sector, which may impact on the development of air transportation in Brazil, constitutes a major concern.

In order to put all stakeholders - from the supply and demand side - on the same page and look for proper alternatives that can be implemented either by the governmental agencies or by the private sector, SAF Connection (Conexão SAF, in Portuguese) was established by the National Civil Aviation Agency (ANAC) and the National Petroleum, Natural Gas and Biofuels Agency (ANP) in 2024. SAF Connection is a national informal forum, composed by more than 110 private and public stakeholders, for the discussion of the challenges and opportunities for the promotion of SAF production and deployment in Brazil.[3]

The initiative is organized into five different working groups, in which discussions all stakeholders can actively participate. The working groups are led by national coordinators, who represent government institutions, and focus on the following topics: (i) SAF certification and quality of product; (ii) infrastructure and deployment; (iii) regulation of the mandate for airlines; (iv) Financing and incentive policies; and (v) taxation. Since the law Fuels of the Future has been enacted, the discussions in SAF Connection are in full swing, especially those related to the implementation of the CO_2 reduction mandate for airlines and the incentives for SAF production, which are key for the development of this market in Brazil in the short term.

One important aspect of SAF Connection is that it provides the forum for social participation in an open and transparent manner. Governments alone may not have the whole expertise or tools to design effective policies, and allowing the private sector, the academia and civil society to make their contributions is a good practice that adds much value for the policy-making process.

b) Financing

One paramount aspect for the development of any nascent industry is providing access to financing mechanisms that can help reduce uncertainties and risks associated with a new market. To facilitate the implementation of SAF projects in Brazil, a joint public call for business plans has been put forward by the National Bank for Economic and Social Development(BNDES) and Finep (a public enterprise for financing studies and projects linked to the Ministry of Science and Technology), which will provide up 6 billion Brazilian reais (approximately USD 1.1 Billion) in funding

3 For more information on SAF Connection, please access https://hotsites.anac.gov.br/conexaosaf/

of SAF and maritime fuels projects. Surprisingly, the response from the market was much higher than expected: 76 proposals were received, summing up more than BRL 167 billion (approximately USD 29 billion) for SAF and maritime fuels. Currently (April 2025), BNDES and Finep are evaluating the proposals received and looking into additional financing opportunities aiming at increasing the budget available and assisting the development of this market in Brazil.

c) Research & Development and quality assessment

Research and development are fundamental pillars for exploring and evaluating the feasibility of new pathways and feedstocks for SAF production. Brazil has a potential to produce SAF from different feedstocks, some of them very unique to the Brazilian geographical position and climate conditions. In this regard, the Brazilian government has established a partnership with the most prominent national research centers, such as the Brazilian Agricultural Research Corporation (Embrapa), the University of Campinas (UNICAMP), the University of Rio Grande do Norte (UFRN) and Getulio Vargas Foundation (FGV) to finance up to USD 2 million in research related to SAF production in Brazil. The SAF Network aims at fostering studies on new SAF conversion processes and new feedstocks, ILUC modelling and risk-based analysis, sustainability criteria and certification schemes, cost-benefits analysis of public policies for SAF production.

In addition to this initiative, the Brazilian government has also carried out several studies on the availability of feedstock and feasibility of production to subsidize the decision-making process during the discussions on the Fuels of the Future. Those studies were carried out by the Energy Research Institute, which is linked to the Ministry of Mines and Energy. Those studies have drawn important conclusions for the policy-making process in Brazil, such as:[4]

1. SAF production in Brazil can have a lower carbon intensity compared to the same conversion processes in other countries due to integrated plants.
2. Brazil can stand out in SAF production due to its expertise in biofuels and the availability of land, biomass, and other renewable energy sources.
3. Existing initiatives for the construction of biorefineries can meet a portion of the emissions reduction required by CORSIA and National SAF Program. But, in the long term, it is necessary to diversify the feedstocks used in biofuels production, which could catalyze job creation and income distribution to rural areas in Brazil.

Finally, once SAF production is in place in Brazil, the National Petroleum, Natural Gas and Biofuels Agency (ANP) will need to carry out its own quality assessment procedures in order to ensure that the SAF deployed in Brazil meets all the quality and safety standard required from a drop-in fuel, In this regard, the Brazilian government has already made the investment to equip ANP with the proper tools and make its laboratory ready to test the SAF produced and deployed in Brazil according to ASTM and national safety and quality standards.

4 Available at: https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/combustiveis-sustentaveis-de-aviacao-no-brasil-perspectivas-futuras.

A quiver of policy tools needed to hit sustainable aviation fuel targets

By Ilkka Hannula and Jeremy Moorhouse (IEA)

Introduction

Sustainable aviation fuels (SAFs) are a key tool for reducing emissions from aviation and are set to expand to over 2% of global aviation demand by 2030 in the IEA's main case forecast based on legislated SAF support policies. This growth is being driven primarily by mandates, incentives and financial support in the United States, Europe and Japan. Nearly all expected production to 2030 is based on mature commercial technologies – specifically hydroprocessed esters and fatty acids (HEFA) – using feedstocks such as vegetable oils and residue oils.

In the IEA's forecasted accelerated case[1], which includes the implementation of planned SAF support policies, SAF use would further double, approaching 5% of global aviation demand by 2030. Such growth would make a significant contribution toward ICAO's aspirational target of a 5% reduction in international aviation CO_2 emissions by 2030, with announced SAF projects offering more than enough capacity to meet this level of demand. However, even this more optimistic trajectory falls well short of the IEA's Net Zero Emissions by 2050 Scenario, which depends on SAFs providing near 25% of total aviation fuel demand by 2035.

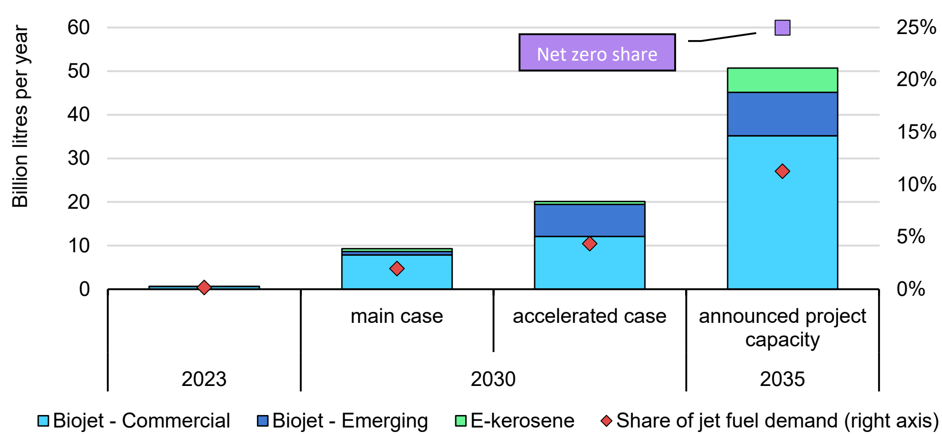


FIGURE 1: Sustainable aviation fuel demand, 2023 to 2035 main, accelerated case and announced capacity. Source: IEA (2024) Renewables 2024[2], IEA (2024) Oil 2024[3] and IEA (2024) World Energy Outlook[4]. Announced project capacity adapted from Argus Direct[5] (2024) Global sustainable aviation fuel & renewable diesel refinery database. Note: "Commercial" includes HEFA and "Emerging" includes alcohol-to-jet and Fischer-Tropsch. The "main case" is based on legislated policies and existing markets conditions including costs, feedstocks and production capacity. The "accelerated case" assumes planned policies are legislated and actions are taken to remove market barriers such feedstock availability and capacity additions to meet new demand.

1 https://www.iea.org/data-and-statistics/data-tools/renewable-energy-progress-tracker
2 https://www.iea.org/reports/renewables-2024
3 https://www.iea.org/reports/oil-2024
4 https://www.iea.org/reports/world-energy-outlook-2024
5 https://direct.argusmedia.com/

Despite growing momentum, three interrelated challenges threaten to limit the pace and scale of SAF deployment beyond the main case forecast and post 2030. First, commercial SAFs are near triple the price of fossil jet fuel[6] and only a handful of countries have established clear SAF targets backed by enforceable penalties or incentives to compensate the cost gap. Second, most planned facilities rely on a narrow subset of the potential sustainable biomass feedstock base, and there is limited innovation support to diversify feedstocks and reduce the costs of new processing technologies. Third, even where SAF requirements exist, many lack accompanying financing frameworks capable of catalysing project investment.

To address these challenges and to enable SAF deployment, three core policy enablers must be deployed in tandem. **Performance-based policies** to compensate the cost gap and reward fuels with the lowest lifecycle emissions, **innovation and feedstock diversification** support to expand the set of economic and scalable production pathways and, **targeted financial instruments** to reduce investment risk, and support project construction.

Performance based policies

Long-term demand policies act as the foundation of SAF strategies; but they are only effective when paired with penalties and incentives to compensate the cost gap and establish clear performance requirements to ensure compliance. Performance based policies strengthen this foundation by enabling fair and transparent comparisons between SAF pathways based on their lifecycle greenhouse gas (GHG) intensity, not simply their origin or volume. SAFs vary widely in emissions performance depending on the feedstock used, conversion technology and choice of energy inputs. While all pathways can offer potential for GHG reductions, aligning financial incentives with GHG performance encourages continuous improvement and rewards the most effective solutions. Critically, this approach often encourages more efficient use of limited feedstocks, directing them to applications with greatest emissions impact per litre.

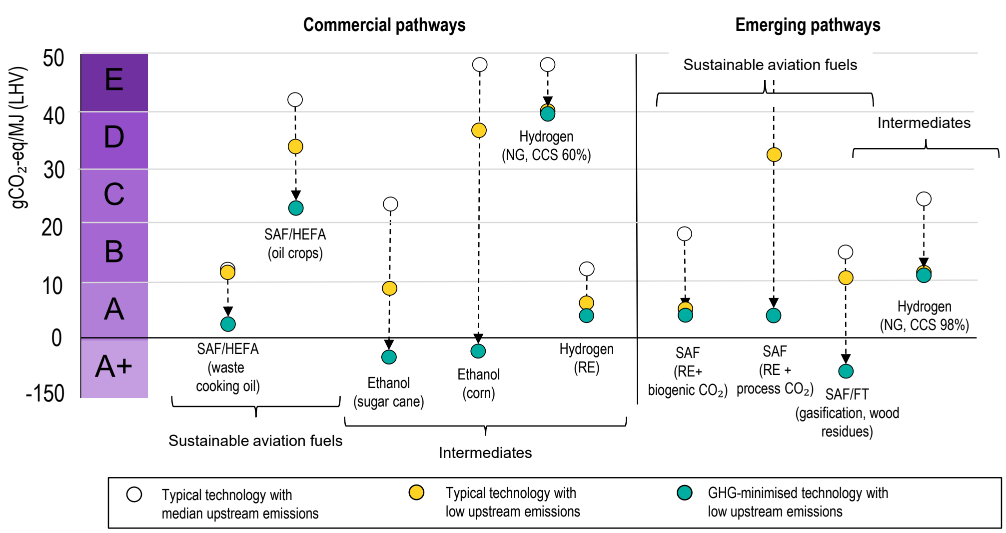


FIGURE 2: Example of a quantitative GHG intensity labelling system for selected sustainable fuel pathways. Source: IEA (2024) Towards Common Criteria for Sustainable Fuels[7]. Note: Fossil jet fuel has a life cycle carbon intensity of 89 gCO_2-eq/MJ[8].

6 https://www.iea.org/reports/renewables-2024
7 https://www.iea.org/reports/towards-common-criteria-for-sustainable-fuels
8 https://www.icao.int/MID/Documents/2022/CORSIA-SAP Seminar/4.CEF_Intro_v1.pdf

Performance based policies can take many forms, including minimum GHG thresholds, carbon intensity reduction targets and performance linked incentives. The EU's ReFuel Aviation regulation for instance sets use targets and requires SAFs with 70% or greater improvement over fossil fuels. In the United States the Inflation Reduction Act (IRA) provides a base incentive of USD 0.33 per litre for SAFs meeting a 50% improvement threshold, with payments up to USD 0.46 per litre for fuels with superior performance. This approach rewards incremental improvement but does not guarantee fuel uptake or total emission reductions. Brazil takes yet another approach in its National Program for Sustainable Aviation Fuel[9], requiring annual GHG reductions that airlines must meet with SAFs, guaranteeing emission reductions but not volumes.

Given the international nature of aviation, domestic performance based policies must be designed with compatibility in mind. Here, CORSIA, plays a critical role by establishing minimum GHG thresholds and clearly defining lifecycle methodology to allow for cross-border compatibility.

There is also value in aligning sustainable fuel carbon accounting practices across aviation, maritime, road and industrial sectors since many of the fuels share supply chains and single production facilities can serve multiple uses. For instance, the IMO's recent net-zero regulations for global shipping[10] announcement includes developing a set of default emission factors for sustainable fuels with considerable methodological overlap with pathways covered by CORSIA. There is good potential for broad alignment, since direct emissions over a fuels lifecycle is well understood.

However, some of the most contentious lifecycle variables — especially ILUC for biofuels, additionality requirements for electrolytic hydrogen, or the role of fossil-based CO_2 feedstock for e-fuels — require careful political and methodological decisions. Where quantitative data is unavailable or uncertain, such as the case with ILUC, risk-based approaches — when based on objective and transparent indicators — can be used to certify low-risk agricultural practices across feedstock types. Ultimately, performance frameworks must be supported by broader governance structures that protect environmental integrity and preserve public trust.

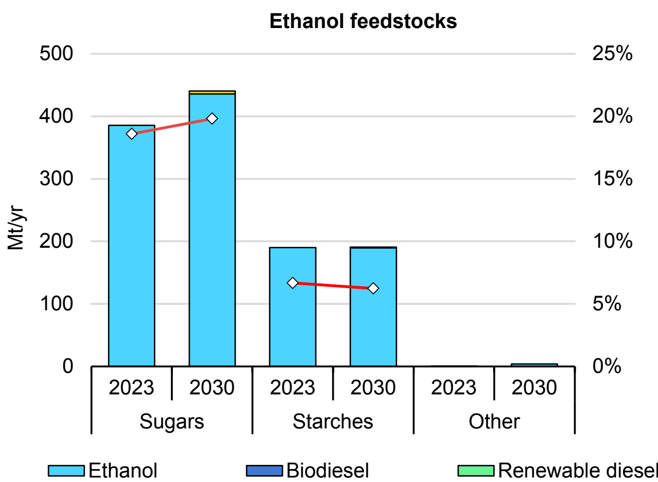
Innovation to diversify feedstocks and reduce costs

Accelerating the uptake of SAFs will depend on deploying a diversity of innovations ranging from agricultural practices to new conversion technologies. In the IEA's Net Zero by 2050 Scenario, biomass use for the energy sector is limited to 100 EJ to avoid conflicts with other uses of land, notably for food production and biodiversity protection. This amount falls within the lower range of global estimates of global sustainable bioenergy potentials. Considering competition with other bioenergy uses the amount is sufficient to meet one third of aviation demand by 2050. However, nearly all SAF capacity expected to be commissioned by 2030 relies on vegetable oils and residue oils. These are the same feedstocks relied upon by renewable diesel and biodiesel producers, leading to intensifying competition. Combined demand would drive up residue oil use to near 80% of collectible supply and vegetable oils up seven percentage points from 2023 levels to 27% of global supply under current policy settings by 2030. Ethanol feedstocks are under less pressure as growing biofuel demand matches growth in global sugar and starch production to 2030.

A range of policy levers can help unlock the potential of improving yields through approaches such as sequential cropping and enabling production on degraded and marginal land. These include restrictions on unsustainable land-use. For example, CORSIA's sustainability criteria[11] and Brazil's RenovaBio[12] prohibits the removal of native vegetation for biofuel feedstocks production. Another approach is to create dedicated pathways for sequential cropping and for crops grown on marginal or degraded land, as included in CORSIA and the EU's feedstock eligibility criteria. In addition, financial support can help reduce the

9 https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2024/lei/l14993.htm
10 https://www.imo.org/en/MediaCentre/PressBriefings/pages/IMO-approves-netzero-regulations.aspx
11 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
12 https://atosoficiais.com.br/anp/resolucao-n-758-2018

risk of adopting new seed varieties and planting techniques. For instance, the United States has provided funding[13] for research into winter oilseed crops including efforts to integrate them into existing rotations. De-risking new seed varieties and planting methods are also needed to expand planting, such as US financial support for such studies[13].



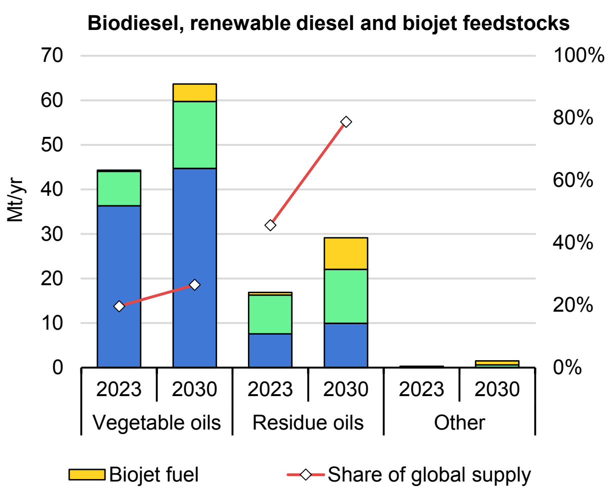


FIGURE 3: Global biofuel feedstock demand, main case, 2023 to 2030. Source: IEA (2024) Renewables 2024[14] see for detailed notes. Note: Share of global supply based on FAO (2024) Agricultural Outlook 2024-2033 including feedstock supply for food, feed and industrial uses.

On the conversion side, innovation in processing technologies is critical to widen the SAF feedstock base. Emerging routes include alcohol-to-jet, Fischer-Tropsch synthesis using solid biomass, and electrolytic routes to jet fuel (e-kerosene). In aggregate, these pathways could contribute up to 10 EJ of sustainable fuels by 2050. Production from such first-of-kind facilities will be more expensive than today's commercial SAF pathways. However, targeted support can help reduce costs[15] through economies of scale and learning, eventually nearing those of HEFA facilities. Guaranteed demand using mandates (as in the UK[16]), capital support for first-of-a-kind projects (as in the United States[17]) and technical approvals through ASTM or equivalent standards are all needed to support new projects. Equally important is the integration of new pathways into existing regulatory frameworks, as seen in California's LCFS, which incorporates novel SAF routes through protocol updates.

Finance

Even with demand policies and innovation support, targeted financial instruments are essential to mobilise investment. SAF developers face several risks: uncertain long-term demand, evolving regulatory frameworks and, variable SAF and credit prices. These dynamics make it difficult for developers producing a new product for a new market to secure financing at competitive terms, particularly in emerging markets where policy support may be less stable.

For instance, in the United States the Department of Energy has supported two major SAF projects with near USD 3 billion in flexible loans via its Title 17 Clean Energy Financing Program[18]. In Brazil, BNDES announced dedicated support of near USD 1.2 billion for sustainable aviation fuel development, building on similar supports for ethanol facilities. India's ethanol expansion offers a relevant model as well, its interest subvention scheme[19] and guaranteed pricing, enabled ethanol capacity to expand nearly fivefold

13 https://portal.nifa.usda.gov/web/crisprojectpages/1032231-fueling-winter-canola-cultivar-availability-to-meet-new-demand-for-oil.html
14 https://www.iea.org/reports/renewables-2024
15 https://iea.blob.core.windows.net/assets/17033b62-07a5-4144-8dd0-651cdb6caa24/Renewables2024.pdf
16 https://www.gov.uk/government/collections/sustainable-aviation-fuel-saf-mandate
17 https://www.energy.gov/eere/bioenergy/articles/first-ethanol-alcohol-jet-synthetic-aviation-fuel-production-facility?nrg_redirect=472803
18 https://www.energy.gov/lpo/title-17-clean-energy-financing
19 https://pib.gov.in/PressReleasePage.aspx?PRID=2109157#:~:text=Under%20this%20modified%20Ethanol%20Interest,being%20borne%20by%20the%20Central

in five years. The United Kingdom is in the process of developing a revenue certainty mechanism[20] that sets a fixed, long-term price for SAF, regardless of market dynamics.

Other mechanisms can help aggregate demand and signal long-term market confidence. Tradable certificates, such as RSB's Book & Claim Programme[21], allow obligated parties or voluntary buyers to support SAF deployment without physical blending, opening doors for international supply chains. Green capital markets are also playing a growing role. Neste, for instance, issued a €700 million green bond[22] to finance its Rotterdam SAF expansion, aligning proceeds with sustainability criteria under its Green Finance Framework.

Conclusion

The first wave of regulations and incentives is only beginning to spur investment in sustainable aviation fuels, but it is already clear that a coordinated and comprehensive policy approach is essential.

Performance-based policies can compensate the cost gap with fossil jet fuel and ensure fuels are rewarded for their actual GHG benefit. Innovation and feedstock diversification enable long-term growth without compromising land or food systems by unlocking feedstock pathways and making them cost competitive. And financing tools create the conditions for developers to take investment risks and build the infrastructure needed for scale. Together, these elements form a robust policy ecosystem — one capable of driving sustained growth and achieving near-term and long-term targets.

20 https://www.gov.uk/government/consultations/saf-revenue-certainty-mechanism-approach-to-industry-funding/sustainable-aviation-fuel-revenue-certainty-mechanism-approach-to-industry-funding
21 https://rsb.org/programmes/book-and-claim/
22 https://www.neste.com/news/neste-corporation-issues-a-eur-700-million-green-bond-with-5-year-maturity

Global Landscape of SAF Accounting Methodology and Registry Systems

By Azim Norazmi and Michael Schneider (IATA)

Introduction

Sustainable Aviation Fuels (SAF) has emerged as the most pivotal solution to help aviation achieve its net-zero carbon emissions target by 2050. However, to fully realize its benefit and deploy SAF in the most cost-effective and environmentally efficient way, a global and robust accounting and reporting system needs to be adopted to facilitate SAF deployment. Such a system would need to ensure a credible accounting of SAF environmental attributes through appropriate transparency and prevention of double counting while providing verifiable data to instill confidence in SAF-associated claims. This article explores the current global landscape of SAF accounting methodology and registry systems, highlighting key methodologies and registries and the challenges of achieving a globally harmonized approach to SAF deployment and integration.

Why accounting and registry systems matter for SAF deployment

SAF supply chains are often more complex than conventional aviation fuels (CAF). SAF adoption involves not only the uplifting of physical SAF molecules into aircraft but also the claiming of its associated environmental attributes. SAF emissions reduction is accounted for on its lifecycle basis and does not occur at the tailpipe of the aircraft engines. As such, SAF can be produced and consumed in one region, but the environmental benefits can be accounted for in another words, SAF accounting can be done on a purchase basis.

In general, a fit-for-purpose SAF accounting framework would enable airlines to claim the environmental benefits from SAF purchases to meet or reduce their regulatory obligations and fulfill additional commitments. A robust SAF accounting system – or network of interoperable systems – offers the following benefits:

- Ensures immutable tracking of the environmental attributes to enable verification.
- Provides full transparency of the claims made over any specific batch of SAF.
- Prevents double counting from double issuance, usage, or claiming.
- Allows stacking of incentives to maximize opportunities to fund SAF's higher prices.

Utilizing flexible and trusted chain-of-custody mechanisms, such as mass balance or book and claim[1], can unlock additional benefits for increased efficiency in SAF production and transport:[2]

- Enables SAF production where it is most efficient.
- Provides increased demand for production facilities geographically distant from larger airports.
- Avoids unnecessary transport of SAF and feedstocks, minimizing cost and the associated incremental emissions, enabling efficient deployment.
- Promotes competition.

1 As defined by the ISO 22905:2020 – Chain of custody general terminology and models.
2 Read further about SAF accounting benefits published by IATA, which are accessible here: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/iata---saf-accounting-benefits.pdf

Global landscape of SAF accounting methodology and registry systems

Over the years, the global landscape of SAF accounting systems and registries has rapidly evolved and continues to develop to support efficient SAF deployment and adoption. These systems play a critical role in tracking SAF environmental attributes and verifying SAF purchases and usage while ensuring transparency, preventing double counting, and supporting the achievement of emissions reduction targets by airlines and their customers. As governments, airlines, and fuel producers/suppliers collaborate to scale up SAF adoption, a range of registries and accounting frameworks have emerged to address the complex needs of the market. These systems are designed to provide reliable methods for documenting SAF production, transfer, transaction, and consumption, covering regulatory and voluntary compliance related to SAF. Developing and integrating these systems through a global interoperability framework is crucial for building robust and transparent SAF ecosystems that support sustainable goals and efficient SAF deployment globally.

Table 1 (Appendix) summarizes these systems to provide an overview of the global landscape of SAF registry systems and the accounting methodologies they employed.

SAF accounting methodology under the ICAO's CORSIA framework

The CORSIA Standard and Recommended Practices (SARPs) provisions recognize that jet fuel and SAF are not segregated at airports but are typically co-mingled. CORSIA-eligible fuels (CEF) can be mingled in fuel pipelines, storage terminals, and airport storage systems, all upstream from its use in aircraft. The CEF purchased by a particular airline may not be physically used in its aircraft, and it will not be feasible to determine the specific CEF content at the point of uplift in an aircraft, given the nature of the upstream supply chain. Claims of emissions reductions from using CEF by airlines are based on the mass of CEF according to purchasing and blending records[3]. Furthermore, according to ICAO Doc 9501 - Environmental Technical Manual, Volume IV, the CEF can be produced and uplifted anywhere in the world as long as they satisfy CORSIA reporting requirements by the CORSIA SARPs[4].

Key Challenges of SAF Accounting Systems and Registries

Despite tremendous progress, several challenges to achieving a globally harmonized accounting system still exist. While SAF is used for the same reason, i.e., to address emissions reduction, the methodology by which the emission reductions are accounted for across different frameworks still slightly differs. This creates confusion and market inefficiency. There's also a lack of certainty to the eligibility of accounting SAF emission reductions using Book and Claim as a chain of custody model. In particular, the Greenhouse Gas Protocol (GHGP) lack of recognition on Book and Claim remains a major barrier to unlocking corporate SAF demand. There's a high consensus that using SAF registries could help ensure traceability between physical SAF molecules and their associated environmental attributes. However, interoperability between registries is still lacking despite industry efforts to standardize data fields, reporting formats, and certificate attributes.

The game changer: The IATA SAF accounting and reporting methodology and the SAF registry by CADO

The IATA SAF accounting and reporting methodology provides airlines and SAF users with a consistent approach for accounting and reporting emissions reduction associated with SAF use[5]. Developed by over 40 airline experts worldwide, the methodology is feedstock-agnostic and technology-neutral. Moreover, the methodology complements existing international frameworks, such as the ICAO's CORSIA framework and the GHGP, while reinforcing consistency without duplicating efforts. It also

3 Note 1, Clause 2.2.4 of ICAO CORSIA SARPs, Annex 16 Vol IV, Part II, Monitoring of CORSIA eligible fuels claims
4 Clause 3.3.5.5 ICAO Doc 9501, Environmental Technical Manual, Volume IV, Use of CORSIA eligible fuels
5 The IATA SAF accounting and reporting methodology was published in Jan 2025 and can be accessed here: https://www.iata.org/en/programs/sustainability/reports/saf-accounting-reporting-methodology/

provides guidance for SAF emissions reduction in per-passenger and per-shipment calculations.

Recognizing the need for a credible, transparent, and globally interoperable accounting system, the Civil Aviation Decarbonization Organization (CADO), founded by IATA, had recently launched a global SAF registry – a purpose-built infrastructure supporting regulatory and voluntary SAF transactions worldwide[6]. The SAF registry is designed with international compatibility and interoperability in mind. Key features of the SAF registry include:

- **Follows the natural SAF value chain following the GHG Protocol philosophy:** Scope 1 and 3 emissions are properly aligned and are consistently and accurately accounted for throughout the value chain.
- **Involves all SAF stakeholders in the value chain, including all end-users:** Monitor and report SAF usage and emissions reductions effectively through a cohesive and streamlined process.
- **Supports voluntary and regulatory reporting and claiming of SAF:** Compliance with regulatory frameworks such as CORSIA and EU ETS. Ability to integrate future regulations.
- **Enables Mass Balance SAF and Book & Claim Accounting:** Flexible SAF accounting across the supply chain. Emission reduction is credited irrespective of the physical location of SAF.
- **Ensures interoperability and avoids double issuance and claiming of SAF:** Ensures data exchange with other registries, enhancing stakeholder transparency and trust.
- **Neutral governance and transparency:** The SAF registry operates as a non-profit, with a robust governance platform under CADO, ensuring neutrality, transparency, and trustworthiness.
- **Minimized cost for SAF transactions:** The system will be free to all users until April 2027. It will then operate on a cost-recovery basis.

In short, the SAF Registry by CADO provides a credible, centralized, and scalable system to unlock SAF investments and accelerate global SAF deployment and adoption.

The road ahead: Building trust and scale-up

SAF is undoubtedly one of the most promising solutions for decarbonizing the aviation sector, but realizing its potential scale requires more than just increasing its production. It requires transparent, trusted, and harmonized accounting systems and methodologies to accurately account for its environmental benefits while avoiding double counting and reducing any administrative burden associated with its accounting. The global aviation industry has the opportunity and the responsibility to lead and demonstrate the pathways in building a credible, transparent, and scalable market for SAF. Careful coordination and radical collaboration across governments, industry, and standard bodies are needed to enable the aviation industry to create a global and robust accounting framework that instills confidence and preserves integrity in the environmental benefits associated with SAF. The formulation of CADO and the SAF registry is a testament to the industry's determination to address the urgent need for a global and robust SAF accounting framework to facilitate efficient SAF deployment and unlock additional demand to increase SAF productions. ICAO Member States are encouraged to recognize and adopt SAF accounting methodologies and systems for international aviation to enable:

- The claiming of emissions reductions from SAF use toward different regulatory schemes (e.g., CORSIA).
- The tracking of the sustainability attributes and life-cycle emissions linked to the feedstock across geographies, production pathways, transportation, and use of SAF.
- The different stakeholders to claim a SAF purchase against their specific emissions scopes while avoiding double counting and double claiming any given batch of fuel.

6 Announcements of CADO (https://www.iata.org/en/pressroom/2025-releases/2025-03-24-01/) and its SAF registry (https://www.iata.org/en/pressroom/2025-releases/2025-04-03-01/). CADO is incorporated as a not-for-profit organization in Canada, with its headquarters in Montreal. IATA is the founding member of CADO, and its role will include ongoing technical support and operations. CADO governance membership is open to international organizations and companies in the SAF value chain.

Appendix

TABLE 1: Summary of Global SAF Registries and Accounting Systems

System Name	Developer(s)	Market Supported	Development Status	SAF Accounting Methodology Used	Chain of Custody (CoC) considered	Key Features/ Unique Aspects	Key Challenges	Website/ Reference
SAF Registry	Civil Aviation Decarbonization Organization (CADO) – founded by IATA	Regulatory and Voluntary	Active since April 2025	IATA SAF Accounting & Reporting Methodology (aligned with ICAO's CORSIA and GHG Protocol framework)	Physical Segregation, Mass Balance, Book and Claim (based on purchase and blending records)	Cover both regulatory and voluntary requirements Offer minimum cost for SAF transactions and operate on a cost-recovery basis Strong government support and collaboration Interoperability with other SAF registries & accounting systems Designed to align with GHGP requirements	Requires further development for enhanced functionality Requires widespread industry adoption and collaboration despite already having many stakeholder supporters.	Link
123Carbon Platform	123Carbon	Voluntary	Active since September 2022	Accounting based on the issuance of Environmental Attributes Certificates (EACs)	Book and Claim	Focus on market integrity Robust digital security and tracking features	Require further industry adoption	Link
Assure SAF Registry	4Air	Voluntary	Active since May 2023	Blockchain-enabled accounting of SAF transactions based on customers' sustainability obligations and requirements	Physical and Book and Claim transactions	Blockchain-powered (tamper-proof tracking) Decentralized verification by multiple stakeholders	Scalability and blockchain adoption Integration with legacy systems	Link
RSB Book and Claim Registry	Roundtable on Sustainable Biomaterials (RSB)	Voluntary	Active since November 2023	Voluntary Well-to-wake (WtW) accounting methodology with stringent sustainability criteria	Book and Claim	Strict adherence to RSB's robust sustainability framework and ethical standard	Cost per SAF transaction	Link

System Name	Developer(s)	Market Supported	Development Status	SAF Accounting Methodology Used	Chain of Custody (CoC) considered	Key Features/ Unique Aspects	Key Challenges	Website/ Reference
ISCC SAF Credit Transfer System	International Sustainability & Carbon Certification (ISCC)	Voluntary	Active since April 2024	Voluntary Well-to-wake (WtW) accounting methodology	Mass balance	"Plug-and-play" system that complements existing supply chain certification systems Designed closely aligned with requirements set by the Science Based Targets initiative (SBTi) and GHGP.	Requires valid ISCC trader certification	Link
SAFc Registry	Rocky Mountain Institute (RMI), Sustainable Aviation Buyers Alliance (SABA), and Environmental Defense Fund (EDF) and is operated by Energy Web.	Voluntary	Active since December 2023	Voluntary Well-to-wake (WtW) accounting methodology	Book and claim	Align with the Roundtable on Sustainable Biomaterials (RSB) Book & Claim Manual and Registry Recognition Framework requirements. Will seek other standard recognition, including ISCC and ISO	Integration with legacy systems	Link
Avelia	Shell, Accenture, American Express Global Business Travel (AMEC GBT)	Voluntary	Active since June 2022	Voluntary Well-to-wake (WtW) accounting methodology	Book and claim	Blockchain enabled Designed to help transact Shell SAF volumes	Integration with legacy systems Limited to SAF volume from Shell	Link
Union Database (UDB)	EU Commission, DG Energy, and EU ETS administrators	Regulatory	Active since January 2024	EU Renewable Energy Directive (EU RED) and EU Emissions Trading System (EU ETS)	Physical segregation and mass balance	Track SAF production in the EU under the EU RED scheme	Interoperability with other registries, including the national SAF registry	Link
ICAO CORSIA Central Registry (CCR)	International Civil Aviation Organization (ICAO)	Regulatory	Active since June 2022	ICAO accounting methodology for CORSIA-eligible fuels (CEFs)	Physical Segregation, Mass Balance, (claims based on purchase and blending records)	Used to track information submitted by individual states to ICAO to track CORSIA-related information, including CORSIA-eligible fuels	Interoperability with other registries	Link

System Name	Developer(s)	Market Supported	Development Status	SAF Accounting Methodology Used	Chain of Custody (CoC) considered	Key Features/ Unique Aspects	Key Challenges	Website/ Reference
Examples of national registry systems extended to track SAF production as well								
German Nabisy System	German Federal Ministry of Economics and Energy (BMWi)	Regulatory	Active since 2020	EU Renewable Energy Directive (EU RED) and EU Emissions Trading System (EU ETS)	Physical segregation and mass balance	Used to track SAF production and/or use in Germany	Interoperability and integration with other registries, in particular, the Union Database (UDB)	Link
French CarbuRe – The biofuel management platform	French Ministry of Ecological Transition and Solidarity	Regulatory	Active since 2022	EU Renewable Energy Directive (EU RED) and EU Emissions Trading System (EU ETS)	Physical segregation and mass balance	Used to track SAF production and/or use in France Started during French SAF mandate implementation, now ReFuelEU Aviation	Interoperability and integration with other registries, in particular, e.g., UDB	Link

Bridging the Sustainable Aviation Fuel (SAF) Premium

Navigating Registries, Incentive Stacking, and Scope 1 & 3 Sales

By Isabel Galiana (Future Energy Global)

Introduction

Sustainable Aviation Fuel (SAF) is aviation's strongest near-term lever for cutting greenhouse-gas (GHG) emissions, yet it still supplies well under one per cent of global jet-fuel demand. Cost is the binding constraint: commercially available SAF is priced at two to five times the price conventional Jet A-1, which is saddling airlines with a premium of roughly 800 to 2400$ per metric tonne. Because sector profit margins seldom exceed 10 per cent, few carriers can absorb or pass through that spread.

In the near term, the gap is less about technology than about market architecture: fragmented policy, uneven certification rules, and immature attribute markets keep capital sidelined and scale elusive. Bridging it demands (i) airtight registries, (ii) durable incentives, (iii) transparent Scope 1 and Scope 3 markets, and (iv) trusted intermediaries capable of turning a thicket of regional rules into bankable, cross-border contracts. The sections below map each of these threads and outline practical priorities for regulators, producers, airlines, investors, and large corporate flyers.

Integrity First: Registries and Certification

Market confidence starts with irrefutable tracking. Credible carbon accounting is the hinge on which the SAF market turns. Every SAF tonne must carry a verifiable, single-use claim so that the environmental benefit cannot be double-counted or overstated. To date, ISCC, the Roundtable on Sustainable Biomaterials (RSB) and ClassNK have anchored eligibility under ICAO's CORSIA framework, tracing feedstocks from origin to wing and assigning each batch a lifecycle-carbon-intensity (CI) score that becomes its passport to incentives and emissions reporting. On related initiatives, IATA's Digital SAF Registry, now in pilot phase, will knit airline purchasing systems directly into this chain of custody, while the emerging Assure™ registry aims to offer a neutral, blockchain-backed ledger capable of reconciling transactions across multiple certification schemes.

The rules inside these systems are not interchangeable. ISCC prohibits any resale of Scope 3 attributes once a State incentive—such as a mandate—has been claimed; RSB allows limited resale only when strict additionality tests are met; IATA and Assure have provisions that could permit capped transfers provided both seller and buyer disclose them in public retirement logs. Even seemingly small differences—how a pathway's CI is calculated, whether co-processing is allowed, which auditor must sign off—can determine whether a batch is eligible for a tax credit, a CORSIA Scope 1 claim, or a corporate Scope 3 reduction.

For airlines, producers, and corporate buyers, a deep working knowledge of these registries and regulations is therefore indispensable. Without it, an ostensibly attractive transaction can collapse at audit time, leaving revenue on the table or, worse, exposing parties to compliance breach. Mastery of registry nuance—understanding exactly when and how Scope 1 and Scope 3 claims can be registered, retired, or transferred—is what turns a promising SAF supply agreement into a bankable, reputation-proof deal.

The Global Incentive Patchwork

Public support for SAF varies sharply by region, creating a mosaic of mandates and fiscal levers that developers must navigate.

- ICAO's CORSIA scheme, moving into its mandatory 2nd Phase in 2027, lets airlines meet offset obligations by substituting certified SAF, but the list of eligible fuels and methodologies is being updated every year to encompass new technologies and feedstocks, adding planning complexity.
- In Europe, the ReFuelEU regulation provides demand certainty through a steadily rising blending mandate—2 percent in 2025, 6 percent by 2030—yet offers no direct subsidy, forcing carriers and suppliers to finance the premium while racing to expand airport infrastructure.
- The United States couples renewable-fuel identification numbers (RINs) with a dedicated SAF tax credit. Although generous, the dollar value of these incentives can swing with federal politics, raising the cost of capital for producers.
- Across Asia, countries such as Japan, Singapore and South Korea are locking in mandates and capital-expenditure grants between 2025 and 2027, but domestic supply chains and certification capacity are still coalescing. This patchwork means that a project's viability often hinges less on technology than on its ability to layer incentives from multiple jurisdictions while hedging against policy drift.

Incentive Stacking and Environmental-Attribute Markets

Because no single instrument erases the premium, successful projects layer multiple revenue streams. Production credits or grants move the supply curve; airlines keep the Scope 1 compliance value; and, where certification rules allow, corporate flyers finance Scope 3 certificates. Fuel chemistry complicates the picture: HEFA, alcohol-to-jet, and Fischer–Tropsch pathways each sit at different CI baselines and thus capture different incentive levels. Developers must therefore synchronise feedstock, refinery technology, and policy stacks from the start—no trivial task when CI scoring diverges from California to Singapore.

Book-and-Claim: A Global Demand Engine

SAF blending remains concentrated at a handful of hubs, leaving many routes physically out of reach. Regional carries servicing isolated regions or island states already facing high costs could be pushed out by SAF mandates and penalties. Book-and-Claim (B&C) resolves the mismatch by separating environmental attributes from molecules. A tonne of certified SAF is produced and uplifted where infrastructure exists; the physical fuel is separated from a digital certificate for its verified GHG reduction; an airline and/or corporate customer anywhere retires that certificate against its own inventory. Producers see wider demand, airlines avoid transport-emission penalties, and corporate budgets can contribute to financing SAF for their corporate travel.

Three safeguards will be needed for B&C to succeed. First, common data fields across registries (ISCC, RSB, IATA, Assure and others). Second, public retirement logs that prevent double claiming. And lastly, updated GHG-Protocol guidance so corporates can book Scope 3 reductions with confidence. With these in place, corporate-travel budgets—often larger than airline net profits—can shoulder a meaningful share of the premium.

The Role of Ecosystem Facilitators and Brokers

Every SAF deal is bespoke. Airlines differ in fleet mix, route geography, and reporting obligations; corporates vary in accounting rules and reputational aims; producers juggle feedstock logistics, certification timelines, and capital constraints. An independent, neutral intermediary translates this complexity into executable contracts.

A skilled facilitator aggregates demand across carriers, matches it with output from multiple refineries, and structures offtake agreements that respect varying CI scores, delivery points, and registry requirements. Take a European carrier seeking alcohol-to-jet under RSB when an Asian refinery offers HEFA under ISCC: the broker reconciles documentation, so the environmental claims hold. Facilitators also track shifting tax-credit guidance, confirm ongoing Scope 3 eligibility, and manage delivery-point CI adjustments that change payout schedules. By turning a labyrinth of rules into clear risk-adjusted pathways, they accelerate growth without compromising rigour.

Conclusion

SAF's evolution from niche to mainstream rests on more than advanced chemistry. It requires a durable framework that safeguards integrity, aligns incentives, and disperses cost across the entire travel ecosystem. Trusted registries—now strengthened by increased use of ISCC, RSB and IATA's incoming ledger—anchor credibility. Well-designed incentive stacks provide the economic bridge, and Book-and-Claim unlocks access to Scope 1 in underserviced regions and global Scope 3 demand. Yet few airlines or fuel producer scan navigate, unaided, the swirling mix of regional mandates, fiscal incentives, registry rules, and pathway-specific CI calculations. Independent facilitators step into that breach, converting complexity into coherent, cross-border contracts. When these elements fit together, the daunting premium that keeps SAF out of most wings begins to shrink—a transformation that can turn today's costly ambition into an attainable reality within this decisive decade.

Impact of Hydrogen in Aviation

By Tina Jurkat-Witschas, Christiane Voigt, Simon Unterstraßer, Ulrike Burkhardt and Markus Rapp (DLR)

Introduction

Aviation accounts for about 4% of the total anthropogenic effective radiative forcing (ERF), resulting from aircraft operations since the 1940s. Thereby more than half of the aviation induced ERF is very likely caused by non-CO_2 effects, such as contrails and NO_x emissions. One measure to potentially reduce both CO_2 and non-CO_2 effects from aviation is the use of green hydrogen. Different applications of hydrogen such as direct burn or the use of hydrogen in fuel cells for electric propulsion are developed by the aviation industry, with the promise to decarbonize aviation. Still, the impact of the non-CO_2 effects on climate from these propulsion systems is unquantified as direct measurements were missing until recently and model capabilities need to be enhanced. DLR in collaboration with industry and academic partners investigates the effects of hydrogen on the formation of contrails and NO_x emissions and their effect on climate in internally and industry funded projects as well as using funding by German and European funding sources. These research activities are flanked by emission and contrail measurements from new lean burn technologies which provide a reference of current technologies for the low-soot regime. As the industry is transitioning to the use of hydrogen, projects on the impact of hydrogen leakages and their effect on climate forcing agents have also been launched.

Past Achievements

The goals of the Paris Agreement are not achievable without major changes in the Aviation system, such as a shift to hydrogen, extensive use of SAF and a combination of technological and operational measures. Past studies have focused on specific aircraft concepts (e.g. the multifuel blended wingbody) and simplified models to assess the climate impact of contrails and NO_x emissions from the use of hydrogen in aviation. Past work of DLR and partners has shed light on the impacts of SAF on non-CO_2 effects combining measurements, process modelling and global climate models. This unique understanding is the basis on which the capabilities for current assessments of hydrogen combustion and fuel cell technologies on non-CO_2 effects are built upon. A suite of world-wide unique airborne in-situ measurements together with process and climate modelling provide the means to improve our understanding of contrails and contrail cirrus from current and new technologies and enable the evaluation of mitigation options.

Scientific background

The emissions of hydrogen combustion are comprised of NO_x and water vapor and for fuel cells of water vapor and possibly water in liquid form. Water vapor emissions from aircraft mostly contribute through the formation of contrails to the aviation climate impact. Water vapor emissions of high flying super- and hypersonic aircraft however are a large contributor to their respective climate impact. Depending on the flight altitude of hydrogen propelled aircraft, the effect of water emissions on climate could be enhanced.

Due to the fundamentally different formation process of contrails from hydrogen combustion and fuel cells may differ substantially to contrails from conventional fuels. While ice crystals in conventional contrails form on emitted soot or volatile particulates, it is unclear whether hydrogen combustion or fuel cell exhausts contain initially any particles. One possible scenario is that ice crystal formation occurs predominantly on ambient aerosols entrained into the humid plume. These aerosols may be the nuclei for

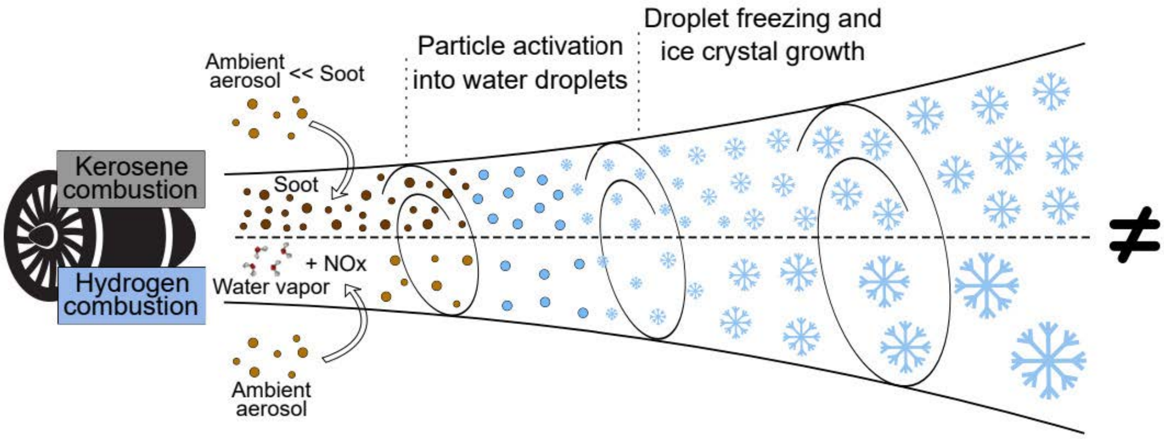


FIGURE 1: Conceptual picture of the formation pathway of contrails from hydrogen combustion in contrast to conventional kerosene-based contrails. Contrails from hydrogen combustion offer the possibility to have larger and less particles which reduce the lifetime of the contrail (Diss De la Torre Castro).

contrail ice particles. The resulting reduction in initial ice crystal number decreases the lifetime of contrail-cirrus and on global scale their radiative forcing. Furthermore, the higher emission index of water vapor shifts the contrail formation altitude to higher temperatures. Projects at DLR aim at measuring and modelling the formation pathways of contrails from hydrogen combustion and fuel cells as well as lean burn and supersonic aircraft (Figure 1).

Benefits of the project

DLR has substantially enhanced the modelling and measurement capabilities of contrails from hydrogen propulsion.

New and smaller instruments operating autonomously were installed on different airborne platforms for the detection of aerosol particles, trace gases and ice crystals from hydrogen combustion and fuel cells. Particularly, in the Blue Condor project, Airbus and DLR partnered to provide first measurements of contrails from a small hydrogen combustion engine installed on a glider operated at contrail formation altitude. Supporting box models were developed and provided a theoretical framework, showing that the initial ice number could be reduced by 80 to 90% in the absence of contaminations like lubrication oil. Oil entering through leakages into the hot exhaust may form small oil droplets. Box model simulations suggest that oil particles could be the dominant nuclei when soot particle numbers are low (low-soot regime) or zero (e.g., for hydrogen combustion). The design of the fuel cell system allows to modify the heat and water vapor emission. These additional degrees of freedom can affect the initial contrail formation process and ultimately also the contrail climate impact. First experiments of ice crystal measurements from a bulk liquid water release system show a large reduction of the initial ice crystal number compared to conventional contrails. Final conclusions on the contrail composition can only be drawn with measurements of representative exhaust conditions. Large eddy simulations for different atmospheric conditions were performed to understand H_2 contrail formation for a large parameter space. Based on this data set, parametrizations of early contrail properties are developed and integrated into a global climate model that computes the radiative response to the contrail cirrus properties. Based on climate model simulations, surrogate models like AirClim will assess the combined impact of non-CO_2 effects on surface temperature. On a fleet level, these assessments will be compared to corresponding simulations for current and future technologies with conventional and sustainable low-aromatic aviation fuels.

With the combination of measurements and model chains, DLR is targeting a holistic, evidence-based climate impact assessment of hydrogen propulsion aircraft (Figure 2). This work supports legislative aviation authorities and industrial stakeholders for investment decisions into a climate neutral aviation sector.

FIGURE 2: (upper panel) Picture of the Blue Condor glider equipped with a hydrogen engine (front) and a kerosene engine (back) both forming contrails of different optical thickness (Rogero et al., 2024; https://www.dlr.de/en/latest/news/2025/world-first-in-flight-measurements-of-contrails-from-hydrogen-propulsion). (lower panel) Picture taken from the instrumented chase aircraft Egrett during contrail and emission measurement of a turbo prop aircraft equipped with a water release system simulating fuel cell emissions (Neumann et al., 2025).

Future Directions

In the future, DLR will be focusing on three areas to improve our understanding of emissions and contrails:

1. Emissions and formation pathways of contrails and clouds from hydrogen propulsion but also from RQL and lean burn technologies, in particular the impact of lubrication oil and ions on contrail formation.
2. Quantification of emissions and contrail properties through airborne and ground-based measurements.
3. Modelling of local and global contrail radiative effects for different technologies and different fuel types in the low-soot regime.

DLR is actively involved in or leads different projects to address these challenges. Specifically, DLR is coordinator of the Horizon Europe project A4CLIMATE with 18 partners to investigate the effect of contrail formation in the low-soot regime. DLR also leads campaigns investigating aircraft effects on high and low clouds. While not representative for hydrogen propulsion emissions, these investigations will still enhance our understanding on the effects of sulfur and soot emissions from current aircraft on clouds, to reduce their climate impact uncertainty.

DLR is active in a national funded project where contrail formation and properties of hydrogen propulsion systems are emulated in a German high-altitude test facility. This will enable contrail measurements in a controlled environment, with a large flexibility on emission parameters and thermodynamical properties and allows to better validate contrail formation models. Further, DLR and partners investigate the effect of particulate emissions like oil and ions on contrail formation in engine test rig environments. Airborne flight test programs will focus on emission measurements with enhanced capabilities in ion measurements as well as ultra-fine particles. Furthermore, long term goals are the miniaturization of instruments for installation on different chase aircraft to measure emissions and contrails from demonstrators in flight. On the modelling side, the application of machine learning methods will be expanded.

Conclusion

Hydrogen propelled aircraft offer the possibility to decarbonize aviation. First important steps to constrain estimates of the non-CO_2 effects of these technologies, in particular the formation of contrails, have been made. Since the use of hydrogen will require large aircraft modifications, the impact on the environment has to be integrated into the engine and aircraft design to avoid counteracting contrail effects to the gain from mitigated CO_2 emissions. The impacts of hydrogen propulsion on climate are currently explored within DLR in order to advise aircraft and engine manufacturers on mitigation strategies. This advice is given on a science-based framework combining measurements with high-resolution and global modelling. Next to global simulations on the contrail climate impact exploring a wide parameter space of fuel cell and hydrogen combustion exhaust conditions, future work will focus on emission and contrail measurements to assess their actual climate impact.

vSimilarly, current technologies like lean burn engines offer a massive soot reduction but depend on the additional reduction of volatile particle emissions to substantially reduce contrail ice particle number and the respective climate impact (Figure 3). Further strategic and systematic fundamental research in collaboration of academia and industry is required to pave the way for future competitive climate compatible aviation.

FIGURE 3: Foto taken from the cockpit of the DLR research aircraft Falcon chasing an Airbus A320neo in 50 m distance to probe the emissions from its CFM LEAP-1A engines during the NEOFUELS/VOLCAN project coordinated by Airbus and DLR (Voigt et al., 2025 submitted; https://www.dlr.de/de/medien/videos/2023/video-projekt-volcan)

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Aviation Impact Accelerator (AIA)

By Professor Rob Miller (University of Cambridge)

2030 Sustainable Aviation Goals: Five Years to Chart a New Future for Aviation

Introduction

The aviation sector stands at a pivotal crossroads. It holds the potential to drive systemic, transformative change — or risk falling irreversibly behind in the race to achieve net-zero emissions. Building on insights from the **Aviation Impact Accelerator's model**, our latest report, *2030 Sustainable Aviation Goals*, identifies the most critical leverage points within the aviation ecosystem. These leverage points can trigger decisive interventions leading to powerful, sector-wide shifts. The four Sustainable Aviation Goals outlined in this report are specifically designed to focus efforts on these key areas, significantly raising ambition and laying a robust foundation for achieving net-zero aviation by 2050.

It is also vital to challenge a dangerous misconception embedded in many existing net-zero aviation pathways: the idea that transition will be smooth, with multiple technologies coexisting beyond 2050. History shows that technological transitions are rarely smooth; competing technologies typically vie for dominance until one prevails and displaces the others. This misperception of a smooth transition is harmful, as it creates the illusion that delaying action will result in only a minor increase in emissions by 2050. The findings of this report, supported by the Aviation Impact Accelerator (AIA) model, clearly demonstrate that this assumption is flawed. Transformative change will close — with profound implications for the sector and the climate alike. The next five years are not just an opportunity; they are a necessity.

The five-year plan involves immediately implementing four Sustainable Aviation Goals which provide a plan for delivering net zero aviation by 2050. These goals originated during the inaugural meeting of the Transatlantic Sustainable Aviation Partnership, held at MIT in April 2023 with representatives from the UK, US, and EU governments. The report was launched at New York Climate Week 2024 in partnership with King Charles III's Sustainable Markets Initiative.

The figure below shows the current trajectory of the aviation sector, alongside the projected scenarios for achieving net zero aviation by 2050 through implementing the 2030 goals outlined in the AIA's report. The shaded regions show the uncertainty of the various scenarios. The first thing to take away is that the current trajectory is highly uncertain, where in the worst case aviation is doing more climate damage than if we did nothing. The second thing to take away is that there is a wide range of possible pathways to net zero by 2050, two being shown here, but that these all require strong action over the next five years.

2030 Goal 1: Operation Blue Skies

In 2025, governments and industry should create several Airspace-Scale Living Labs to enable, by 2030, the start of deployment of a global contrail avoidance system. These labs must have the capability to test, learn, and pivot approaches while operating within a realistic airspace environment.

Aviation's climate impact extends beyond CO_2 emissions to include nitrogen oxides, stratospheric water vapour, particulate matter, and particularly, the formation of persistent contrails. Among these, contrails have the most significant warming effect, generally comparable

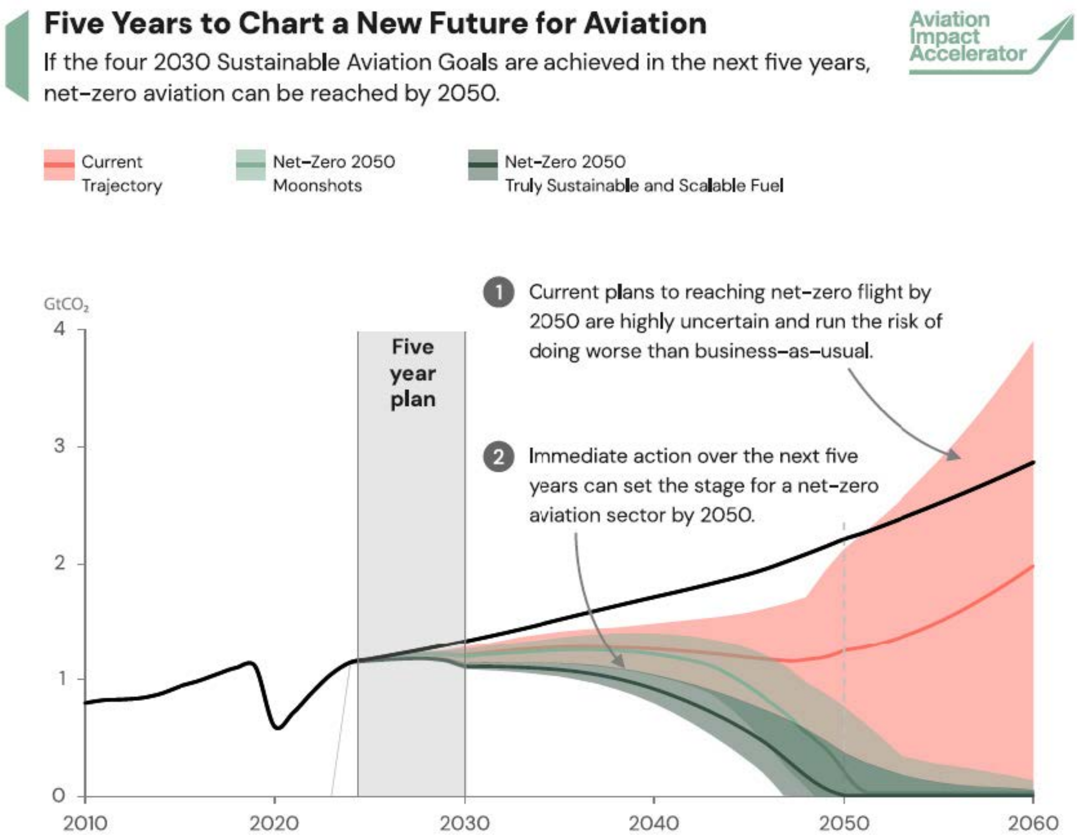
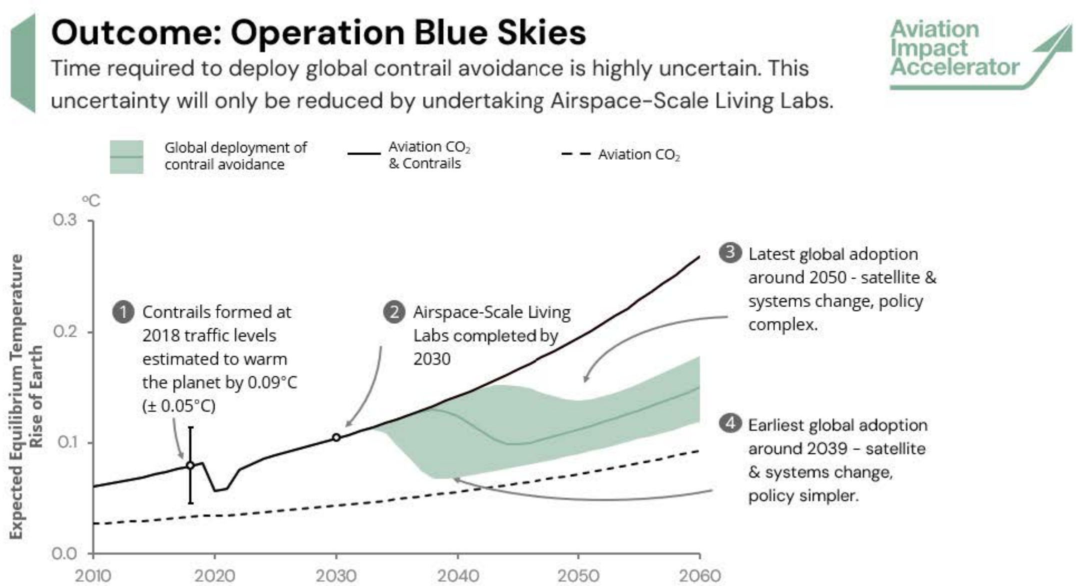


FIGURE 1



Assumptions: Equilibrium climate sensitivity of 0.80°C/(W/m²) (c.f. 0.86°C/Wm², IPPC AR6). 2018 contrail ERF 57.4 mW/m² ±70% (Lee *et. al.* 2021), scaled with demand; AIA model for km demand growth (~3.8% p.a.) & efficiency gain (accounts for next generation aircraft). Permission to deviate aircraft for targeting avoidance of all persistent contrails scales from 0% to 85% (barriers, Teoh et al. (2020)) and 95% (no barriers) after scale-up; success rate: 60% (barriers), 90% (no barriers)

FIGURE 2

in magnitude to CO_2 emissions, though with far greater uncertainty. The climate impact of persistent contrails is due to their warming impact as they spread into cirrus-like clouds trap in heat.

The climate impact of global aviation in 2050 is shown in Figure 2. This shows that the projected climate impact of global aviation CO_2 in 2050 is approximately 0.07°C, while the warming from the formation of contrail cirrus clouds could add between 0.035°C and 0.2°C. When the impact from contrails is acknowledged, total climate impacts from aviation are significantly higher than the impacts from CO_2 alone, as Figure 2 illustrates.

Persistent contrails can be avoided by adjusting an aircraft's altitude in regions where contrails form, known as Ice Supersaturated Regions (ISSRs). These regions are pancake-shaped—wide but shallow—making altitude changes effective in preventing contrail formation. However, predicting the location of ISSRs is uncertain, and altitude changes can increase fuel consumption by a few percent.

The main challenge in implementing an effective contrail avoidance system lies in the numerous uncertainties, from the underlying science to the variety of potential implementation methods. The ideal way to address these uncertainties is through a learn-by-doing approach in a realistic, field-based environment. To facilitate this, several Airspace-Scale Living Labs must be established by the end of 2025. These Labs must be designed for iteration—capable of testing, learning, and pivoting as experience is gained. If successful, the outcome of a global contrail avoidance system, launched in 2030 is shown as the green region in Figure 2.

In developing these Labs, it is crucial to draw on experiences from fields where public confidence is paramount, such as medical trials and epidemiology. Each Lab should be designed to represent the real nature of the challenge in a particular region of the world i.e., to capture the full range of weather and flight traffic conditions that are likely to be encountered. The Labs should also be conducted at a scale that accurately replicates real-world complexities while ensuring statistical quality and following a transparent review process.

The objective of the Labs is to develop the experience and strategic planning necessary to start the deployment of a global contrail avoidance system by 2030.

Goal 2: Systems Efficiency

In 2025, leading governments should set out a clear commitment to the market about their intention to drive systems-wide efficiency improvements. In tandem, governments and industry should work together to develop strategies so that, by 2030, a new wave of policies can be implemented to unlock these systemic efficiency gains.

Reducing fuel burn in aviation can be achieved through conventional measures such as new aircraft and engine technologies and improved operational efficiency. These conventional measures, shown in red in Figure 3, can lead to up to a 22% reduction in fuel burn by 2050.

However, several bold efficiency measures exist which are currently hard to access because they involve systems-wide change. These measures are shown in green in Figure 3. If implemented, these measures could reduce fuel burn by up to 50% by 2050. Figure 3 shows both the fuel burn reductions which could be achieved by both conventional and bold measures, broken down into the various actions.

The three types of bold measures include:

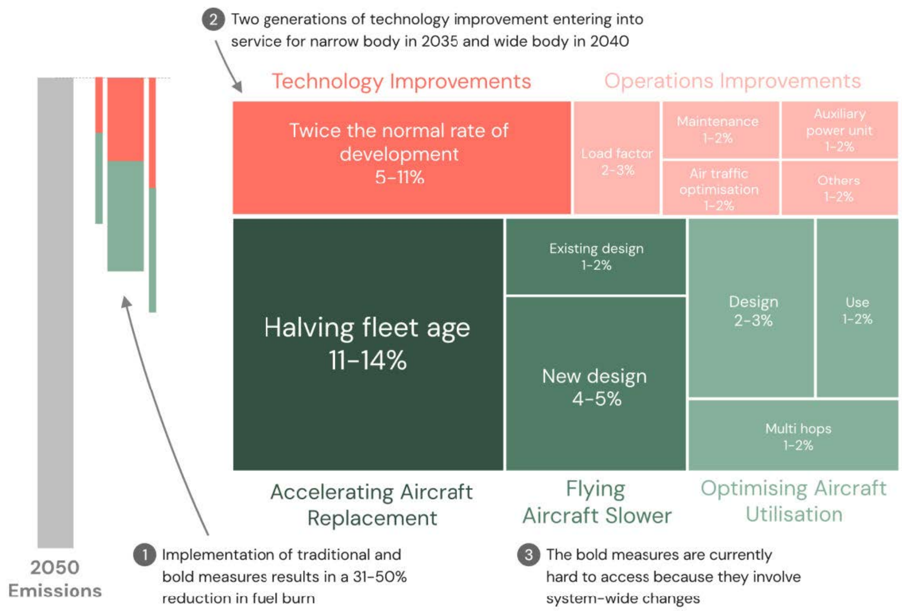
1. **Accelerated Replacement**: Increasing aircraft production to halve the fleet age.
2. **Fly Slower**: Reducing flight speed by around 15%, increasing transatlantic flight times by about 50 minutes.
3. **Match Range**: Ensuring more aircraft operate close to their design range by introducing new aircraft types and optimising purchasing and operating practices.

These bold measures are often overlooked and said to be too difficult because they are not under the control of individual organisations and require sector-wide reforms. However, all net zero pathways for aviation are hard and it is important that governments understand what policies are required to drive these systemic changes and what market signals are required.

Examples from other sectors show what's possible: the US Corporate Average Fuel Economy (CAFE) standards cut automotive fuel burn by 25% since 1975, with similar initiatives in the EU, Japan, and China. Aviation could

How can Fuel Burn be Halved by 2050?

Bold strategies like accelerating aircraft replacement, flying aircraft slower, and optimising aircraft utilisation can significantly reduce fuel burn.

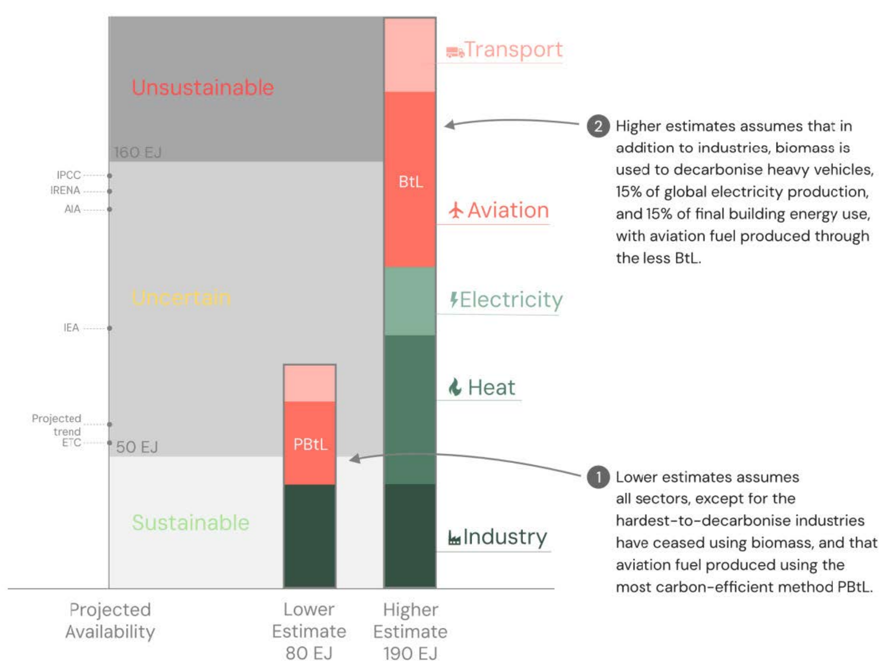


Assumptions: Other operations include decreasing aircraft weight (e.g. lighter seats) and use of automated operations and fuel management systems at airports (source: ICAO (2022)). Analysis on fleet age is based on global fleet data (Oliver Wyman 2020). Analysis on flight speed is based on work conducted at MIT (Yutko (2014), Lovegren (2011)). Analysis on range is based on data reported by ICCT (2020).

FIGURE 3

How much Biomass do all Sectors Require?

The total global biomass required to decarbonise all sectors, including aviation, by 2050 is estimated to be between 80 EJ and 190 EJ.



Assumptions: Biomass projections sourced from: ETC (2021). IEA (2023). IRENA (2022). IPCC (2011). The biomass allocation to transport (shipping, heavy & off-road vehicles) is the co-products of SAF production. Biomass projections exceeding ~160 EJ require significant land use changes, which are assumed to be unsustainable without other major shifts e.g. food production. AIA model used for 2050 biomass requirements for SAF & co-products. Lower estimate based on ETC (2021), higher estimate based on IRENA (2022) (non-transport effects).

FIGURE 4

follow suit by introducing Green Mandates for annual fuel reductions, offering loan guarantees for efficient aircraft purchases, reforming taxation to accelerate fleet turnover, and incentivising aircraft scrappage.

Goal 3: Truly Sustainable and Scalable Fuel

In 2025, governments should reform Sustainable Aviation Fuel (SAF) policy development to adopt a cross-sector approach, enabling rapid scalability within global biomass limitations. By 2030, governments and industry should implement a demonstration and deployment strategy that enables SAF production to move beyond purely biomass-based methods, incorporating more carbon-efficient synthetic production techniques.

Globally, progress is being made in deploying Sustainable Aviation Fuels (SAFs). One key resource for the production of such fuels is biomass – which provides the carbon critical for the development of the fuel. However multiple sectors draw on and are planning to draw on this resource, and producing it has implications for land use which is already highly pressured. There are real limitations to the scale of biomass that can be safely deployed across the economy and constraints on the sources.

Figure 4 shows two cross sector scenarios for future global biomass demand. In a lower-demand scenario, only the hardest-to-decarbonise industries continue using biomass, and aviation fuel is produced using the most efficient method. In a higher-demand scenario, biomass is also used to decarbonise heavy vehicles, parts of electricity generation, and building energy use, with aviation fuel made less efficiently. Even this higher estimate assumes an ambitious shift away from biomass in other sectors. The key takeaway is that by 2050, global biomass demand will vary significantly depending on how aggressively other sectors transition to alternative solutions and how aviation competes for limited biomass resources.

Current SAF policies focus narrowly on reducing aviation's life cycle emissions, overlooking the broader impact of biomass demand on other sectors. Without reform, SAF production could drive up emissions elsewhere, undermining both its environmental benefits and long-term scalability. To avoid this, aviation must adopt a cross-sector perspective that prioritizes minimizing total emissions across the economy. This shift offers aviation a chance to lead globally by promoting coordinated, sustainable biomass use. Governments must urgently reform SAF policies to enable cross-sector planning, giving industry the certainty to invest. By 2030, they should advance SAF production beyond biomass-based methods, incorporating more carbon-efficient synthetic techniques, and ensure aviation develops its own low-carbon electricity and green hydrogen supplies without diverting resources from other sectors.

Goal 4: Moonshots

In 2025, launch several high-reward experimental demonstration programmes to enable the focus on, and scale-up of, the most viable transformative technologies by 2030. These programmes must generate the necessary experience to assess the technology's scalability and develop the expertise required for deployment.

The primary pathway to decarbonising aviation currently focuses on producing Sustainable Aviation Fuels (SAF). However, the substantial resource requirements and complexity of fuel production present significant challenges and risks in realising this approach.

Relying solely on SAF could be avoided through the adoption of transformative technologies. In the automotive sector, for example, the shift to battery electric vehicles reduced both the planned and potential dependence on biofuels. Similar transformative technologies for aviation could include cryogenic hydrogen or methane fuels, hydrogen-electric propulsion, or synthetic biology to dramatically lower the energy demands of fuel production. Each of these technologies offers the potential to reduce aviation's resource requirements and simplify fuel production compared to SAFs. By investing now in frontier technologies, governments have a once-in-a-generation opportunity to lead in transforming aviation, much like electric vehicles have reshaped the automotive industry.

However, for such an effort to achieve significant climate benefits by 2050, demonstration programmes must be launched immediately. These programmes should be

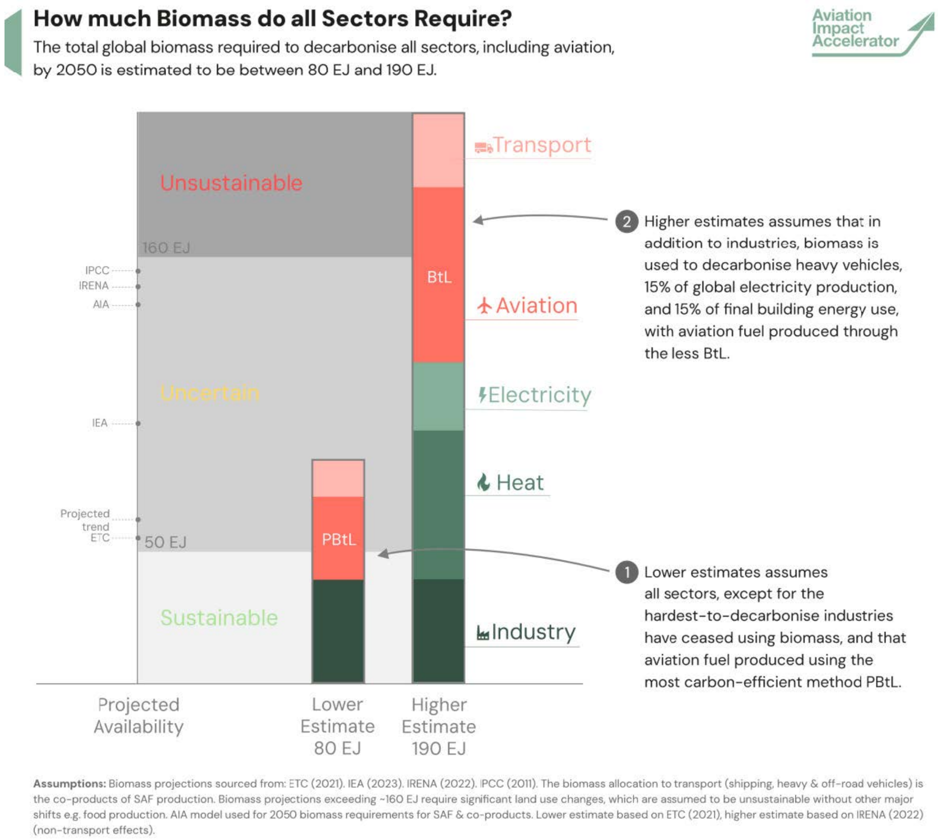


FIGURE 5

designed to give real insight into the viability of new technologies by 2030, allowing the focus on and scale-up of the most viable transformative technologies shortly after. They must generate the experience needed to assess the scalability of these technologies and develop the expertise required for their deployment.

The relative cost of the Moonshot demonstration programs is relatively small, however the cost of implementing them, if successful is not, because they require a significant change to the aviation sector. The cost of the transition to liquid hydrogen fuel on the average ticket cost is shown in Figure 5. The key take-away is that the ticket cost of hydrogen in 2050 is comparable to introducing biofuel but is more affordable than fuels like Power-and-Biomass-to-Liquid.

Conclusion

If the ambitious five-year plan outlined in this article and detailed further in the *2030 Sustainable Aviation Goals* report, is implemented, the aviation sector could be set on a credible path to net zero by 2050. Each of the four Goals targets a critical leverage point for system-wide change. Failure to implement and achieve them by 2030 would close the window for meaningful transformation, leaving the world to confront the escalating climate consequences of an aviation industry projected to at least double in size by 2050. The urgency of this moment cannot be overstated.

ICAO

CHAPTER SIX

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

Introduction to CORSIA

By ICAO Secretariat

Introduction

In 2016, at the 39th Session of the ICAO Assembly, Member States reached a historic milestone by adopting the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the first global market-based measure for any industry sector. CORSIA was designed to complement the three pillars of the basket of in-sector measures (aircraft technologies, operational improvements, and sustainable fuels) in supporting the medium-term global aspirational goal of carbon neutral growth from 2020 (CNG2020). The importance and commitment to the scheme has been reiterated at ICAO's 40th and 41st Assemblies in 2019 and 2022 respectively.

CORSIA works by requiring aeroplane operators to offset a portion of their CO_2 emissions from international flights, above a defined baseline. Operators report verified data to their States of attribution through a robust monitoring, reporting and verification (MRV) system, with States in turn submitting aggregated data to ICAO to determine annual growth factors. Based on these, operators are assigned offsetting requirements which are then fulfilled either through the purchase and cancellation of eligible emissions units from approved programmes, or through the reduction of offsetting requirements by claiming the life-cycle benefits of eligible aviation fuels. The route-based coverage approach ensures that all flights in a given international route are treated equally irrespective of the State of attribution of the aeroplane operators performing the flights. Exemptions apply for small operators, certain types of flights (humanitarian, medical and firefighting operations), and specific aeroplane types.

Significant work has been put into developing the framework to implement CORSIA. In line with the mandate given by the ICAO Assembly, the ICAO Council, with the technical contribution of the Council's Committee on Aviation Environmental Protection (CAEP), developed and updated the Standards and Recommended Practices (SARPs) for CORSIA implementation, reflected in Volume IV of Annex 16 (*Environmental Protection*) to the Convention

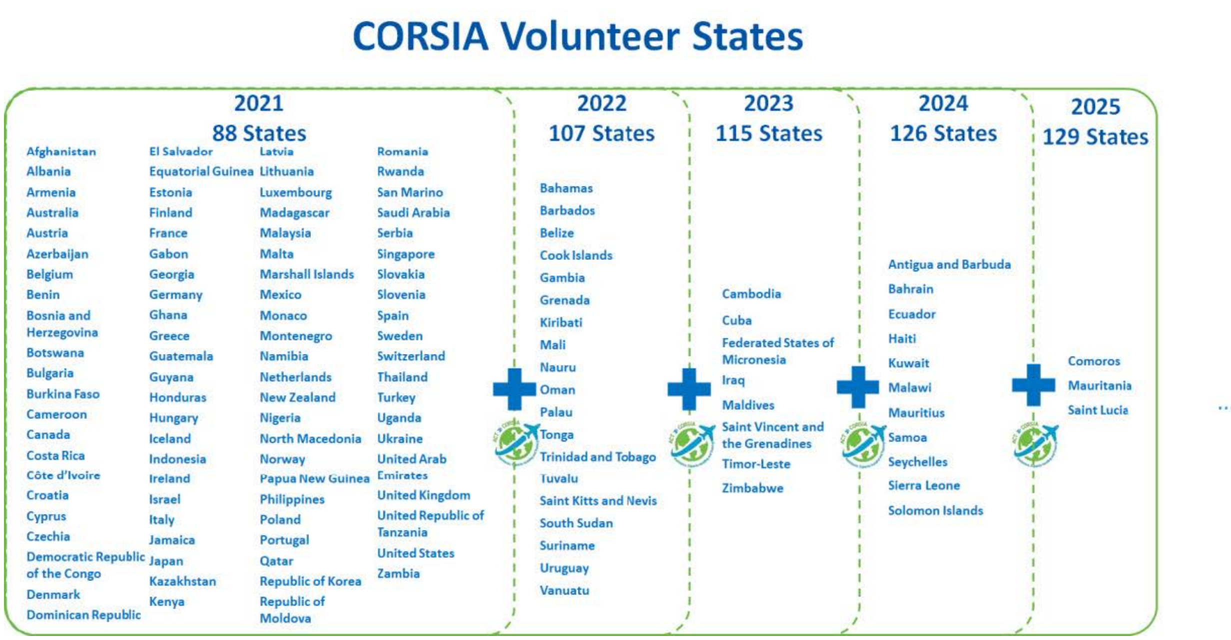


FIGURE 1: Evolution of States voluntarily participating in CORSIA

on International Civil Aviation. To support stakeholders in the implementation of the CORSIA SARPs, technical guidance was developed and updated by CAEP and published in the form of Volume IV of the *Environmental Technical Manual* (Doc 9501).

States have demonstrated strong and increasing commitment to CORSIA. Throughout CORSIA's pilot phase (2021 – 2023) and first phase (2024 – 2026), voluntary participation to determine the routes subject to offsetting requirements has steadily grown from 88 States in 2021 to 129 States in 2025. These States represent a significant share of international aviation activity, ensuring the integrity and global applicability of the scheme.

Implementation Progress

CORSIA's implementation has been built upon a robust monitoring, reporting and verification (MRV) system, which has proven both adaptable and inclusive. Since the beginning of the implementation of CORSIA's MRV system in 2019, States and aeroplane operators have consistently met CORSIA's requirements, with emissions data reported through the CORSIA Central Registry (CCR) now covering 99% of international 2023 CO_2 emissions, with 121 States having reported data; more information on the role of the CCR in CORSIA implementation can be found in the CCR article in this chapter.

The ICAO Council, supported by CAEP, continues to oversee critical improvements to the CORSIA regulatory framework; key recent milestones include the adoption of the Second Edition of Annex 16, Volume IV[1], applicable from 1 January 2024, and the Third Edition of the *Environmental Technical Manual* (Doc 9501), Volume IV[2], containing technical guidance updated in line with the update to the CORSIA SARPs.

Notably, it is expected that the sector's growth factor for year 2024 will have a value above zero; this will imply the generation of offsetting requirements for the first time since CORSIA's inception, marking a new operational chapter for the scheme.

There have also been important developments on matters related to both CORSIA Eligible Fuels and CORSIA Eligible Emissions Units, two aspects that will be ever more important as offsetting requirements are generated during the scheme's first phase.

CAEP's work on matters related to CORSIA Eligible Fuels has yielded important results. Sustainability criteria for Lower Carbon Aviation Fuels (LCAF) have been approved to complement the previously approved sustainability criteria for Sustainable Aviation Fuels (SAF). Progress has also been made to facilitate the sustainability certification of CORSIA Eligible Fuels with the approval of a third Sustainability Certification Scheme (more information in the SCSEG article in this chapter). In early 2025, guidance to support verification bodies on the verification of emissions reduction claims from CORSIA Eligible Fuels was made publicly available. All these developments have to be considered against the backdrop of the adoption of the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies, the main outcome of the Third ICAO Conference on Aviation Alternative Fuels (CAAF/3, Dubai, United Arab Emirates, 20 – 24 November 2023) (more information in the article on this matter in Chapter 5).

Regarding developments on CORSIA Eligible Emissions Units, it is important to note that to date the ICAO Council has approved six programmes for supplying CORSIA Eligible Emissions units to the CORSIA first phase, based on the recommendation from the Council's Technical Advisory Body (TAB). The Council has also conditionally approved five additional programmes. In 2025, TAB is undertaking the re-assessments of programmes eligible for first phase to make recommendation on their eligibility to supply CORSIA units for the 2027-209 compliance period (part of the CORSIA second phase). More information on TAB's work can be found in the TAB article in this chapter.

Regarding the potential supply of CORSIA Eligible Emissions Units, TAB presents to the Council regular updates on the basis of its recommendations on programme eligibility. The latest supply analysis by TAB, presented in October 2024, estimated the potential total supply of CORSIA Eligible Emissions Units for CORSIA's first phase; the analysis

1 https://www.icao.int/environmental-protection/CORSIA/Pages/SARPs-Annex-16-Volume-IV.aspx
2 https://www.icao.int/environmental-protection/CORSIA/Pages/ETM-V-IV.aspx

showed that the six fully eligible programmes have the potential to issue a volume of CORSIA Eligible Emissions Units in a range from around 900 million to more than 2 billion units for mitigation years 2021-2026, if such units were to obtain host country attestation in accordance with the procedures assessed by TAB. The host country attestation is a key measure to avoid double claiming of units used in CORSIA. Through the attestation, the host country confirms that emissions units are created where mitigation is not also counted toward its National Determined Contribution (NDC) of the Paris Agreement and its intention to properly account for the use of CORSIA Eligible Emissions Units. In this regard, the ICAO Secretariat is working to raise awareness of this important requirement among relevant stakeholders and encourages States to facilitate the issuance of host country attestations for CORSIA purposes.

CORSIA Periodic Review

When reaching agreement on CORSIA in 2016, ICAO Member States established that the scheme would undergo periodic reviews every three years, starting in 2022. Those reviews were set in place to allow for necessary adjustments to be made to the scheme, considering new information and developments that could impact the scheme and its objectives.

The 2022 CORSIA periodic review was a display of the scheme's ability to respond to global challenges. Based on the Council's recommendations arising from the review, the 41st Session of the ICAO Assembly adopted a new CORSIA baseline, set at the 2019 emissions level for CORSIA's pilot phase, and at 85% of the 2019 emissions level from 2024 onwards, thus replacing the original 2019 – 2020 average baseline affected by the COVID-19 pandemic. Additionally, the Assembly agreed to extend the 100% sectoral approach for the calculation of offsetting requirements in the 2030 – 2032 period, with a combination of 85% sectoral and 15% individual for the 2033 – 2035 period. These changes reflected CORSIA's adaptive design, and the collective will of States to preserve the relevancy of the scheme.

Building on this, the Council is currently undertaking the 2025 CORSIA periodic review with the support of CAEP's analytical expertise, whose technical inputs are made publicly available through the CORSIA webpage[3]. Any recommendations of the Council arising from the review will be considered by the 42nd ICAO Assembly in September 2025. More information on the 2025 CORSIA periodic review can be found in the article on this matter in this chapter.

Implementation Support and Capacity Building

As CORSIA implementation progresses, so too does the global cooperation underpinning its success. The ICAO Assistance, Capacity-building and Training for CORSIA (ACT-CORSIA) programme remains central to ICAO's *No Country Left Behind* initiative, providing technical assistance, capacity-building, and training to States. The Buddy Partnership component of ACT-CORSIA has proven especially impactful, with 119 States receiving support as of 2025 through cooperation with trainers from 16 States[4]. These partnerships have been instrumental in ensuring equitable participation and implementation across all regions.

ICAO, under the Global Aviation Training (GAT) programme, continues to provide courses on CORSIA; the CORSIA Verification Course, launched in 2019 to train verification bodies, was updated in September 2023 to align its contents with the Second Edition of Annex 16, Volume IV. In light of the increasing interest on aspects of CORSIA implementation such as CORSIA Eligible Fuels and CORSIA Eligible Emissions Units, it is expected that three more courses on CORSIA will be available in the last quarter of 2025.

Training activities on CORSIA are complemented with the continuous development and update of outreach materials such as the CORSIA Frequently Asked Questions (FAQs)[5], updated on an annual basis, and the monthly issues of the CORSIA Newsletter[6].

3 Information available in the CORSIA webpage (www.icao.int/CORSIA), section *CORSIA Periodic Review*.
4 Information available in the CORSIA webpage (www.icao.int/CORSIA), section *ACT-CORSIA*.
5 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx
6 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIANEWSLETTERS.aspx

Conclusion

CORSIA stands as a unique example of a global commitment by the international aviation sector to address climate change through a unified, cooperative approach. As the scheme progresses through its first phase, with the generation of offsetting requirements, and prepares for its second phase, the continued dedication of ICAO Member States, the aviation industry, and civil society will be critical to ensuring that international aviation's growth remains environmentally sustainable.

The steps taken between 2022 and 2025 demonstrate both the resilience and adaptability of CORSIA, with qualities that will be essential in contributing to the broader goals of the international community, including ICAO's long-term aspirational goal of net-zero CO_2 emissions from international aviation by 2050.

Overview of the CAEP/13 updates concerning CORSIA

By WG4 co-Rapporteurs

By Kerri Henry (Canada) and Joonas Laukia (EU EASA)[1]

CAEP's Working Group 4 (WG4) was established at the CAEP/11 Meeting in February 2019 as a successor to the Global Market-based Measures Technical Task Force (GMTF). WG4 focuses on the technical issues related to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a global market-based measure aiming to achieve carbon-neutral growth in aviation compared to 2019 levels. During the CAEP/13 cycle (2022-2025), the WG4 Work Programme consisted of a total of eight tasks (see Table 1).

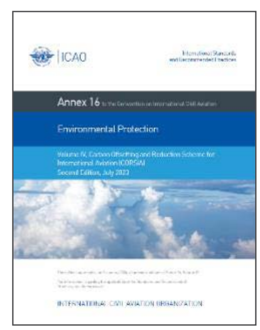
TABLE 1: CAEP/13 WG4 Work Programme

Task Number	Task Title
C.01	Maintenance of Annex 16, Volume IV and related guidance material
C.02	Development of further material on monitoring, reporting and verification (MRV) in CORSIA
C.03	Identification of CORSIA implementation issues and solutions
C.04	EUC Management
C.05	Work on the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)
C.06	Supply, Demand and Price of Units
C.07	Technical Analysis Support
C.08	Support Council on the 2025 CORSIA periodic review

Work was concluded at the CAEP/13 Meeting (Montreal, Canada, 17 to 28 February 2025) with the presentation of the final outcomes for each work item. The meeting agreed that WG4 had satisfactorily fulfilled the Work Programme of WG4 for the CAEP/13 cycle. This article will present the main outcomes of CAEP's work on CORSIA during the CAEP/13 cycle.

CORSIA SARPs and related guidance material

Annex 16, Volume IV provides the Standards and Recommended Practices (SARPs) for CORSIA implementation. CAEP ensures that the SARPs remain up-to-date by incorporating the technical recommendations from the group into proposed amendments to the SARPs. The ICAO Council adopted the first edition of the CORSIA SARPs in 2018 for applicability from 1 January 2019. The second edition of the SARPs was adopted in 2023 and has been applicable to support CORSIA's first phase since 1 January 2024.



During the CAEP/13 cycle, amendments were agreed to the SARPs to provide further clarification on fuel monitoring and data gap filling, i.e., to clarify that there is no restriction to the use of the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) to fill data gaps in the case of CO_2 emissions from international flights not subject to offsetting requirements.

The Environmental Technical Manual (ETM), Volume IV includes the guidance material supporting the implementation of the CORSIA SARPs. Further guidance agreed

1 Kerri Henry and Joonas Laukia are Co-Rapporteurs of Working Group 4 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

FIGURE 1: Distribution of CORSIA verification bodies offering CORSIA accreditation[2]

during the CAEP/13 cycle focused on matters related to CORSIA eligible fuels (CEFs), including new guidance on verification of emissions reduction claims from CEFs, a new section on CEFs in the States' Order of Magnitude checklist, restructuring of the CEF claims template to increase user-friendliness, and updating the Verification Report template to facilitate the review of CEF claims.

Updates to the CORSIA Monitoring, Reporting and Verification (MRV) system

Under CORSIA's MRV system, since 2019, aeroplane operators and States have been reporting robust and verified CO_2 information for international flights on an annual basis. This mechanism ensures that ICAO is aware of the level of international aviation CO_2 emissions and is able to calculate the Sector's Growth Factor, which in turn is an essential component of the formula to calculate each aeroplane operator's CORSIA offsetting requirements. CAEP is constantly reviewing the functioning of CORSIA's MRV system to ensure that the regulatory framework remains up to date.

In addition to the amendments to the CORSIA SARPs and guidance material, CAEP work on the monitoring of fuel use resulted in additional clarifications included in the CORSIA Frequently Asked Questions (FAQs) that are available on the ICAO CORSIA webpage, and the work on verification resulted in developing a map displaying the regional distribution of CORSIA-accredited verification bodies (see Figure 1).

CAEP has also continued its work on the definition of baseline options for new entrant aeroplane operators to be applied once the aeroplane operator Individual Growth Factor is introduced in the formula to calculate operators' CORSIA offsetting requirements for the 2033-2035 compliance cycle. CAEP considered two options for the new entrants' baseline, while noting that such a decision was to be made no later than in 2027 to allow for sufficient time to integrate its outcome into the CORSIA SARPs and national regulations before the applicability and use of the new entrants' baseline in 2033.

Management of CORSIA Emissions Unit Criteria (EUC)

The CORSIA EUC consists of a set of principles by which the emissions unit programmes are assessed for the eligibility to supply emissions units to CORSIA. The CORSIA Emissions Unit Eligibility Criteria were approved by the ICAO Council in 2019. Eligible emissions unit programmes shall meet the Program Design Elements Criteria and the Carbon

2 Based on the 11th edition of Part I of the ICAO document "CORSIA Central Registry (CCR): Information and Data for Transparency" (approved 21 December 2023).

CORSIA | CO_2 ESTIMATION & REPORTING TOOL (CERT)

Offset Credit Integrity Assessment Criteria to ensure the environmental and social integrity of the CORSIA Eligible Emissions Units. The CORSIA Eligible Emissions Units are approved by the Council, based on recommendations of the Council's Technical Advisory Body (TAB).

CAEP work on the EUC during the CAEP/13 cycle was prioritized on measures to operationalize the avoidance of double counting, notably in the light of relevant decisions under the Paris Agreement Article 6. This work led to an agreement on recommendations in relation to the Guidelines for Criteria Interpretation related to various criteria included in the EUC, including on avoidance of double counting, issuance and claiming and on permanence requirements of the CORSIA Eligible Emissions Units. Following Council's approval of the recommendations, those will now be applied by the TAB for its re-assessment of emissions unit programmes seeking CORSIA eligibility beyond CORSIA's first phase.

ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)

The ICAO CORSIA CERT, referenced in Annex 16, Volume IV, is one of the five implementation elements of CORSIA. It is used to facilitate the implementation of simplified monitoring and reporting requirements in accordance with the CORSIA SARPs. States and aeroplane operators can use the ICAO CORSIA CERT to support an assessment of whether the operator is within the applicability scope of the CORSIA MRV requirements, and to assess the operator's eligibility to use the ICAO CORSIA CERT as its CO_2 estimation method. Operators can also use the ICAO CORSIA CERT to fulfil their simplified monitoring and reporting requirements by filling-in the standardized Emissions Monitoring Plan and Emissions Report templates, and to fill any CO_2 emissions data gaps. In addition, States can use the ICAO CORSIA CERT to fill-in CO_2 emissions gaps in case an operator is not able to submit an annual Emissions Report.

The first version of ICAO CORSIA CERT was published in 2018, and the tool has been updated annually by CAEP since then to reflect the latest trends in terms of aeroplane fuel burn, and to update the names of States defining the routes subject to offsetting requirements every year from 2021. The statistical method underpinning the ICAO CORSIA CERT is referred to as the ICAO CO_2 Estimation Models (CEMs), which make use of actual historic fuel burn data, provided by aeroplane operators, to convert the user's input (i.e., aircraft type, aerodromes of origin and destination, Block Time) into estimated CO_2 emissions.

During the CAEP/13 cycle, three versions (for reporting years 2022, 2023 and 2024 respectively) of the ICAO CORSIA CERT were developed and published on ICAO's webpage. Two improvements were also incorporated into the process of developing the annual version of the CERT: streamlining of the process for the review of the CEMs within CAEP, and developing a "hybrid" approach for the Aerodrome Database embedded in the ICAO CORSIA CERT, wherein the information from ICAO eDoc 7910 applicable for a given version of the tool would be complemented with a table of airports put together by CAEP to cover gaps in the coverage and accuracy of ICAO eDoc7910 — *Location Indicators*.

CORSIA Analysis and support to the 2025 CORSIA periodic review

Throughout the past three years, CAEP has continued to provide regular technical support to the ICAO Council on the 2025 CORSIA periodic review. Following the Council's requests to CAEP at its 228th Session in March 2023, CAEP updated its analytical work on CORSIA as an input to the Council. Updates covered by the analysis included: estimates of offsetting requirements, including distribution by ICAO Regions; estimates of demand of CORSIA Eligible Emissions Units considering potential emissions reductions from CEF; estimates of prices of emissions units and related costs associated with offsetting requirements; assessment of CORSIA's impact on aeroplane operators; and projections

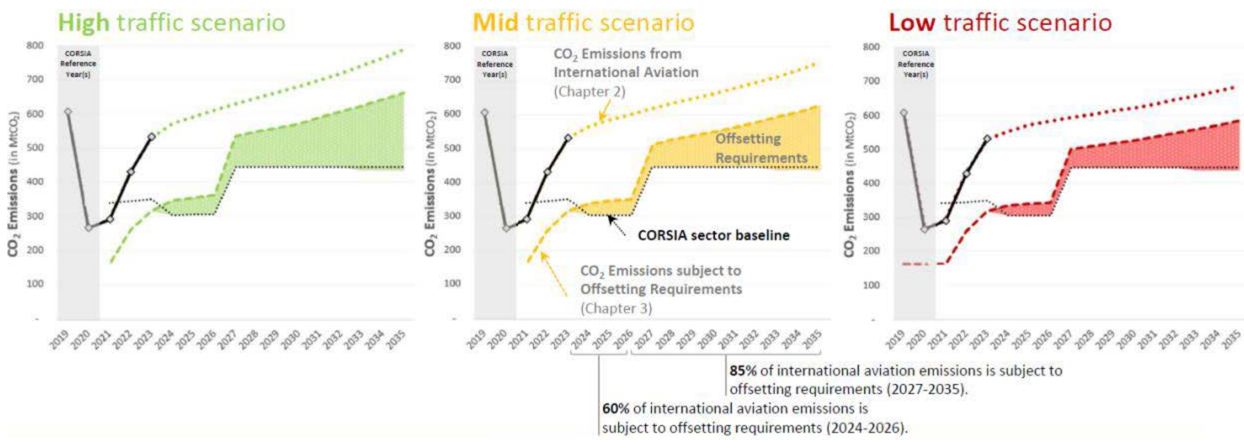


FIGURE 2: Estimation of CORSIA Offsetting Requirements[3]

of net CO_2 emissions through 2035. An initial update of CORSIA Analyses was presented at the 232nd Session of the Council in June 2024, and interim assessments in support of the 2025 CORSIA Periodic Review were presented at the 234th Session in March 2025.

Based on CAEP's interim assessments at the time of writing this article, given amended CO_2 emissions forecasts and the decision of the 41st ICAO Assembly to use 85% of 2019 CO_2 emissions as the CORSIA baseline for the period of 2024-2035, offsetting requirements are expected to start in 2024 under all CAEP/13 traffic scenarios (see Figure 2).

The cumulative offsetting requirements from CORSIA could range from 980 to 1500 $MtCO_2$ from 2024 to 2035 and from 100 to 150 $MtCO_2$ during CORSIA's first phase (2024–2026). In terms of costs associated with addressing offsetting requirements, in the period of 2024-2026, the total cost could range from ≈ USD 1.3 billion using CORSIA Eligible Emissions Units only to ≈ USD 8.4 billion using a mix of CORSIA Eligible Emissions Units and emissions reductions from CEF given a scenario that accounts for the CAAF/3 vision. Such costs could represent around 0.07% to 0.46% of international aviation revenue from 2024 to 2026. Based on these estimations, the future demand for CORSIA offsetting requirements and associated costs for the industry are expected to remain within the estimates of previous assessments.

At the time of writing this article, the Council continues its work on the 2025 CORSIA periodic review, and CAEP is preparing to present its final technical assessment in support of the review at the 235th Session of the Council in June 2025. Based on all inputs received, the Council will produce a report that will be presented to 42nd Session of the ICAO Assembly.

Conclusion

As CORSIA is expected to generate offsetting requirements in connection with 2024 CO_2 emissions, it is imperative to ensure the effectiveness of the scheme through continuous maintenance of the CORSIA SARPs and guidance material, constant review and updates of the MRV system, technical management of the EUC, including alignment with the UNFCCC Paris Agreement developments, and continued support to the Council on the 2025 CORSIA periodic review. CAEP will continue to review and support the implementation of CORSIA during the CAEP/14 cycle (2025-2028).

3 As presented to the 234th Session of the ICAO Council

The Role of ICAO's CORSIA Central Registry (CCR) in CORSIA Implementation

By ICAO Secretariat

Introduction

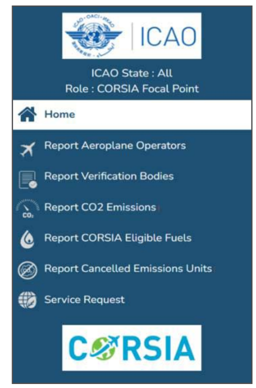
The successful implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) hinges on a robust and transparent Monitoring, Reporting, and Verification (MRV) system. This system is designed to accurately track annual CO_2 emissions from international aviation, serving as the basis for determining offsetting requirements in line with the provisions of Assembly Resolution A41-22 and Annex 16, Volume IV to the Chicago Convention.

This article provides an overview of the role of the ICAO CORSIA Central Registry (CCR) in implementing CORSIA, with a focus on its MRV processes and insights on data reported by States to ICAO through the CCR from 2020 to 2024.

The CORSIA Central Registry (CCR)

Annex 16, Volume IV to the Chicago Convention provides the Standards and Recommended Practices (SARPs) that guide States and aeroplane operators in monitoring, reporting, and verifying CO_2 emissions from international aviation. The document outlines the "what" and "when" of CORSIA implementation, ensuring consistency and transparency in tracking emissions and determining offsetting requirements.

The Environmental Technical Manual (ETM), Volume IV, complements Annex 16, Volume IV by offering detailed guidance, practical instructions, and methodologies for MRV processes, including monitoring CO_2 emissions, reporting data, and verifying compliance. Together, Annex 16, Volume IV, and the ETM form a cohesive system that ensures the effective and standardized application of MRV procedures across all participating States and operators.



The CORSIA Central Registry (CCR) is the platform available for States to fulfill their MRV reporting requirements under CORSIA, in line with Annex 16, Volume IV and the ETM, Volume IV. The CCR is an information management system that allows ICAO Member States to upload and submit CORSIA-relevant information, which includes reports on:

- Aeroplane operators
- Verification bodies
- CO_2 emissions
- Emission reduction claims from CORSIA Eligible Fuels
- Cancelled CORSIA Eligible Emissions Units

Using the information reported by States through the CCR, ICAO compiles the reported CO_2 emissions, and calculates the Sector's Growth Factor (SFG) for international aviation, which is used by States to determine the CO_2 offsetting requirements for each of their aeroplane operators.

In particular, the information and data uploaded in the CCR are used to produce, maintain updated, and make publicly available on the CORSIA website, following their approval by the ICAO Council, the five CCR-related ICAO documents that are referenced in Annex 16, Volume IV:

1. "*CORSIA Central Registry (CCR): Information and Data for the Implementation of CORSIA*", an

umbrella document that comprises the following three documents:

2. "*CORSIA Aeroplane Operator to State Attributions*", with the list of aeroplane operators and the State to which they are attributed.
3. "*CORSIA 2020 Emissions*", which contains the total CO_2 emissions to determine the first year in which a new entrant has offsetting requirements.
4. "*CORSIA Annual Sector's Growth Factor*", that specifies the Sector's Growth Factor (SGF) for a specific year, which is used by States to determine the offsetting requirements of the aeroplane operator(s) attributed to them for that specific year.
5. "*CORSIA Central Registry (CCR): Information and Data for Transparency*", that is divided in:
   - "*Part I: List of Verification Bodies Accredited in States*".
   - "*Part II: Total CO_2 Emissions for 2019 Aggregated for all Aeroplane Operators on each State Pair*", that contains data required for the calculation of the CORSIA baseline.
   - "*Part III: Total Annual CO_2 Emissions and Information for Aeroplane Operators*", that contains data for each reporting year from 2021.
   - "*Part IV: Information on CORSIA Eligible Fuels (CEF) Claimed*", that will be published following the reporting of CEF data by States to ICAO (see also timeline in Table 1).
   - "*Part V: Information on Total Offsetting Requirements and Quantity of Emissions Units Cancelled*", that will be published following the reporting of Cancelled Emissions Units data by States to ICAO (see also timeline in Table 1).

CCR update: Version 2 Enhancements

Following the adoption by the ICAO Council of the Second Edition of Annex 16, Volume IV, the ICAO Secretariat updated the CCR in March 2024 to ensure that it aligns with the revised reporting requirements on verification bodies, CORSIA Eligible Fuels, and cancellations of CORSIA Eligible Emissions Units, as reflected in the Second Edition.

Additionally, the Secretariat improved the CCR based on user feedback from States, improving the interface for greater usability. This update introduced new visual aids, including color coding to indicate pending or overdue submissions and trend graphs for a clearer representation of uploaded data.

Further enhancements were made to the Administration module, optimizing the extraction and processing of information and data.

This updated version of the CCR offers a more intuitive, efficient, and user-friendly experience.

CORSIA Monitoring, Reporting, and Verification (MRV) System and States' submissions through the CCR

The CCR is administered by the ICAO Secretariat and has been implemented as a secure web interface that ensures the integrity and confidentiality of the data submitted by States. Only one CCR user per State is assigned the role of the CORSIA Focal Point (CFP) who can initiate the reporting process and submit data to ICAO. More than one State User (STU) can be nominated by a State to support the work of the CFP, by adding, editing, and deleting data before the report is submitted to ICAO by the CFP. As of the first quarter of 2025, 173 States have access to the CCR, with ICAO having created 173 CFP accounts and an additional 108 STU accounts (total 281 CCR users).

Under CORSIA, aeroplane operators with international flights, unless they qualify for specific exemptions, are subject to MRV requirements. As of 1 January 2019, operators are required to monitor their annual CO_2 emissions from international flights, have them verified through a third-party verification process, and submit them to the States to which they are attributed. States (STUs and CFPs) collect emissions data from all their operators and submit consolidated information to ICAO through the CCR (see Figure 1).

States with operators that wish to claim CO_2 emissions reductions from the use of CORSIA Eligible Fuels during the three-year CORSIA compliance periods are required to submit information and data on such fuels in accordance with the provisions of Appendix 5 to Annex 16, Volume IV. Information on CORSIA Eligible Fuels claims must also be verified prior to its submission to the State of attribution.

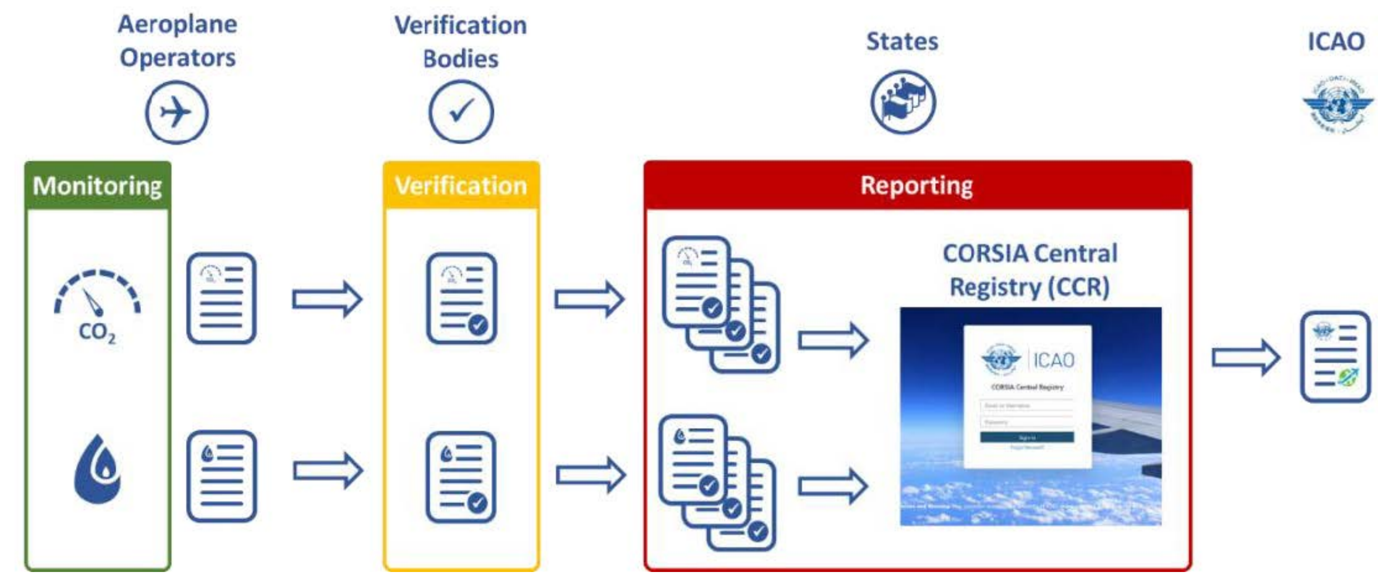


FIGURE 1: Sequence of actions under the CORSIA Monitoring, Reporting and Verification (MRV) system for CO_2 emissions and CORSIA Eligible Fuels

In addition to CO_2 emissions, States are required to submit to ICAO information on aeroplane operators attributed to them, on verification bodies accredited in them, and on CORSIA Eligible Emissions Units cancelled by their aeroplane operators.

As outlined in Appendix 1 to Annex 16, Volume IV, States are required to meet specific deadlines for submitting CORSIA-related information through the CCR for a given year, as detailed in Table 1 below.

TABLE 1: Summary of CORSIA-relevant information to be reported by States to ICAO through the CCR and associated deadlines (Annex 16, Volume IV, Appendix 1).

State Report	**CORSIA First Phase**			**CORSIA Second Phase**		
	2024	**2025**	**2026**	***2027***	***2028***	***2029***
Aeroplane Operators	***30 Nov*** *(2024 AOs)*	***30 Nov*** *(2025 AOs)*	***30 Nov*** *(2026 AOs)*	***30 Nov*** *(2027 AOs)*	***30 Nov*** *(2028 AOs)*	***30 Nov*** *(2029 AOs)*
Verification Bodies	***30 Nov*** *(2024 VBs)*	***30 Nov*** *(2025 VBs)*	***30 Nov*** *(2026 VBs)*	***30 Nov*** *(2027 VBs)*	***30 Nov*** *(2028 VBs)*	***30 Nov*** *(2029 VBs)*
CO_2 Emissions	***31 Jul*** *(2023 Emissions)*	***31 Jul*** *(2024 Emissions)*	***31 Jul*** *(2025 Emissions)*	***31 Jul*** *(2026 Emissions)*	***31 Jul*** *(2027 Emissions)*	***31 Jul*** *(2028 Emissions)*
CORSIA Eligible Fuels*	***31 Jul*** *(2023 CEF)*	***31 Jul*** *(2024 CEF)*	***31 Jul*** *(2025 CEF)*	***31 Jul*** *(2024-2026 CEF)*	***31 Jul*** *(2027 CEF)*	***31 Jul*** *(2028 CEF)*
Cancelled Emissions Units					***31 Jul*** *(2024 – 2026 CEUs)*	

*Information can be reported annually or once at the end of each three-year compliance cycle depending on the frequency of reporting by the operator(s) attributed to the State.

TABLE 2: CORSIA Central Registry (CCR) CO_2 Data Overview: 2019-2023

Description	2019	2020	2021	2022	2023
CCR reports submitted (number)	**119**	**112**	**107**	**115**	**121**
CCR CO_2 emissions submitted (M tonnes)	588	258	280	419	525
Gap-filling States (number)	20	20	23	21	15
Gap-filling (GF) CO_2 emissions (M tonnes)	20.2	7.6	10.4	9.9	5.4
Total of emitter States CCR + GF (number)	139	132	130	136	136
Total of CO_2 emissions CCR + GF (M tonnes)	**608**	**265** (- 56.4%)	**290** (+ 9.4%)	**429** (+ 47.9%)	**530** (+ 23.5%)
CCR coverage before gap-filling (%)	**96.7%**	**97.2%**	**96.5%**	**97.7%**	**99.0%**

State's inputs through the CCR in 2024 and lessons learned from the past years of MRV

Table 2 below provides a comprehensive overview of the CO_2 emissions data reported for 2019 up to 2023 through the CCR, highlighting key metrics such as the number of reports submitted, CO_2 emissions, gap-filling States, and overall CCR CO_2 emissions coverage (before the application of the gap-filling process by the ICAO).

The data submitted by States through the CCR reflect the impact of the COVID-19 pandemic, which significantly reduced air traffic and led to a sharp drop in 2020 CO_2 emissions. However, the data for subsequent years shows a recovery trend, indicating a gradual return to pre-pandemic levels of aviation activity.

The number of gap-filling States has varied over the years, peaking at 23 in 2021 and then decreasing to 15 in 2023. This reduction in the number of gap-filling States, and their associated CO_2 emissions, suggests improved reporting and compliance among States, contributing to more accurate and comprehensive data collected through the CCR.

Overall, the CCR coverage percentage has remained high, consistently above 96%. In 2024, an unprecedented number of 121 States reported their 2023 CO_2 emissions from international aviation through the ICAO CCR,

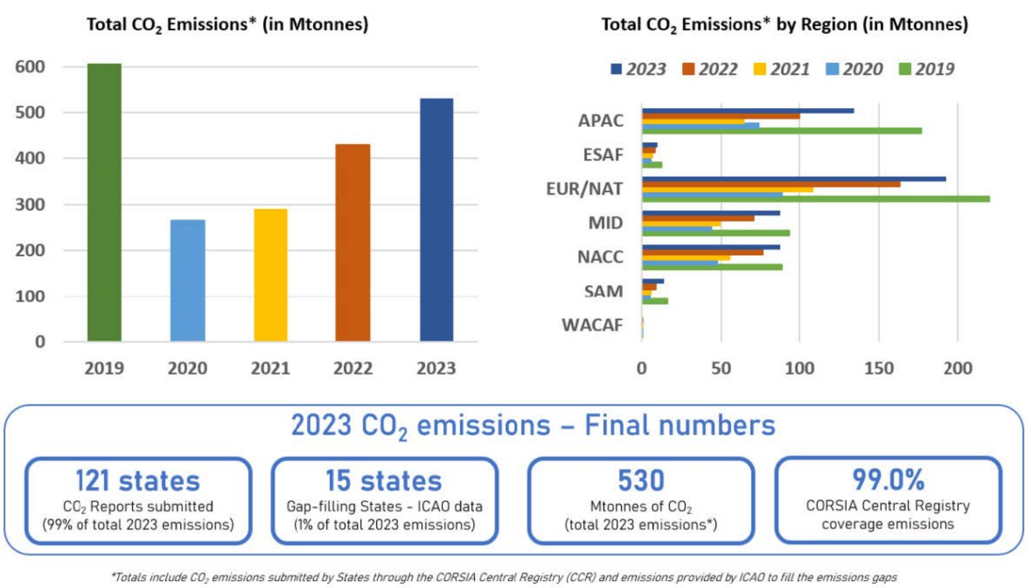


FIGURE 2: 2023 CO_2 emissions reported by States in 2024

increasing its coverage to a historic record of 99% of total CO_2 emissions. In accordance with Annex 16, Volume IV, the ICAO Secretariat filled the CO_2 emissions gap for 15 States (which represent the remaining 1.0% of the total 2023 CO_2 emissions) that did not submit data through the CCR. This high coverage reflects the effectiveness of the CCR in capturing and reporting aviation emissions data, as well as the accountability in the sector's efforts to mitigate climate change.

According to the information stored in the CCR, in 2023 CO_2 emissions from international aviation rose above 2022 levels by about 23.5% to a total of about 530 million tonnes and all ICAO Regions experienced higher emissions than 2022 as a result of the growth in traffic in 2023 (Figure 2).

Building on the increased coverage observed in 2023, in November 2024 a total of 131 States reported through the CCR 670 aeroplane operators attributed to them for the same year. Additionally, 34 States reported through the CCR the accreditation of 56 verification bodies. This information, published on the ICAO CORSIA website in December 2024, is being used in 2025 by States for the preparation and submission to ICAO of their 2024 CO_2 Emissions Reports.

Considerations on the CORSIA Sector Growth Factor

The CORSIA Sector Growth Factor (SGF) is used by States to calculate the annual amount of CO_2 emissions that need to be offset by the aeroplane operators attributed to them (Figure 3). This value is determined by ICAO based on the comparison between reported emissions from a baseline year (2019) and those of subsequent years from 2021 onwards.

The CORSIA Central Registry plays a pivotal role in supporting ICAO's work to gather essential data for calculating the SGF; the calculation of the SGF strongly depends on the timely and accurate reporting of CO_2 emissions data by States.

In October 2024, the ICAO Secretariat calculated the 2023 Sector's Growth Factor, using the 2023 CO_2 emissions data and prepared the third edition of the ICAO document *CORSIA Annual Sector's Growth Factor (SGF)*. The 2023 SGF value is zero (0) given that the CO_2 emissions subject to offsetting requirements in 2023 were lower than the 2019 baseline emissions.

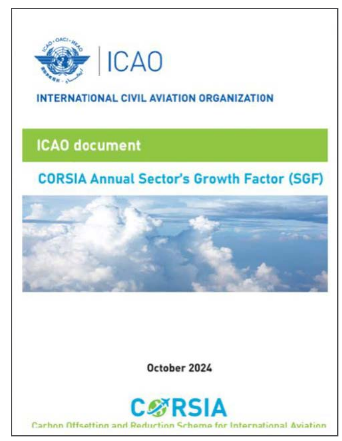


FIGURE 3: Calculation of offsetting requirements in CORSIA

As no offsetting requirements have been accrued for 2021, 2022 and 2023 given that the SGF_{2021}, SGF_{2022} and SGF_{2023} values were 0, no total final offsetting requirements have been accrued for CORSIA's pilot phase (2021-2023).

However, as aviation traffic is recovering to pre-pandemic levels, and the baseline from 2024 is set at 85% of 2019 emissions, the SGF during CORSIA's pilot phase (2024-2026) is expected to be greater than zero for the first time since CORSIA's implementation. To maintain the integrity and reliability of the scheme, it is crucial for States to submit each year accurate and timely reports on their CO_2 emissions by the established deadline of 31 July. This ensures that the ICAO Secretariat has adequate time to process the data and publish the SGF value on the CORSIA website by 31 October of the same year.

Final considerations

The CCR has proven to be an indispensable tool in the successful implementation of CORSIA. By facilitating a robust MRV system in line with the CORSIA SARPs, the CCR ensures transparency, accuracy, and accountability in tracking CO_2 emissions, supporting ICAO States in their efforts to measure, report and mitigate aviation's impact on climate change.

The CCR will continue to play a central role in managing and analyzing CORSIA-related data, facilitating States' reporting, and promoting public transparency in the scheme's implementation. According to the timeline outlined in Appendix 1 to Annex 16, Volume IV, the CCR will remain operational throughout the entire scheme's duration, and at least until 31 July 2037 when States are required to submit to ICAO final data on CORSIA implementation for the period 2033 - 2035.

In the years ahead, ICAO will continue to maintain and, if necessary, enhance the CCR features and functionalities to ensure it remains a user-friendly tool and effectively meets the needs of all ICAO Member States, in line with the ICAO's No Country Left Behind initiative. In addition, ICAO will update the CCR functionalities as needed to reflect any amendments to the CORSIA SARPs reflected in Annex 16, Volume IV, similar to what was done in March 2024 following the applicability of the Second Edition of Annex 16, Volume IV.

The CCR is also set to be an important source of information for the monitoring methodology of ICAO's Long Term Aspirational Goal, focused on tracking progress towards a net-zero carbon emissions goal for international aviation by 2050, particularly within its backward-looking assessment framework. As a centralized global database, its records on CO_2 emissions and on the claims of emissions reductions from CORSIA Eligible Fuels by aeroplane operators will enable the CCR to provide comprehensive, consistent, and transparent emissions data, essential for tracking the aviation sector's actual emissions.

By maintaining and evolving the CCR, ICAO will continue to ensure the effective implementation of CORSIA, reinforce its commitment to climate action, and support the bold transition toward a more sustainable aviation sector.

CORSIA Implementation in the Dominican Republic

By: Judit De Leon, Action Plan Focal Point; Luis Ramirez, CORSIA Focal Point

In October 2018, the Dominican Republic joined the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), adopted by the 39th Session of the ICAO Assembly in October 2016. This mechanism aims to reduce CO_2 emissions in international aviation, promote sustainability in aviation, and contribute to global efforts to combat climate change. Formalizing our participation in CORSIA marked a significant milestone in our efforts to combat climate change.

At the start of the implementation of the CORSIA Monitoring, Reporting and Verification (MRV) system in 2019, there was one Dominican airline (Helidosa Aviation Group) for which the MRV requirements were applicable. In addition to the challenge posed by the fact that these requirements were new, it has to be noted that Dominican Republic did not have an national accreditation body, nor did we have an accredited verification body for compliance with the scheme as required by the Standards and Recommended Practices (SARPs) in Annex 16, Volume IV. All in all, Dominican Republic's Civil Aviation Authority (IDAC) and the operator lacked the expertise to ensure the correct implementation of CORSIA.

In July 2021, IDAC and the Dominican National Accreditation Body (ODAC) signed a memorandum of understanding (MOU) with the aim of establishing a framework for collaboration and reciprocal cooperation, focused on optimizing the conditions that allow for the sharing of relevant information related to the accreditation of national or foreign validation and verification companies or bodies capable of verifying the CO_2 emissions of national air operators.

Each air operator in the Dominican Republic was asked to designate a point of contact to work on issues related to CORSIA. A meeting program was held with these points of contact to explain CORSIA and its implementation. Since 2016, air operators have monitored and reported fuel consumption using the ENV1 form.

Between 2020-2021, in the context of the Assistance, Capacity Building and Training (ACT-CORSIA) programme, consultation meetings were requested for implementation with States such as the United States. The main concerns were associated with the verification bodies and reporting through the CORSIA Central Registry (CCR). Conversations were also held with the points of contact for Panama and Bolivia.

In the years 2021-2023, ODAC recognized the accreditation of an international verification body accredited by another national accreditation body. Air operators used the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT). These first years, due to the impact of the pandemic, verification activities were carried out virtually.

In 2022, an unprecedented event occurred where, from one air operator subject to the requirements in Annex 16, Volume IV, four more Dominican operators became involved. Therefore, the IDAC, as the authority, proceeded to hold meetings with the objective of guiding the numerous operators and communicating the appropriate form for compliance and implementation, as well as identifying training and development needs.

On 18 January 2023, Dominican Aeronautical Regulation (RAD) No. 16, *Environmental Protection*, was published, including compliance requirements under the CORSIA scheme.

In addition, the ODAC created the processes and procedures for the accreditation of verification bodies under the CORSIA scheme, supported by the EASA-EU-CORSIA project.

In December 2023, the Dominican accreditation body awarded its accreditation certificate to the Atabey Innovation Center, making it the first accredited greenhouse gas (GHG) verification body in the Dominican Republic, under the requirements of the Nordom ISO/IEC 14065:2013 standard for greenhouse gas verification activities in CORSIA.

Regarding capacity building activities on CORSIA, we received support from the EASA-EU-CORSIA project, which practically built our capacity with the implementation of CORSIA. Approximately 180 people were trained, including airline operators, verifiers, and accreditation bodies. A course was held with the United Kingdom in November 2024, with the participation of 28 representatives from airline operators and civil aviation authorities.

Under the principle of “No Country Left Behind,” we understand that the spirit of collaboration and integration for compliance with CORSIA is fundamental. Creating the first global market-based scheme that applies to a sector is a major challenge for implementing the next steps, including the purchase and cancellation of CORSIA Eligible Emissions Units and the claiming of emissions reductions from CORSIA Eligible Fuels. Since the Dominican Republic does not have a nation-wide carbon market, there may be challenges in the process of making Dominican operators conversant with the dynamics of carbon markets from where they will need to purchase CORSIA Eligible Emissions Units to meet their offsetting requirements under CORSIA.

CORSIA Emissions Units: Key updates, the role of the Technical Advisory Body and Future Direction

By Grégoire Baribeau (Canada) and Rachid Rahim (Qatar)[1]

Introduction

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is part of the International Civil Aviation Organization's (ICAO) comprehensive measures to achieve carbon-neutral growth for international aviation from 2020 onwards. The landmark agreement on the adoption of the CORSIA was reached during the 39th Session of the ICAO Assembly in 2016. Since then, ICAO and its Member States have successfully implemented the scheme as the only global market-based measure (MBM) addressing CO_2 emissions from international aviation. ICAO continues to work closely with all Member States to ensure that they have the means and capacity to implement CORSIA.

One of the key components of the scheme is the CORSIA Eligible Emissions Units. To operationalize this crucial element of CORSIA, in 2019, the ICAO Council approved the CORSIA Emissions Unit Eligibility Criteria (EUC) and established the Council's Technical Advisory Body (TAB). The TAB assesses a variety of carbon offset programmes against the EUC and makes recommendations to the Council on which units should be CORSIA-eligible. Aeroplane operators are required to cancel CORSIA Eligible Emissions Units to fulfill their CO_2 offsetting requirements under the scheme.

Information about the eligibility of emissions units is presented in the ICAO document *CORSIA Eligible Emissions Units*. This ICAO document, available in the ICAO website[2], is updated regularly by the ICAO Council based on recommendations by the TAB.

Overview

TAB launched the first call for applications for assessment against the EUC in June 2019 and delivered its first recommendations to Council in January 2020. Since then, TAB continues to undertake assessments on an annual basis and recently launched its seventh assessment cycle in early 2025.

TAB's recommendations to the Council arising from its assessment of programmes between 2019 and 2024 have led to the Council's approval of emission units from the following programmes[3]:

Pilot Phase (2021-2023 compliance period)

1. American Carbon Registry
2. Architecture for REDD+ Transactions
3. BioCarbon Fund for Sustainable Forest Landscapes
4. China GHG Voluntary Emission Reduction Program

1 Grégoire Baribeau served as Chairperson of the Technical Advisory Body (TAB) of the ICAO Council until March 2025. Rachid Rahim is TAB's Vice-Chairperson.
2 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Emissions-Units.aspx
3 Not all units from these programmes are eligible for use in CORSIA. Certain emissions units from these programmes are not eligible (see each programme's Scope of Eligibility in the ICAO document *CORSIA Eligible Emissions Units*)

5. Clean Development Mechanism
6. Climate Action Reserve
7. Forest Carbon Partnership Facility
8. Global Carbon Council
9. The Gold Standard
10. Socialcarbon
11. Verified Carbon Standard

First Phase (2024-2026 compliance period)

1. American Carbon Registry
2. Architecture for REDD+ Transactions
3. Climate Action Reserve
4. Global Carbon Council
5. The Gold Standard
6. Verified Carbon Standard

The latest information on eligible programmes and their respective scopes of eligibility is contained in the 12th edition (October 2024) of the ICAO document titled *CORSIA Eligible Emissions Units*. All CORSIA Eligible Emissions Units must be generated from activities that started their first crediting periods in January 2016 or later and meet specific eligibility parameters set out for each programme in the ICAO document.

For the pilot phase (2021–2023 compliance period), eligible units from most programmes must represent greenhouse gas (GHG) mitigation that occurred from 2016 to 2020. Council further approved five programmes to also supply emissions units issued that represent 'post-2020' mitigation for the pilot phase, namely with unit dates from 2021 to 2023.

For the CORSIA first phase (2024–2026 compliance period), in addition to the existing 2016 crediting start date parameter mentioned above, CORSIA Eligible Emissions Units must represent mitigation that occurred between 2021 and 2026.

Technical Criteria

The CORSIA Emissions Unit Eligibility Criteria (EUC) cover a variety of best practices that are broadly recognized across both regulatory and voluntary offset credit programs, in respect of both program design elements and carbon offset credit integrity. This helps ensure that the emissions units are environmentally sound and contribute to sustainable development.

Key technical aspects include, but are not limited to: Programme Governance; Additionality and conservative baselines; Permanence and leakage; Quantification and verification; Avoidance of Double Counting; Sustainable development and Environmental and social safeguards. TAB's application of the EUC is further informed by the *Guidelines for Criteria Interpretation*, last updated in March 2024, which outline detailed expectations for many criteria.

Role of the Technical Advisory Body (TAB)

The TAB's mandate is to make recommendations to the ICAO Council on which emissions units should be CORSIA-eligible. TAB comprises experts from 19 States, reflecting a regional balance, who are highly qualified in the topics of global carbon markets, carbon offsetting, emissions quantification and climate policy.

TAB's assessment process involves a thorough review of the programmes' procedures, standards and unit registries, which follows a step-by-step approach to ensure that the technical assessment and related recommendations are robust and evidence-based. These recommendations are crucial for ensuring that only high-quality emissions units are approved for use by aeroplane operators.

The process starts with submissions of detailed applications by candidate emissions unit programmes. Then, TAB reviews the design elements of these programmes and evaluates the integrity of the carbon offset credits to ensure they meet the EUC. This process results in recommendations on the eligibility of the emissions units, which are then presented to the ICAO Council. The Council decides eligibility on the basis of TAB's recommendations. The final step is the publication of the ICAO document *CORSIA Eligible Emissions Units*, which sets out the scope of eligibility of each approved programme.

TAB's assessment cycles demand considerable expertise and time commitment from TAB members. Each member undertakes extensive desk work processing programme applications and supporting documentation to prepare a thorough assessment. TAB meets formally three times per year and holds informal videoconferences between meetings to continue advancing the work.

TAB ensures transparency by interacting with programmes during the assessment cycle, both in writing and via videoconference. TAB also allows public participation through annual calls for public comments, a webinar at the start of each new assessment cycle, as well as participation in different events to engage with interested stakeholders.

To help illustrate the ICAO document titled *CORSIA Eligible Emissions Units*, TAB now publishes a summary table (available on the ICAO website) listing programmes that have been fully or conditionally approved by the Council to supply units for the different CORSIA phases. This informal table is a valuable resource for stakeholders to understand the status of eligible programmes.

SUMMARY OF THE STATUS OF PROGRAMME ELIGIBILITY FOR THE PROVISION OF CORSIA ELIGIBLE EMISSIONS UNITS (AS OF NOVEMBER 2024)

Programme	2021 -2023 Compliance Period (Pilot Phase)	2024 -2026 Compliance Period (First Phase)	2027 – 2029 Compliance Period (in Second Phase)
American Carbon Registry	2016 – 2023 units[1,2]	2021 – 2026 units[1,2]	*Starting in 2025, TAB will make recommendations to Council on eligibility beyond the CORSIA First Phase.*
Architecture for REDD+ Transactions	2016 – 2023 units[1,2]	2021 – 2026 units[1,2]	
BioCarbon Fund Initiative for Sust. Forest Landscapes	2016 – 2020 units[1]	Conditionally eligible[3]	
Cercarbono		Conditionally eligible[3]	
China Certified Emission Reduction	2016 – 2020 units[1]		
Clean Development Mechanism	2016 – 2020 units[1]		
Climate Action Reserve	2016 – 2023 units[1,2]	2021 – 2026 units[1,2]	
Forest Carbon Partnership Facility	2016 – 2020 units[1]	Conditionally eligible[3]	
Global Carbon Council	2016 – 2020 units[1]	2021 – 2026 units[1,2]	
Gold Standard	2016 – 2023 units[1,2]	2021 – 2026 units[1,2]	
Isometric		Conditionally eligible[3]	
Joint Crediting Mechanism between Japan and Mongolia	Conditionally eligible[3]		
SOCIALCARBON	2016 – 2020 units[1]		
Thailand Voluntary Emission Reduction Programme		Conditionally eligible[3]	
Verra Verified Carbon Standard / Jurisdictional Nested REDD Programme	2016 – 2023 units[1,2]	2021 – 2026 units[1,2]	

Note: All Eligible Emissions Units must be generated from an activity that that started its first crediting periods in 2016 or later.
[1] Subject to various exclusions as set out in the relevant section of the ICAO document titled "CORSIA Eligible Emissions Units".
[2] Units with vintages from 2021 onward have specific requirements relating to host-Party attestations.
[3] Pending further actions by the Programme.

TAB's annual work programme aligns with the Council's meeting cycle to deliver timely recommendations. In 2025, TAB will conduct the re-assessment of emissions unit programmes seeking eligibility beyond the first phase. This process aims to ensure that the programmes continue to meet the criteria for supplying CORSIA Eligible Emissions Units for 2027-2029 (first compliance period of the Second Phase).

TAB will also undertake an assessment of the Paris Agreement Crediting Mechanism (PACM), including the provisions relating to the transition of the Clean Development Mechanism (CDM), as soon as it is operational.

Supply of CORSIA Eligible Emissions Units

At the request of ICAO Council, TAB conducts an annual supply survey of CORSIA Eligible Emissions Units, including information on geographic distribution of activities. The purpose of this survey is to provide the Council with regular updates on potential supply of CORSIA Eligible Emissions Units and to show the supply implications of TAB's recommendations.

TAB's latest supply analysis presented in October 2024 estimated that the potential total supply of CORSIA Eligible Emissions Units for CORSIA's pilot phase (2021-2023 compliance period) was around 550 million – 1.9 billion units. It is important to note that no offsetting requirements have accrued for CORSIA's pilot phase; thus, airlines do not need to purchase and cancel emissions units for that phase.

Regarding the potential supply for CORSIA's first phase (2024-2026 compliance period), TAB's latest estimates range from around 900 million up to more than 2 billion units from the six programmes approved to supply units for the first phase, if such units were to obtain host country attestation (roughly half of these units would also have been eligible for the pilot phase). These figures do not yet reflect the specific eligibility parameters of each programme, which would adjust such estimates. TAB will introduce programme-specific eligibility parameters in future updates of its supply analysis.

It is important to highlight that TAB's supply survey is for information purposes and does not affect a programme's eligibility. Rather, TAB recommendations are based on the assessment of programmes against the Emissions Unit Eligibility Criteria and do not aim to pre-determine the supply of units.

Market availability of CORSIA Eligible Emissions Units

The demand for high-quality emissions units in the aviation sector is expected to grow as aeroplane operators strive to meet CORSIA's carbon-neutral growth targets. The development of new carbon offset projects, including in sectors such as energy efficiency, forestry, agriculture, waste management and renewable energy, will play a crucial role in supplying eligible emissions units. Emerging innovations in carbon capture, utilization and storage (CCUS) and negative emissions technologies (NET) are also anticipated to contribute to the availability of emissions units.

Besides the development of new projects, TAB also recognizes another crucial factor that is linked to the availability of CORSIA Eligible Emissions Units: the host country attestation.

The host country attestation[4] is a key step to prevent double claiming of units used in CORSIA, in particular units representing GHG mitigation that occurred from 2021 onward. Through the attestation, the host country confirms that any CORSIA Eligible Emissions Units used by aeroplane operators will not also be not counted towards a country's Nationally Determined Contribution (NDC), in accordance with the relevant accounting guidance under Article 6 of the Paris Agreement.

Based on the information compiled by TAB, activities under programmes approved to supply CORSIA Eligible Emissions Units for the first phase (2024-2026 compliance period) have obtained host country attestations for up to 18.4 million of units with vintage years 2021–2023.

While programmes are accountable for the integrity and transparency of CORSIA Eligible Emissions Units, the decision to issue attestation letters is ultimately the responsibility of the host countries to GHG mitigation activities. Therefore, to ensure availability of CORSIA Eligible Emissions Units with mitigation years 2021-2026, ICAO Member States are encouraged to finalize their authorization letters well in advance of the January 2028 deadline for aeroplane operators to cancel emissions units for the first phase.

In addition to the above, market dynamics, including the price of carbon credits and the demand from other sectors, will also influence the future supply of CORSIA Eligible Emissions Units.

Future of CORSIA Eligible Emissions Units and TAB assessment

The recent updates on CORSIA Eligible Emissions Units and the role of the TAB underscore the ongoing efforts to ensure the environmental integrity and effectiveness of carbon offsetting in international aviation.

The assessment process and the continuous work of TAB are essential for maintaining the high standards required for CORSIA's success. TAB's thorough assessments ensure that only those emissions units demonstrating high environmental integrity, social safeguards and sustainable development contributions are eligible for use under CORSIA. As the aviation industry strives for carbon-neutral growth, the role of CORSIA and the TAB remains pivotal in achieving ICAO's climate goals.

Future projections indicate growth in both supply and demand for CORSIA Eligible Emissions Units, starting from the first phase of CORSIA (2024-2026). However, the availability of high-quality emissions units for the international aviation sector will depend on the continued support of ICAO Member States and their national focal points under the Paris Agreement, the ICAO Council and TAB, as well as carbon market participants (e.g., programmes, project developers, retailers and brokers). These stakeholders must work collaboratively to establish the necessary conditions for generating high-quality emissions units suitable for use in CORSIA through the next decade.

4 Also known as host country authorization under the Article 6 of the UNFCCC Paris Agreement

Article 6 of the Paris Agreement: Supporting International Climate Cooperation and CORSIA

By Phillip Eyre, Seoyoung Lim, Iana Messetchkova and Perumal Arumugam (UNFCCC Secretariat)

Article 6 of the Paris Agreement facilitates international cooperation on climate action through market and non-market mechanisms. This framework plays an important role in supporting countries to achieve their climate goals and complements the international aviation sector's efforts under ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

With ICAO's triannual Assembly approaching at the end of May 2025, recent developments under Article 6.4 are particularly relevant. Under ICAO's Resolution A39-3, UNFCCC mechanisms are considered eligible for use under CORSIA, provided that they align with the decisions by the ICAO Council. Given this context, it is timely to highlight recent progress in implementing and operationalizing Article 6.4 of the Paris Agreement crediting mechanism (PACM).

Article 6.2: Country-to-Country Carbon Trading

Article 6.2 enables bilateral trading of emissions reductions, known as Internationally Transferred Mitigation Outcomes (ITMOs), between countries.

Article 6.2 provides the transparency and accountability framework for countries to report their cooperation under Article 6. The countries that authorize the use of carbon credits for CORSIA purposes have reporting obligations and would have to follow the relevant guidance.

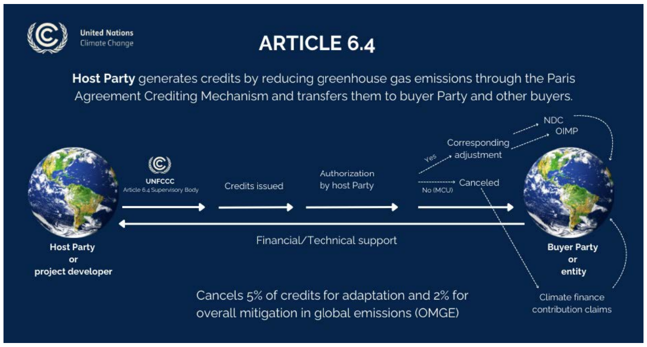
Recent decisions at COP29 have clarified how such trades are authorized, tracked via registries, and reported to ensure transparency and environmental integrity.

Article 6.4: The Paris Agreement Crediting Mechanism

Article 6.4 establishes a centralized UN mechanism (known as the Paris Agreement Crediting Mechanism) for generating high-integrity carbon credits that can support countries in meeting their national climate targets.

The mechanism is also relevant to CORSIA, as it enables the issuance of credits that align with robust environmental and human rights safeguards—key considerations for ICAO's eligible emissions unit criteria.

The Paris Agreement Crediting Mechanism is advancing toward full operationalization: an interim registry is already in place while development of the permanent registry continues.



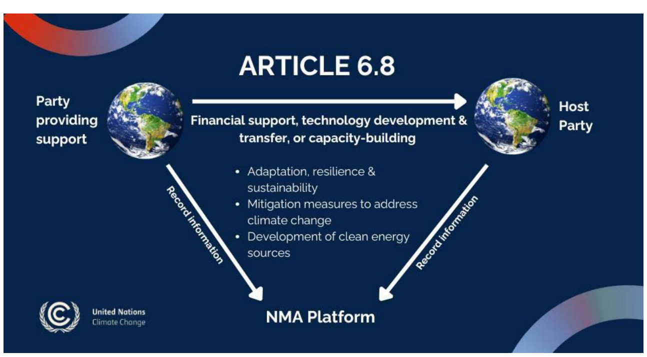
In early 2025, the first two projects were approved for transition from the Clean Development Mechanism, and the first independent auditor was accredited. Methodological standards and safeguards were finalized at COP29, and the Letter of Authorization process has been clarified. The first issuance of Article 6.4 units is expected by the end of 2025.

With Designated National Authorities (DNAs) establishing governance processes, the groundwork is now in place for countries to participate in CORSIA-compliant transactions.

Article 6.8: Non-Market Approaches (NMAs)

Non-market approaches under Article 6.8 allow Parties to cooperate through finance, technology transfer, and capacity-building without trading emissions.

The NMA Platform was launched to connect Parties and stakeholders, share resources, and match needs with available support, enhancing ambition beyond markets.



Interlinkages between Article 6 and CORSIA to ensure environmental integrity

Mitigation outcomes generated through cooperative approaches under Article 6.2, that are from programs eligible under CORSIA or from activities under the Article 6.4 mechanism can be used for compliance under CORSIA, provided that the host country of the activity authorizes their use for "other international mitigation purposes (OIMP)."

To enable transparent tracking and recording, the host country must submit up-front information on such activities intended for use under CORSIA through the initial report to the UNFCCC secretariat. Furthermore, by 15 April of the following year, the host country must report the annual quantities of mitigation outcomes transferred and used for CORSIA purposes in the agreed electronic format. Verified mitigation outcomes used for CORSIA must be reported and accounted for as an annex to the biennial transparency report (BTR), which each Party to the Paris Agreement is required to submit every two years.

Looking ahead

The UNFCCC secretariat and ICAO will work in close coordination to ensure that mitigation outcomes transferred and used for CORSIA are properly reported and accounted for, thereby ensuring that the efforts of aircraft operators under CORSIA are accurately accounted in the international aviation sector's contributions to the achievement of goals set out in the Paris Agreement.

These developments under Article 6 provide a foundation for strengthened collaboration between the UNFCCC and ICAO and support the effective implementation of CORSIA through high-integrity, transparent, and inclusive climate action.

A call to action: Ensuring CORSIA's robust implementation

By Yue Huang and Abijith Amberi Premanand (International Air Transport Association, IATA)

Introduction

CORSIA is an essential element within the basket of measures for international aviation to achieve the long-term global aspirational goal for international aviation (LTAG) of net-zero carbon emissions by 2050.[1] As of today, CORSIA is the only global market-based measure (MBM) that applies to an entire transport sector. To date, the scheme is underpinned by the strong support from governments across the world and the international air transport industry.

While aeroplane operators have been complying with the monitoring, reporting, and verification (MRV) requirements of CORSIA since 2019, 2024 is likely to mark the first year when operators' offsetting obligation kicks in. For the offsetting part, aircraft operators are required to procure and cancel CORSIA Eligible Emissions Units (EEUs) against their offsetting requirements in every 3-year compliance period (for example, from 2024 to 2026, and then 2027 to 2029, and so on).

While the factors affecting the demand for CORSIA EEUs have been well defined, airlines are continuing to face a shortage in their supply. On the positive side, the conclusion of operational rules of Article 6 of the Paris Agreement at the United Nations Framework Convention on Climate Change's (UNFCCC) 29th Conference of the Parties (COP 29) at Baku in November 2024 provides more certainty to unlock the supply of CORSIA EEUs. However, the various factors that would individually or jointly present challenges for CORSIA's robust implementation cannot be ignored. Those factors include, but are not limited to, the duplicative market-based measures imposed by regions and countries, the complex and often fragmented landscape of international environmental policies concerning aviation, and the delay in the issuance of letters of authorization/national attestations from host countries towards CORSIA EEUs.

CORSIA is at an important turning point, and its success demands collaborative efforts between different UN agencies, governments, the industry, and carbon market stakeholders to find practical solutions to overcome these challenges, which are discussed further in the following sections.

Increasing CORSIA's decarbonization potential

As CORSIA is a route-based mechanism, more States participating in CORSIA implies higher coverage of the international aviation emissions under the scheme. Figure 1 illustrates the number of historical (solid bar) and the number of minimum projected (dashed bar) participation of States in CORSIA from 2021, along with their implications on the proportion of international aviation emissions covered under the scheme (line).

The growing commitment of States to CORSIA is evident, with the number of volunteering States increasing from

1 Resolution A41-21:Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change; and Resolution A41-22: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

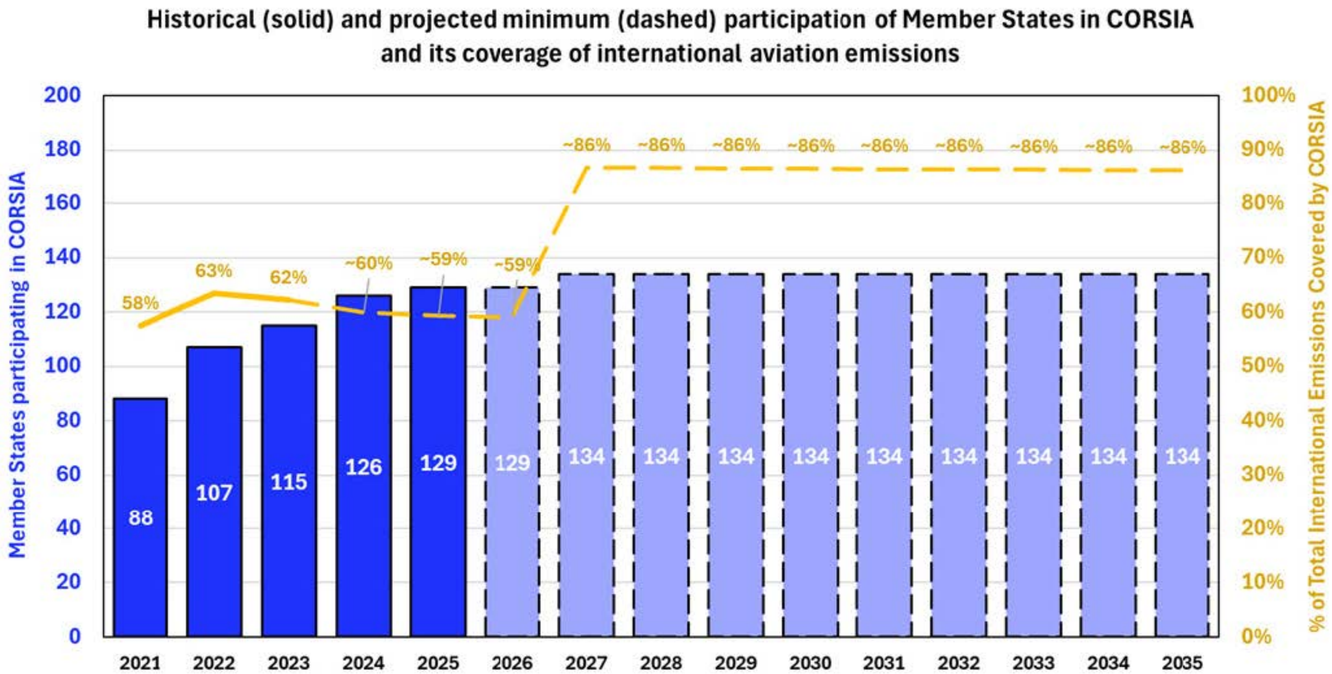


FIGURE 1: Historical and projected minimum participation of ICAO Member States in CORSIA and its corresponding coverage of international aviation emissions (Sources: Versions of the ICAO document – CORSIA States for Chapter 3 State Pairs, CORSIA Central Registry, and IATA Sustainability & Economics)

81 in 2021 to 129 in 2025.[2] Between 2021 and 2023, about 60% of international aviation emissions occurred on routes between two States participating in CORSIA.[3] CORSIA is projected to cover, at least, over 85% of international aviation emissions from 2027 onwards.

This projection takes into account that States whose individual share of international aviation activities in the Revenue Tonne Kilometres (RTKs) in the year 2018 is higher than 0.5 per cent of total RTKs are required to join CORSIA from 2027, as established in Assembly Resolution A41-22. It is important to note that earlier participation of the States with high international traffic volumes, such as Brazil, China, India, the Russian Federation, and Viet Nam, in 2026 could significantly impact CORSIA's coverage in that year. Volunteering from other States not currently participating in CORSIA is also expected to increase CORSIA's coverage. This further underlines CORSIA's growing potential to contribute to the international aviation sector's decarbonization and the need to ensure its strong implementation.

Continuous effort to strengthen CORSIA's environmental integrity

To ensure the environmental integrity of CORSIA, the ICAO Council awards eligibility to programs that can issue CORSIA EEUs based on a set of eligibility criteria. CORSIA Emissions Unit Eligibility Criteria define the elements and measures that must be in place to ensure the units have social and environmental integrity, guarantee that CORSIA EEUs deliver the desired CO_2 emissions reductions, and that no double-counting of their associated emissions reductions occurs.

Double claiming could occur when the emissions units used by aircraft operators in CORSIA are also claimed by another party, such as the host country seeking to meet its nationally determined contributions (NDCs) under the Paris Agreement. To address this issue, ICAO requires eligible programs to obtain a host country attestation to avoid double claiming, a key measure defined in the CORSIA eligibility criteria, and make it publicly available

2 Versions of the ICAO document – CORSIA States for Chapter 3 Sate Pairs, CORSIA Central Registry
3 According to data from the CORSIA Central Registry

before operators can use the associated CORSIA EEUs. Essentially, the national attestations demonstrate that the host countries will refrain from using reductions associated with CORSIA EEUs for their NDCs compliance. This is a welcome approach to minimizing the risk of double claiming.

Accelerated implementation of Article 6 of the Paris Agreement is key

Mitigating the risk of double claiming requires prompt action from the host countries to implement the institutional arrangements that ensure the timely issuance of the national attestations (also known as host country authorization).

In this context, it is important to note that under the UNFCCC process, countries have adopted provisions under Article 6 of the Paris Agreement. Following decade-long negotiations, agreement on open items in Articles 6.2 and 6.4 was achieved at UNFCCC COP 29, resulting in the finalization of the rules in Article 6.2 that provides essential guidance on the process and timing of authorization, its content, voluntary format, changes to authorization, transparency, including the requirement to state the conditions under which authorizations can be revoked, applications of first transfer, sequencing and timing of reporting, correcting inconsistencies, and interoperability of registries, among other elements. This development is a breakthrough in implementing Article 6 and CORSIA as it clarifies to host countries the steps needed to issue letters/statements of authorization (essentially, the national attestations, in ICAO language) and apply corresponding adjustments toward CORSIA EEUs. This is expected to increase certainty for project developers and, consequently, the supply of CORSIA EEUs.

Progress in unlocking and upscaling CORSIA EEUs

In February 2024, the first batch of CORSIA EEUs for airlines' compliance under the scheme was made available through the Architecture for REDD+ Transaction (ART) program for a jurisdictional project based in Guyana. This was followed by the Guyana government's announcement that the associated emission reductions had undergone corresponding adjustment, authorized, and reported to the UNFCCC.

With more programs being approved by the ICAO Council towards the end of 2024, the industry is hopeful that this will lead to an increased timely supply of CORSIA EEUs with the necessary national attestations.

Avoiding a patchwork of market-based measures and pushing for the unified implementation of CORSIA

The ICAO Assembly established CORSIA as the "only global market-based measure applying to CO_2 emissions from international aviation so as to avoid a possible patchwork of duplicative State or regional MBMs, thus ensuring that international aviation CO_2 emissions should be accounted for only once."[4]

Despite this, certain States and regions have established MBMs that also apply to international aviation CO_2 emissions. For example, since 2012, the European Union has implemented its Emission Trading System (EU ETS), a cap-and-trade mechanism, on international routes between European Member States, which also falls within the scope of CORSIA. Furthermore, some countries have already implemented levies on air transport aimed at either achieving an environmental benefit or raising funds to decarbonize other industries, double-charging international aviation emissions.

Apart from complicating operators' compliance requirements, such duplicative efforts also differ from CORSIA's approach as an offsetting mechanism that guarantees robust CO_2 reductions. For some operators, they imply double charging the same tonnes of CO_2 emissions under two different MBMs. It is also worth noting that countries that have implemented such duplicative efforts are also Member States of ICAO and were instrumental in developing and establishing CORSIA.

4 Resolution A41-22: Consolidated statement of continuing ICAO policies and practices related to environmental protection — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

The patchwork of MBMs is observed not only at the regional and national levels but also internationally. The governments of France, Barbados, and Kenya led the Global Solidarity Levies Task Force (GSLTF), established at COP 28 in 2023, to examine innovative sources of climate finance. In its recent public consultation in February 2025, the GSLTF proposed various options for these innovative sources of climate finance. Aviation was identified as one of the targeted sectors for this climate finance.[5] As the United Nations does not apply taxes on businesses or individuals, such measures are more likely to be implemented by individual States.

It is important for the GSLTF and the UN agencies to respect the deliberations and decisions of the States under the auspices of ICAO, which has the prerogative to manage international aviation emissions. The ICAO Member States decided that CORSIA presents the fairest, non-distortive, cost-effective way to achieve effective CO_2 reductions through its unified implementation as per the Standards and Recommended Practices in Volume IV of Annex 16 to the Convention on International Civil Aviation. This approach would also reduce the regulatory and compliance burden and limit any adverse impacts on developing countries' trade and tourism.

Conclusion

The strong commitment from ICAO Member States so far to CORSIA is also reflected on the air transport industry's side, with 670 operators from 131 Member States successfully complying with the requirements of CORSIA (including MRV) in 2024.[6] However, to maintain the scheme's integrity and enable it to function as a credible decarbonization lever for the sector, actions must be taken to avoid duplicative MBMs on international aviation CO_2 emissions.

Furthermore, the landmark agreements on Article 6 of the Paris Agreement achieved at COP 29 provide sufficient clarity to host countries to issue letters of authorization/attestation statements for projects aiming to supply credits for operators to use under CORSIA as CORSIA EEUs. Accelerating these efforts is crucial to creating sufficient liquidity in the CORSIA EEUs market in a timely manner.

5 The following options were proposed for aviation: a kerosene fuel levy; private jets fuel levy; a modular ticket levy; and a frequent flyer levy
6 According to data from the CORSIA Central Registry

CORSIA Eligible Fuels Certification: Processes and Progress

By Juan Ignacio Hermira Herranz (SENASA, Spain)[1]

Sustainability Certification Scheme role under CORSIA

Aeroplane operators can reduce their offsetting requirements under CORSIA through the use of CORSIA Eligible Fuels (CEF), which includes CORSIA sustainable aviation fuels (SAF) and CORSIA lower carbon aviation fuels (LCAF).

Annex 16, Volume IV provides the following definitions relating to CEF:

- *CORSIA eligible fuel*. A CORSIA sustainable aviation fuel or a CORSIA lower carbon aviation fuel, which an operator may use to reduce their offsetting requirements.
- *CORSIA lower carbon aviation fuel*. A fossil-based aviation fuel that meets the CORSIA Sustainability Criteria under this Volume.
- *CORSIA sustainable aviation fuel*. A renewable or waste-derived aviation fuel that meets the CORSIA Sustainability Criteria under this Volume.

To be claimed under CORSIA, all CEF must be certified by a CORSIA-approved Sustainability Certification Scheme (SCS). An SCS is an organization that defines a set of sustainability guidelines that are used to demonstrate compliance with specific regulatory or voluntary frameworks. The SCS develops a set of system documents that define the programme scope that is being certified, which in this case matches the CORSIA requirements.

Under CORSIA, the SCS verifies that the CEF production supply chain participants from feedstock through to fuel production and blending (which under CORSIA are called economic operators) comply with the specific CEF production criteria for CORSIA. Beyond the blend point, chain of custody is tracked by the standard CORSIA Monitoring, Reporting and Verification process defined in Annex 16, Volume IV (see Figure 1).

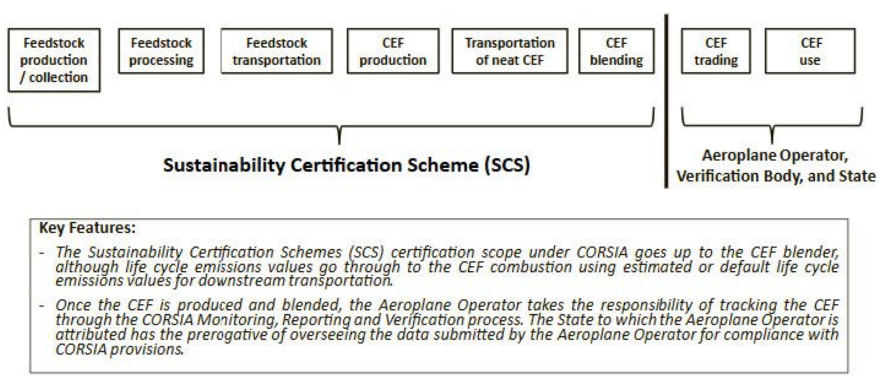


FIGURE 1: The SCS certification requirements along the CEF production supply chain.

1 Juan Ignacio Hermira Herranz is co-Rapporteur of the Sustainability Certification Schemes Evaluation Group (SCSEG).

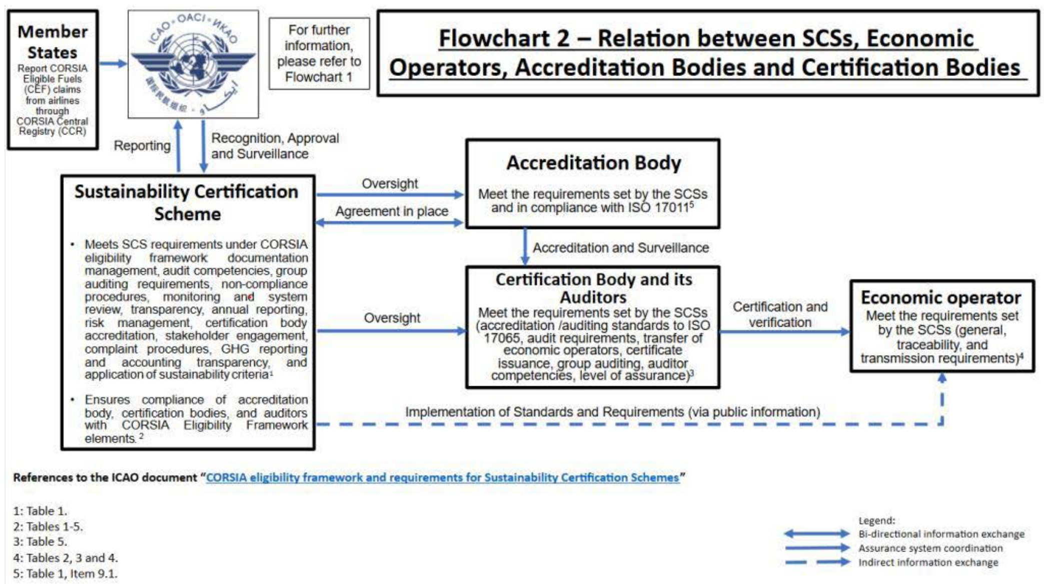


FIGURE 2: The relationship between Sustainability Certification Schemes (SCSs), certification bodies and auditors, accreditation bodies, and economic operators.

The SCS oversees certification bodies and their auditors, who execute the verification of compliance with the SCS programme by the economic operators. The SCS also ensures appropriate accreditation of their Certification Bodies. The relationships among these entities is described in the flow chart in Figure 2, also posted on the ICAO website.

Economic operator certification involves on-site and/or desk audits, depending on the type of facility and whether it is a first audit or not. Auditing occurs at facility and batch level. Group auditing may be undertaken under specific conditions, which reduces the overall auditing burden associated with the certification process while ensuring an appropriate level of assurance. Auditors ensure that the CEF production meets the definitions of the feedstock or conversion process defined in the CORSIA documents, that the life cycle emissions value is appropriately applied, and that all CORSIA-related requirements are met, including compliance with all the CORSIA sustainability criteria.

SCS Approval Under CORSIA

Only SCSs that have met the requirements in the *CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes* (Eligibility Framework) are able to certify CEF economic operators. The Eligibility Framework includes requirements the SCS itself must meet relating to governance, transparency, system scope, etc., as well as requirements the SCS must apply to economic operators, including compliance with the *CORSIA Sustainability Criteria for CORSIA Eligible Fuels*, the *CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels*, and the *CORSIA Methodology for Calculating Actual Life Cycle Emissions Values*, as well as traceability, information transmission, governance and other requirements in the Eligibility Framework. Furthermore, the SCS must apply a set of requirements to Certification Bodies that execute the auditing and certification. The requirements on SCSs and economic operators are set by Working Group 5 (formerly Fuels Task Group) of the ICAO Committee on Aviation Environmental Protection (CAEP).

To determine if an SCS complies with the requirements in the Eligibility Framework and is capable of reliably performing CEF certifications, SCSs are evaluated by a separate ICAO technical working group, the Sustainability Certification Scheme Evaluation Group (SCSEG), which reviews the SCS application form, system documents, programme governance, competencies, requirements on their auditors and certification bodies, and requirements they apply to the economic operators (supply chain participants leading to the production of CEF). The SCSEG evaluates both public and business confidential documents submitted by the SCS and solicits additional information as needed.

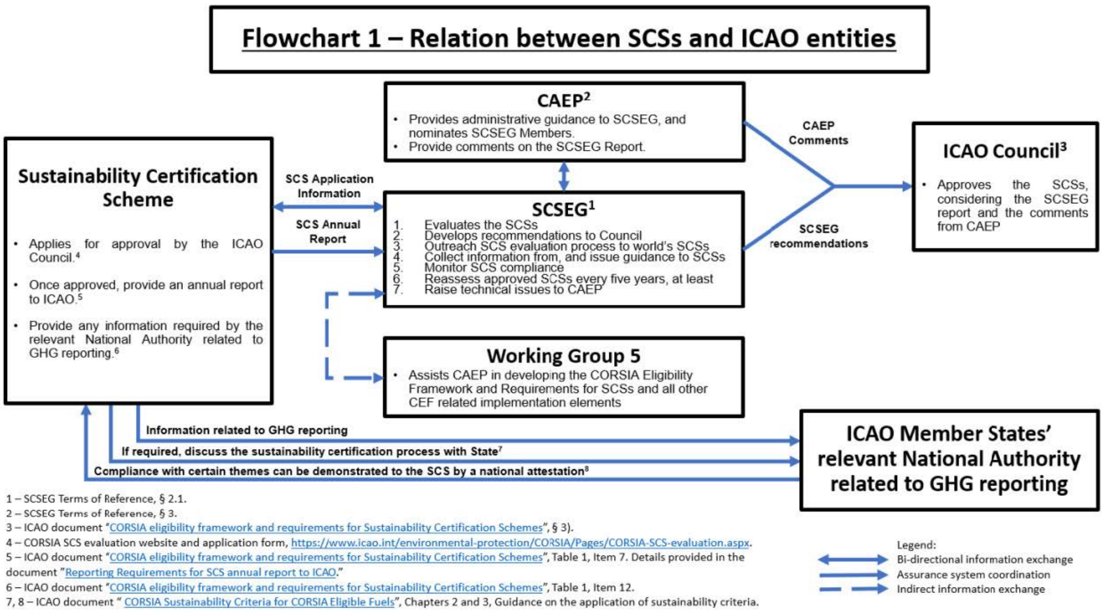


FIGURE 3: The relationship between Sustainability Certification Schemes (SCSs) and ICAO entities.

If the SCSEG determines that an SCS applicant is sufficiently rigorous and compliant with the CORSIA requirements, the SCSEG drafts a recommendation for the ICAO Council. The SCSEG then submits the report to CAEP for a comment period of 30 days to add their perspective, although the CAEP does not approve the SCSEG recommendations. Once the CAEP comment period is complete, the SCSEG submits the recommendation report to the ICAO Council. The Council assesses the recommendation and determines whether to approve the SCS. If approved, the SCS can then be added to the list of CORSIA Approved Sustainability Certification Schemes.

The relationship among SCSs and ICAO entities is shown in the flow chart in Figure 3, also posted on the ICAO website.

As of October 2024, three SCSs have been approved to certify CEF:

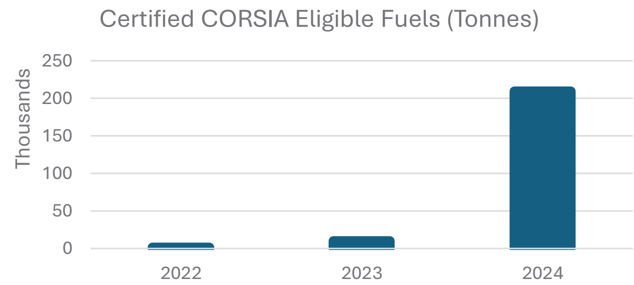
- International Sustainability and Carbon Certification (ISCC)
- Roundtable on Sustainable Biomaterials (RSB)
- ClassNK
- The SCSEG provides implementation guidance to the SCSs on an ongoing basis.

ICAO welcomes applications from SCSs from private sector, non-governmental organizations, or State organizations. Moving forward, SCSEG plans to accept applications on an ongoing basis through March 15, 2026, after which new applications would be accepted from February 1-March 15 annually. More information on the application process can be found on ICAO's website.

CORSIA Eligible Fuels Certification Progress

The approved SCSs provide annual reports to ICAO indicating the economic operators that have been certified as well as individual batches of CEF that have been certified. Economic operator certifications have expanded since the first year of reporting, while batch certification by each SCS has varied. Total CEF volume has greatly increased since the first certifications were undertaken. In 2022, nine batches of CEF were certified totaling 1,542 tonnes of fuel. In 2023, an additional 30 batches of CEF were certified totaling 9,740 tonnes of fuel. In 2024[2], an additional 112 batches of CEF were certified, totaling 209,178 tonnes of fuel.

2 These figures reflect what has been submitted to the SCSEG in the annual reports. At time of publication, the SCSEG is in the process of approving these figures.



CEF production is expected to continue to expand as aviation sector growth leads to further need for emissions reduction via low carbon fuels.

The SCS annual reports also provide insight into potential future CORSIA emissions reductions claims and provide a mechanism to check that claims that are submitted to ICAO match the certified batches.

Conclusion

As aviation continues to rebound and grow, the need for emissions reduction options will increase. Therefore, ICAO anticipates a growing demand for CORSIA Eligible Fuels in the future which will need to be certified for use. CORSIA approved SCSs are facilitating more expedient CEF certification, reducing barriers to CEF production expansion and market entry. ICAO anticipates expanded SCS participation and welcomes additional applications from private sector, non-governmental organizations, or State organizations.

Certification of CORSIA eligible fuels

Experience and expectations of a CORSIA-approved Sustainable Certification Scheme

By Nael Aoun (ClassNK)

Background

The Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has set a goal of replacing 10% of domestic aviation fuel sales with sustainable aviation fuel (SAF) by 2030. Stimulated by government subsidies, Japanese fuel producers, blenders, traders, and airlines are planning actively to establish domestic SAF production facilities.

Cosmo Oil has partnered with Mitsui & Co. and LanzaJet to produce approximately 150,000 Kilolitres (kl) of SAF annually at its Sakaide Distribution Terminal by 2029. In parallel, Cosmo Oil has completed the construction of a SAF production facility at its Sakai Refinery, which is set to produce 30,000 kl annually by 2030. The SAF, derived from used cooking oil, is already certified as CORSIA eligible fuel (CEF). The facility is expected to begin full production in April 2025.

ENEOS, Idemitsu Kosan, and Taiyo Oil are also planning to establish SAF production facilities in Wakayama, Yamaguchi, and Okinawa, respectively. The planned capacities of these facilities are 400,000 kl/year, 250,000 kl/year, and 200,000 kl/year, respectively.

Major Japanese traders, such as Itochu and Marubeni, have also become active in the field of SAF. Itochu, in cooperation with Neste (a neat SAF supplier) and GS Caltex (a blender), has supplied the first CEF batch to Narita International Airport for use by Japan's two major passenger airlines, All Nippon Airways (ANA) and Japan Airlines (JAL).

Meanwhile, Marubeni, in collaboration with the Korean oil refining company HD Hyundai Oilbank, has conducted Japan's first supply of co-processed SAF, which was delivered to ANA.

Last but not least, Japanese airlines, as the key stakeholders in SAF supply and consumption, are engaging actively in SAF initiatives. They are partnering with fuel producers, blenders, and traders, signing SAF supply agreements with refiners and traders, conducting SAF pilot projects, and launching book-and-claim programs to further stimulate SAF production and distribution.

All these initiatives are establishing rapidly a robust SAF supply chain within and to Japan.

The vast majority of Japanese SAF is expected to be derived from used cooking oil. The flagship initiative for this effort is the 'Fry to Fly Project,' which unites numerous Japanese cities, municipalities, and stakeholders from both the public and private sectors. The project aims to collect the hundreds of thousands of tons of used cooking oil generated by Japanese households, public facilities, and businesses and convert it into SAF. The cities of Yokohama and Suita, and Ota Ward, have already begun collecting used cooking oil for SAF production.

In Japan, approximately 2.5 million tons of edible oil are distributed annually. Of this, about 380,000 tons become reusable waste cooking oil, with nearly half repurposed as livestock feed and over 30% exported overseas. These figures highlight the significant potential for expanding SAF production from used cooking oil in Japan.

ClassNK's role

Ever since airlines began reporting their emissions in accordance with ICAO-CORSIA, ClassNK has been the sole approved CORSIA verification body in Japan[1]. As such, ClassNK is a key stakeholder in efforts to reduce aviation sector emissions, aligning with its century-old mission to protect human life, property, and the environment. Therefore, expanding into CEF certification and verification was a natural progression for ClassNK.

To achieve this, ClassNK launched its ClassNK Sustainability Certification Scheme (ClassNK SCS) in 2024[2]. In October 2024, the ICAO council approved ClassNK SCS as meeting the requirements outlined in the ICAO document *CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes*[3]. As a result, ClassNK SCS became eligible to certify economic operators in the CEF supply chain for compliance with CORSIA's sustainability criteria for CEF.

Harnessing its connections with key players across the CEF supply chain in Japan, ClassNK SCS is currently working with major Japanese oil producers, blenders, traders, airlines, and domestic universities to achieve the first ClassNK SCS-certified CEF by the end of 2024 or early 2025. In 2025, additional projects with these stakeholders are planned to further increase the volume of CEF certified under the ClassNK SCS program.

At the same time, ClassNK SCS is reaching out actively to potential certification bodies to encourage their accreditation under ClassNK SCS and support the expansion of CEF certification. The organization is already in the process of accrediting such certification bodies in Japan and Southeast Asia. Ultimately, ClassNK SCS aims to drive the growth of CEF production and trade across East and Southeast Asia.

These projects in Japan and East/Southeast Asia will focus on producing CEF from raw materials such as used cooking oil. ClassNK SCS is proud to promote the recycling of used cooking oil.

Since receiving approval in October of last year, ClassNK SCS has received numerous inquiries from fuel producers and SAF raw material manufacturers. The organization is eager to begin certifying and supervising projects in the near future.

1 Listed as "Nippon Kaiji Kyokai" in the ICAO document "CORSIA Central Registry (CCR): Information and Data for Transparency", Part I (List of Verification Bodies Accredited in States): https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_docs/CCR%20Info%20Data%20Transparency_PartI_12ed_web.pdf

2 https://www.classnk.or.jp/hp/en/authentication/scs/

3 https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO%20document%2004%20-%20Approved%20SCSs%20-%20October%202024.pdf

Bringing CORSIA to a new level while shaping global carbon markets and fostering international cooperation

By Pedro Piris-Cabezas (Environmental Defense Fund – EDF)

Introduction

The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) was adopted by the International Civil Aviation Organization (ICAO) in 2016 as a global market-based measure to mitigate the sector's growing climate impact. A large majority of ICAO's 193 Member States have committed to implementing CORSIA. The scheme employs two necessary and complementary approaches: 1) capping the sector's CO_2 emissions and 2) offsetting emissions that exceed the cap through high-integrity carbon credits or CORSIA Eligible Fuels (CEF).

During its first effective phase with actual offsetting obligations (2024 to 2026), these regulations apply only to international flights between ICAO Member States that have volunteered to participate. When the mandatory phase begins in 2027, CORSIA will extend to all international flights, with some exceptions –for example, for Small Island Developing States (SIDS) or those with a small share of international flights. The CORSIA framework has potential to prevent up to 1.5 billion tons of CO_2 emissions from entering the atmosphere by 2035 while contributing to sustainable development.

In parallel, in 2022 and 2023, ICAO committed to achieving net zero carbon emissions by 2050 and agreed on a global framework for cleaner aviation fuels, including an 5% GHG reduction goal in 2030.

Shaping global carbon markets and international cooperation

CORSIA holds significant potential to shape global carbon markets and promote international cooperation. Article 6 of the Paris Agreement outlies how counties can pursue voluntary cooperation to meet their climate targets, including carbon offsets, and provides crucial guidelines to prevent double counting in interactions between national climate efforts and CORSIA. In the near term, the demand for high-integrity offsets under CORSIA will drive mitigation outcomes generated via Article 6, subject to rigorous reporting and accounting rules, thereby setting the standard for global carbon markets.

The interplay between CORSIA and Article 6 could create a virtuous cycle, mutually reinforcing adherence and stimulating the growth of robust international carbon markets.

CORSIA integrity: Offsets and fuels

For CORSIA offset programs to maintain environmental credibility, they must be based on high-quality credits and avoid double counting –where, for instance, an emission reduction is claimed both by the country of origin and the purchasing airline. Significant progress has been made for

CORSIA-eligible offsets, with stringent high-integrity criteria and mechanisms in place to prevent double counting.

A similar challenge exists for CEF. However, although notable advances have been achieved regarding their sustainability, further measures are needed to prevent double counting of emission reduction claims associated with CEF use, as well as to continue improving the life cycle assessment methodologies to avoid, e.g., unintended consequences on ecosystems and vulnerable communities. Improved monitoring, reporting and verification (MRV) rules are also necessary to strengthen the chain-of-custody of CEF after its blending with conventional jet fuel. For example, intermediate purchasers or traders of blended CEF are not subject to mandatory third-party certification under CORSIA, which creates a material weakness, potentially breaking the chain of custody of CEF sustainability credentials with dire consequences.

Without strong standards, alternative fuels that do not generate genuine emissions reductions and create net harm could flood the market driven by generous subsidies and support in key jurisdictions around the world, thereby displacing not only high-integrity CEF but also demand for high-integrity offset credits.

Moreover, the potential for the inclusion of low-integrity mitigation outcomes as part the life cycle assessment of CEF –such as it could be the case with non-permanent soil carbon sequestration claims or inconsistent energy attribute certificates for energy inputs— could result in material emissions reduction claims that do not meet CORSIA's rigorous criteria for offsets, undermining the credibility of the scheme.

Addressing double claiming in CEF claims

All CEF are vulnerable to double claiming, which necessitates urgent guidance. Preventing double claiming is crucial for the credibility of CEF but also for the overall integrity of CORSIA. It is equally essential for Parties to the Paris Agreement and the United Nations Framework Convention on Climate Change (UNFCCC).

Parties must access reliable information on CEF features and use to fulfil their reporting and accounting obligations. Under the Paris Agreement, Parties need to submit a Biennial Transparency Report that includes the National Inventory Report (NIR) and a Structured Summary with progress updates on the Nationally Determined Contribution (NDCs) (Figure 1). The Structured Summary comprises each Party's selected indicators for tracking progress and an Emissions Balance that documents the debits and credits of Internationally Transferred Mitigation Outcomes (ITMOs) Additionally, Annex I Parties[1] to the Convention are required to provide an annual stand-alone NIR. Finally, Parties engaged in cooperative approaches under Article 6.2 of the Paris Agreement must report on ITMO activity no later by mid-April of the following year.

Similarly, countries have MRV obligations under CORSIA. The CORSIA Central Registry, the primary repository for information on international aviation CO_2 emissions and CORSIA claims, corresponds to the Structured Summary under the Paris Agreement (Figure 1). The CCR captures the necessary information to track progress toward ICAO's climate goals, including on aeroplane operators' claims of emissions reductions from CEF use and on their cancellation of CORSIA Eligible Emissions Units to meet their offsetting requirements in CORSIA. The information compiled by ICAO on emissions units is comparable to the Emissions Balance in Parties' Structured Summaries. In the case of ICAO, there is not a need for a Biennial Transparency Report including NIRs because it holds no practical value for tracking progress toward ICAO's climate goals. However, a conceptual inventory can be viewed as underlying the CCR, mirroring the international bunker data reported in NIRs by applying the same IPCC guidelines and aggregating all bunkers used for international aviation.

The reporting requirements under the Paris Agreement and the Convention necessitate that countries receive timely data on CEF usage under CORSIA to meet their obligations, independently of the temporal flexibility

1 Annex I Parties include the industrialized countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition, including the Russian Federation, the Baltic States, and several Central and Eastern European States.

afforded to aeroplane operators under CORSIA's MRV system. Unfortunately, these temporal flexibilities, combined with insufficient information available in the CORSIA Central Registry, generate a temporal mismatch preventing countries to access data on a timely manner.

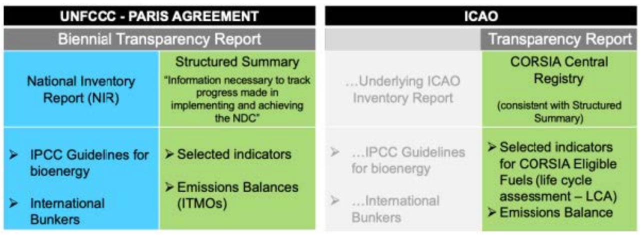


FIGURE 1: Summary of transparency reports under the Paris Agreement and ICAO CORSIA, which are critical for ensuring that proper accounting and reporting of emissions units and fuels.

A way forward to preventing double claiming

With appropriate guidance under the relevant ICAO documents (without necessitating amendments to the SARPs Annex 16, Volume IV), data collected by CORSIA-approved Sustainable Certification Schemes (SCSs) could enable countries to accurately report and account for CEF claims while preserving the integrity of the environmental claims and the flexibility for aeroplane operators to claim CEF use anytime within the CORSIA compliance cycle.

First, countries could incorporate all biogenic CEF use under CORSIA as provided by SCSs as international bunker in their emissions inventories, ensuring timely reporting and accounting obligations under the PA and the UNFCCC, and thereby preventing double claiming of CEF.

Second, to prevent double claiming of mitigation outcomes already reflected in national inventories that are also included as part the life cycle assessment of CEF, concerned countries should authorize, report, and account for these reductions following Article 6 guidance for ITMOs under the Paris Agreement.

A straightforward method for operationalizing these measures could be the issuance of a letter of attestation, whereby countries commit upfront to ensuring that double claiming does not occur. SCSs should require relevant economic operators (e.g., the CEF producer) to obtain and integrate this attestation into the sustainability record. This approach would replicate the procedures already applicable to CORSIA emissions units.

Bringing CORSIA to the next level

Following its initial implementation, ICAO should begin focusing on adapting CORSIA to achieve the imperative of a net zero climate impact by 2050. To that end:

1. CORSIA's ambition should align its near-term goals with the net zero carbon 2050 objective, establishing a meaningful trajectory with an aviation carbon budget compatible with the Paris Agreement's temperature targets and integrating CEF in accordance with ICAO's global framework for cleaner aviation fuels (adopted in November 2023).
2. The current focus on CO_2 should be expanded to encompass the full spectrum of aviation's climate impacts while delivering necessary air quality and public health co-benefits.
3. CORSIA's high integrity compliance mechanism should generate effective price signals to inform mitigation strategies across the entire basket of measures (aircraft technology, operations, alternative fuels, and offsets).

Continued engagement on CORSIA high-quality carbon credits, including removals, will be crucial. These credits are essential not only through 2035 to meet CORSIA's current obligations but also for compensating unmitigated non-CO_2 climate impacts and residual lifecycle emissions from sustainable aviation fuels in the long term.

Key takeaways

Significant progress has been made under CORSIA, but its success hinges on:

1. Continued enhancement of the criteria that ensure the integrity of emissions units and CEF, and
2. An improved MRV system for CEF to ensure transparency and avoid double claiming of emissions reduction claims.

With robust implementation, CORSIA can create a virtuous cycle that aids both countries and aeroplane operators in meeting their climate responsibilities. To fulfil this promise, it is imperative to preserve and enhance the integrity of CORSIA.

Moving forward, ICAO should consider the alignment of CORSIA with an extended net zero target for 2050 that effectively incorporates non-CO_2 climate impacts; so that, in the medium to long term, CORSIA can generate effective price signals that inform mitigation strategies across all elements of the basket of measures.

The 2025 CORSIA periodic review

By ICAO Secretariat

Introduction

The implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is founded upon a series of design elements that represent the "conceptual architecture" of the scheme. These design elements define key aspects of CORSIA such as its phased implementation, the equal consideration of flights operating a same route, the calculation of offsetting requirements, the applicability of CORSIA to new operators, or which international aviation activities are exempted from the scheme.

When ICAO Member States agreed to adopt CORSIA at the 39th Session of the ICAO Assembly in 2016, the CORSIA design elements were defined on the basis of a wealth of knowledge supported by technical inputs from the Committee on Aviation Environmental Protection (CAEP). The agreement also established a periodic review mechanism that, every three years from 2022, would serve as the basis to assess the need to make adjustments to the CORSIA design elements.

The rationale for the establishment of the periodic review mechanism is easily understood considering the timeline of CORSIA implementation. The historical agreement on CORSIA in 2016 embarked the international aviation community on an ambitious journey to implement the first global market-based scheme applicable to any sector at least up to the end of 2035. Hence, ICAO Member States considered it necessary to periodically assess the circumstances under which CORSIA would be implemented, in order to determine whether the CORSIA design elements, as defined in 2016, would still be "fit for purpose".

The cautious approach imbued in the CORSIA periodic review mechanism also serves as the rationale for the CORSIA safeguards provision, whose application is envisaged to serve as a response to circumstances that may prevent CORSIA implementation from contributing its fair share to the sustainable development of the international aviation sector.

As later events showed, it did not take long to prove that this cautious approach was well justified.

The impact of the COVID-19 pandemic and the 2022 CORSIA periodic review

In line with the schedule established in 2016, the first CORSIA periodic review was to be conducted by the ICAO Council, with the technical contribution of CAEP, according to a process and timeline that would result in a series of Council recommendations to the 41st Session of the ICAO Assembly in October 2022.

In March 2020, prior to the start of Council's work on the 2022 CORSIA periodic review, the outbreak of the COVID-19 pandemic had a significant impact on the international aviation sector. In June 2020, the Council considered an initial analysis of CAEP's inputs on the impact of the COVID-19 pandemic on CORSIA and decided to apply the CORSIA safeguards provision by deciding that 2020 emissions should not be used during CORSIA's pilot phase (2021–2023) to define the scheme's baseline.

When, in March 2021, the Council agreed on the process and methodology for the 2022 CORSIA periodic review, there was no doubt that this first review would be greatly influenced by the impact of the COVID-19 pandemic on CORSIA implementation, whose assessment featured prominently on the subsequent technical inputs regularly provided by CAEP. Council's recommendations arising from the 2022 CORSIA periodic review included the following adjustments to the CORSIA design features:

- for the CORSIA baseline, using 2019 emissions for the pilot phase (2021–2023), and using 85% of 2019 emissions after the pilot phase (2024–2035);
- for the calculation of CORSIA offsetting requirements, changing the percentage use of the sectoral and individual operator's growth factors as 100% sectoral and 0% individual (for 2030–2032 period), and 85% sectoral and 15% individual (for 2033–2035 period); and
- for the new entrant threshold, change of reference emissions from 2020 to 2019.

The ICAO Assembly, at its 41st Session, considered Council's recommended adjustments to the CORSIA design features listed above and incorporated them in Assembly Resolution A41-22, *Consolidated statement of continuing ICAO policies and practices related to environmental protection – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)*.

Operationalizing the 2025 CORSIA periodic review

The 2025 CORSIA periodic review began in earnest in March 2023, when the Council requested CAEP to undertake work to support the Council in this task. It is important to note that the Council requested CAEP to conduct its work building upon the process established for the 2022 CORSIA periodic review; in doing so, the Council acknowledged that the type of technical inputs provided by CAEP in the previous periodic review were adequate for the upcoming one, thus bringing an element of **continuity** that served as a connecting thread between both.

This continuity in process-related matters has to be considered in conjunction with an element of **novelty** derived from the fact that the circumstances in which the 2025 CORSIA periodic review is being undertaken significantly differ from those of the 2022 CORSIA periodic review. Two factors help explain such novelty:

1. The 2025 CORSIA periodic review is being undertaken without a disrupting factor of the caliber of what the COVID-19 pandemic represented to the 2022 CORSIA periodic review; the international aviation sector has emerged from the crisis showing traffic volumes trending towards the high-recovery scenarios forecasted at the end of the 2022 CORSIA periodic review.
2. CORSIA implementation has progressed three more years; at the time when the Council presented its 2022 CORSIA periodic review recommendations to the 42nd Session of the ICAO Assembly, the scheme's pilot phase was still under way and this, together with the disruptive effect of the COVID-19 pandemic, limited the extent of the practical lessons that could be derived from CORSIA implementation. In contrast, the 2025 CORSIA periodic review can complement its forecasting analysis of CORSIA implementation in the first phase (2024–2026) and beyond with an assessment of the past implementation of CORSIA's pilot phase.

Since March 2024, CAEP has provided regular updates of its technical inputs to the Council, which has reviewed these inputs with the support of its Climate and Environment Committee (CEC). When necessary, the Council has provided CAEP with additional guidance on areas where subsequent iterations of its technical analysis should focus.

Overview of CAEP's technical inputs to the 2025 CORSIA periodic review

The Council, since the start of the 2025 CORSIA periodic review, has provided an indication of the aspects of CORSIA implementation to which CAEP's technical inputs were expected to pay particular attention, namely: the assessment of the cost impact of the offsetting requirements generated in CORSIA; and the related assessment of supply, demand and price of CORSIA Eligible Emissions Units and CORSIA Eligible Fuels, as well as their regional distribution. In relation to the information provided by CAEP on matters related to CORSIA Eligible Emissions Units, it is important to acknowledge the contribution of the Council's Technical Advisory Body (TAB), which has provided the Council with regular updates on the supply of CORSIA Eligible Emissions Units, including with respect to their sectoral and geographic distribution.

For the sake of transparency, CAEP's inputs to the Council have been made publicly available (following Council's consideration) in the ICAO website[1]; at the time of writing this article, the latest technical analysis by CAEP had been presented to the Council in March 2025.

The inputs provided by CAEP thus far allow for some initial insights, subject to the completion of the Council's work on the 2025 CORSIA periodic review, and without prejudging the final outcome of this work:

- The adjustments to the CORSIA design elements as per the recommendations of the 2022 CORSIA periodic review have strengthened the scheme's robustness and have helped CORSIA absorb the shock caused by the pandemic since its outset in early 2020.

- The most recent technical inputs provided by CAEP reaffirm the accuracy of past estimates, as shown by the following examples:

  - At the end of the 2022 CORSIA periodic review, the estimation of offsetting requirements that would be generated under the scheme through 2035 was calculated to range between 600 and 2100 million tonnes of CO_2 for the scenario whereby the CORSIA baseline would be defined using 85% of 2019 emissions after the pilot phase (2024–2035); the latest information provided by CAEP in the context of the 2025 CORSIA periodic review provides a range of offsetting requirements between 980 and 1500 million tonnes of CO_2; this latter range is narrower than, and falls within, the one considered in 2022, which shows that the 2022 estimates were well-founded and that the successive iterations of the CAEP analysis have allowed for higher accuracy in the estimation of the offsetting requirements.

  - CAEP's latest estimate on the cost addressing offsetting requirements generated during CORSIA's first phase (2024 – 2026) ranges from 1.3 to 8.4 billion USD, which falls within the cost range estimated by CAEP to support deliberations towards the agreement on CORSIA in 2016; in particular, CAEP points out that this cost could represent between 0.07% and 0.46% of international aviation revenue.

- CORSIA implementation proceeds as expected, not only in relation to the analyses conducted in the context of the previous 2022 CORSIA periodic review, but also in relation to the technical information that served as the basis for the 2016 agreement on CORSIA.

- CAEP's inputs thus far seem to indicate that there is no technical reason to recommend adjustments to the CORSIA design elements in the context of the 2025 CORSIA periodic review, unlike what happened in the 2022 CORSIA periodic review as a result of the impact of the COVID-19 pandemic.

More information on CAEP's technical inputs can be found in the article on CAEP/13 updates concerning CORSIA in this chapter.

The way forward

At the time of writing this article, the Council continues its work on the 2025 CORSIA periodic review. CAEP will provide further updates to its technical inputs to the Council in June 2025, including information on the supply of CORSIA Eligible Fuels and CORSIA Eligible Units, and their prices and subsequent costs of the scheme. Following this, the Council will produce a report that will be presented to the 42nd Session of the ICAO Assembly (23 September – 3 October 2025); the report will set out the Council's conclusions and recommendations for consideration by the Assembly.

Pending the Council's final report on the 2025 CORSIA periodic review, all the work undertaken thus far provides a picture of CORSIA characterized by the **stability** of its implementation. Notwithstanding the significant contextual differences between the 2022 and the 2025 CORSIA periodic reviews, the latter has benefited from the governance and procedural arrangements put in place at the time of the first CORSIA periodic review.

Looking beyond the completion of the 2025 CORSIA periodic review, it is important to note that the 2028 CORSIA periodic review will take place after the completion of CORSIA's first phase (2024 – 2026), during which

1 www.icao.int/CORSIA, section *CORSIA Periodic Review*.

offsetting requirements will be generated for the first time, thus leading to the practical implementation of CORSIA's provisions related to the cancellation of CORSIA Eligible Emissions Units and the claiming of emissions reductions from CORSIA Eligible Fuels. Therefore, the 2028 CORSIA periodic review will allow for the assessment of aspects of CORSIA implementation not considered by its two predecessors; the proven capacity of the Council, with the support of CEC, CAEP and TAB, to build upon previous work while adapting to new circumstances will be a guarantee of the successful completion of the task ahead.

A Recap of ICAO's Journey towards 2016 CORSIA Agreement

By ICAO Secretariat

2025 marks three decades since ICAO first began exploring market-based measures (MBMs) for international aviation, during which extensive analysis and consultations were conducted, leading to the ICAO Assembly's 2016 agreement on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Despite the insights gained through years of consultations and deliberations, some UN bodies and other organizations have again resurfaced proposals targeting the aviation as a source for levies and taxes to generate funding for climate finance. It is important to note that ICAO, its Member States and the aviation community thoroughly considered options such as an aviation levy before deciding on a market-based measure (CORSIA) to complement other in-sector measures to address CO_2 emissions from international aviation. This article will revisit the rationale and journey towards the adoption of CORSIA.

Initial MBM Options

The ICAO Committee on Aviation Environmental Protection (CAEP) evaluated various types of levies since 1995 to study its effectiveness in addressing the environmental impact of aircraft engine emissions. The ICAO Council also adopted in 1996 a Council Resolution on Environmental Charges and Taxes, which made a conceptual distinction between a charge and a tax.

> *"A charge is a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation, and a tax is a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis".*

The ICAO Council strongly recommended that **any levies be in the form of charges rather than taxes, and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions**, while also recalling the non-discriminatory principle outlined in Article 15 of the Chicago Convention.

As CAEP advanced its work on the technical analysis of the MBM options over the years, the ICAO Assembly consistently urged **States to refrain from unilateral actions to introduce emission-related levies.** Between 2001 and 2004, CAEP concluded its analysis with diverging views over emission levies. A key challenge was the **concerns of developing countries that emission levies could increase operational costs and impose financial pressure on their air carriers with detrimental impacts on their long-term growth, as well as broader economic and social development.**

The 35th ICAO Assembly in 2004 recognized that ICAO was not ready for the implementation of GHG emissions charges internationally and called for additional guidance and studies as well as consideration of an open emissions trading system (ETS), whereby aircraft operators could trade carbon credits with other sectors. An assessment of the legal aspects of emissions charges and its compatibility with the Chicago Convention was also conducted in 2005, yielding diverging views.

The 36th ICAO Assembly in 2007 first introduced carbon offset mechanisms as another MBM option for international aviation. The Assembly also recognized the urgent and critical need to address emissions from international aviation, emphasized ICAO's leadership role in this area, and agreed on the technical and operational aspects of mitigation measures to address international aviation emissions.

Narrowing Down MBM Options toward CORSIA

The aviation industry faced significant uncertainties in the period from 2009 to 2012 due to a fragmented approach in addressing international aviation emissions. Several States and regions proceeded with unilateral MBMs, despite repeated calls from the ICAO Assembly urging States against implementing unilateral MBMs. This patchwork of MBMs encountered strong resistance from other States and the aviation industry as it was seen as unilateral, duplicative, and market-distorting.

The 37th ICAO Assembly in 2010 achieved an important global agreement on the guiding principles for MBMs and decision to explore a global scheme for international aviation. The Assembly affirmed that **multilateral collaborative actions by all States through a global sectoral approach under ICAO is the most appropriate mechanism to effectively address international aviation emissions**.

At the request of the ICAO Council, the ICAO Secretariat, with consultancy support, assessed the feasibility of global MBM options in 2011-2012. The study identified very **significant differences in additional aircraft operating costs to achieve CO_2 targets through levies** compared to ETS or offsetting. An ICAO Council Ad-hoc Group reviewing this matter subsequently dismissed levy-based options, citing concerns that levies would **suppress demand without encouraging fuel efficiency improvements, involve unresolved legal issues, exclude access to carbon markets, increase economic burdens, and fail to align with the guiding principles of MBMs**. The Group recommended options to the ICAO Council based on a carbon offsetting mechanism and ETS.

Further assessment on the feasibility of the global MBM options continued in 2013 resulting in the publication of ICAO Document 10018, *Report of the Assessment of Market-based Measures* which showed that three options were technically feasible and could contribute to achieving environmental goals. Following this, the 38th ICAO Assembly in 2013 agreed to develop a global MBM for international aviation to be implemented from 2020, for decision by the 39th ICAO Assembly in 2016. The agreement reflected the strong support of ICAO Member States for a global solution to address international aviation emissions.

In 2014, the ICAO Council established the Environment Advisory Group (EAG) to make recommendations to the Council. **The EAG revisited aviation levies but concerns persisted about their effectiveness in delivering environmental benefits, unresolved legal issues, political feasibility, and fair revenue distribution.** As a result, there was no momentum to pursue the global levy proposal. While the ETS option was also previously considered, there were concerns over the **higher implementation cost, administrative complexity, market volatility and limitations on the ability of the sector to grow**, which were considered to be contrary to the Chicago Convention. As a result, by 2016, the ICAO Council started to discuss draft Assembly Resolution text to create a global offsetting scheme for international aviation to achieve the goal of carbon neutral growth from 2020 (CNG2020).

This ultimately led to the groundbreaking agreement on CORSIA at the 39th ICAO Assembly. Notably, the ICAO Assembly emphasised that "**CORSIA is the only global market-based measure** applying to CO_2 emissions from international aviation so as to avoid a possible patchwork of duplicative State or regional MBMs, thus ensuring that international aviation CO_2 emissions should be accounted for only once".

Some key advantages of CORSIA and its design features include the following:

- **Cost-effective option** allowing for a clear emissions reduction based on the ICAO global aspirational goal of CNG2020 for the international aviation sector.
- **Fair distribution of requirements** as airlines only need to offset emissions above the sector's baseline, rather than facing blanket charges / taxes.
- **Incentivizes emissions reduction** within the sector, in particular using sustainable fuels to reduce an airline's offsetting requirements.
- **Administrative simplicity** as emissions and offsets are tracked and reported through an ICAO central registry.
- Phased implementation accommodates the **special circumstances and respective capabilities of States**, while **minimizing market distortion** through the equal treatment of airlines on the same international air routes; and
- Also accounts for the **concerns of developing countries and emerging economies** through the provisions for

new entrant operators, as well as through the definition of the annual sector's growth factor for the calculation of operators' offsetting requirements.

Aviation Levy/Taxation and CORSIA

While ICAO, its Member States and the aviation industry made significant progress in addressing climate change challenges, developments outside the sector related to climate financing have raised important concerns while also presenting opportunities for cross-sector collaborations.

There have been discussions at the UNFCCC Conference of the Parties (COP) meetings about the possibility of aviation emissions levies to contribute to global climate financing around 2009.

During this period, ICAO engaged with the UN High-level Advisory Group on Climate Change Financing (AGF), sharing the sector's achievements and concerns about aviation emission levies. The AGF estimated that aviation could generate up to USD 6 billion annually through fuel levies or ETS but also **recognized that further work on carbon-related instruments should be carried out in ICAO.** In 2011, a World Bank/IMF report again suggested that a carbon charge on aviation could raise substantial climate finance, without acknowledging ICAO's ongoing efforts in aviation decarbonization and the AGF's conclusion. Thereafter, the Paris Agreement in 2015 set a goal for developed countries to mobilize USD 100 billion annually by 2020, with no reference to the aviation sector. In 2024, the COP29 meeting further adopted the New Collective Quantified Goal on Climate Finance (NCQG), aiming to triple finance to developing countries to at least USD 300 billion per year by 2035.

Over the last 30 years, significant efforts have gone into developing a global MBM to address international aviation emissions under ICAO's leadership. Expert groups and high-level State representatives extensively analyzed various MBM options through technical and policy assessments and consultations, culminating in the thoroughly-discussed landmark CORSIA agreement by the ICAO Assembly in 2016. It is crucial to understand that the transboundary nature of international aviation operations requires a globally harmonized MBM in the form of CORSIA to effectively and feasibly address international aviation emissions, while accommodating the special circumstances and respective capabilities of States.

Moreover, it should be recalled that **the complementary role of an MBM scheme is to address aviation emissions that cannot be reduced through aviation in-sector measures, rather than to generate revenue for other purposes.** With the adoption of a collective long-term global aspirational goal (LTAG) of net-zero carbon emissions by 2050 at the 41st ICAO Assembly in 2022, **access to financial resources within the sector became even more critical**, as scaling up sustainable aviation fuels (SAFs) and other cleaner aviation energies to achieve the LTAG will require an estimated USD 3.2 trillion in cumulative investments by 2050.

As the specialized UN agency for international aviation, ICAO has worked tirelessly to develop a global solution to address international aviation emissions, with the strong support of its Member States and the aviation industry. The recent revival of proposals on aviation levies by some UN bodies and other organizations are deeply concerning as they risk undermining the significant achievements and extensive efforts made to develop a global MBM for international aviation, as well as the LTAG, that was agreed by the ICAO Assembly. **Stakeholders both within and without the aviation sector are encouraged to recognize the history and significance of a global MBM for international aviation and to continue supporting the implementation of CORSIA as the only global MBM for international aviation, ensuring the sustainable development of the sector and effective mitigation of aviation emissions.**

* For further details on the evolution of MBMs, please refer to the ICAO article "Evolution of Market-Based Measures: ICAO's Three-Decade Climate Action Journey to CORSIA", available at https://www.icao.int/environmental-protection/CORSIA/Documents/Evolution%20of%20ICAO%20MBMs%20(Levies)%20and%20CORSIA_FINAL.pdf .

ICAO

CHAPTER SEVEN

State Action Plans

Advancing Sustainable Aviation: The ICAO State Action Plan initiative

By ICAO Secretariat

The International Civil Aviation Organization (ICAO) is making significant efforts towards ensuring the sustainable growth of aviation through its State Action Plans initiative. Launched in 2010, the State Action Plan initiative aims to assist ICAO Member States with developing their strategies to reduce CO_2 emissions from international aviation. Throughout the years, the initiative has gained momentum, particularly with the growing focus on Sustainable Aviation Fuels (SAF) and other aviation cleaner energies, all of which are integral to addressing climate change and supporting the achievement of the long-term aspirational goal (LTAG) of net-zero carbon emissions by 2050.

Collaborative Global Efforts

ICAO has seen strong engagement and cooperation from its Member States since the introduction of the State Action Plan initiative. As of May 2025, **150 Member States** have voluntarily submitted their Action Plans, covering **99.11% of global international aviation traffic** measured in **Revenue Tonne Kilometres (RTK)**. This is a significant milestone, demonstrating the commitment of ICAO and its Member States to mitigate aviation's environmental impact and progress toward global climate goals.

FIGURE 1: Map of the State Action Plans submitted to ICAO as of May 2025.

What are the core elements of a State Action Plan?

State Action Plans is a comprehensive living document that outlines each State's measures to reduce CO_2 emissions from international aviation. In this regard, the State Action Plans consist of five key components:

1. **Nomination of Focal Points**: Each State designates a focal point and alternate focal point (if applicable) responsible for the development, udpate and submission of the action plan.
2. **Baseline Scenario (scenario without action)**: States assess their current emissions and future emissions in the case where no action is taken.
3. **Mitigation Measures**: States select from ICAO's Basket of Measures, determining which emission-reduction strategies are most appropriate for their national context.
4. **Expected Results (scenario after taking action)**: States calculate and quantify the expected emissions reduction from the implementation of their selected mitigation measures,
5. **Assistance Needs**: States can include the assistance required to implement their selected mitigation measures.

Aligning with the Long-Term Aspirational Goal (LTAG)

The crucial role of the State Action Plan was highlighted in Resolution A41-21 which requested the Council to regularly monitor progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG, through various tools or mechanisms including monitoring of information from the State Action Plans and means of implementation. In this regard, Member States have been encouraged to regularly submit updates to the action plans every three years, allowing ICAO to track and compile global progress in line with international resolutions and goals.

Supporting States with Updated ICAO Guidance

ICAO remains committed to providing Member States with the necessary tools and resources to develop, update, and implement their State Action Plans. In 2024, ICAO released the fourth edition of Doc 9988, *Guidance on the Development of State Action Plans on CO_2 Emissions Reduction Activities: Towards LTAG Implementation*, which introduces updates that aim to address the recent environmental developments and support the implementation of LTAG goals. The updated guidance includes:

- **Incorporation of SAF, LCAF and other Aviation Cleaner Energies**: The guidance highlights the pivotal role of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF), and other aviation cleaner energies in achieving emission reduction targets.
- **Harmonized Reporting**: provides templates which will allow all States to report quantified data in a harmonized manner to support the aggregation of information.
- **Capacity-Building and Financial Support**: The guidance also emphasizes ICAO's capacity-building efforts and provides information on the financial instruments available to help States implement their mitigation strategies.

The Role of Sustainable Aviation Fuels (SAF)

The development and deployment of SAF are considered among the most effective mitigation measures for reducing CO_2 emissions from international aviation. The ICAO Global Framework, adopted by CAAF/3 in 2023, sets a collective global target to reduce CO_2 emissions in international aviation by 5% by 2030. States have been strongly encouraged to integrate their policies, actions, and roadmaps for SAF and other cleaner fuels into their action plans, allowing ICAO to monitor global progress more effectively. A dedicated session on State Action Plans was delivered on 6 June 2024 as part of the ACT-SAF Series #12,[1] focusing on the incorporation of SAF into State Action Plans.

1 https://www.icao.int/environmental-protection/Pages/ACT-SAF-Series.aspx.

The assessment of 102 State Action Plans submitted and updated since 2020 indicates that 78 States have included SAF as one of mitigation measures, and 102 States have included their national long-term CO_2 reduction measures and targets in their State Action Plans submitted to ICAO.

Building Capacity for Future Success

ICAO supports Member States in meeting their emission reduction targets through robust capacity-building programmes, including regional seminars and training to develop and implement SAPs, and the ICAO SAP Buddy Programme,[2] a peer-learning initiative that pairs States to exchange best practices and provide mutual support in SAP development. Through these SAP Buddy Partnerships, ICAO fosters a collaborative environment where States can learn from one another and share insights to improve their action plans.

ICAO also developed a draft agreement of cooperation intended to serve as a model framework that Member States can utilise to facilitate international partnerships. In this regard, as of 2025, ICAO recognizes the following SAP Buddy Partnerships (Figure 2).

Global Progress: A Regional Breakdown

As of 2025, **150 out of 193 Member States** have submitted their State Action Plans, representing **99.11% of global RTK**. Figures 3 and 4 shows a regional breakdown of the State Action Plan submissions.

Partners		Status of Action Plan		
State providing support	State receiving support	Under development	Submitted to ICAO	Posted on the ICAO website
Bulgaria	North Macedonia		X	X
Spain	Ukraine		X	X
Namibia	Zambia		X	
Kenya	Botswana		X*	X*
Dominican Republic	Panama		X	X
Namibia	Gambia		X	
Italy	Madagascar		X*	X*
Brazil	Mozambique		X	X
Spain	Bolivia (Plurinational State of)		X	X
Indonesia	Timor-Leste	X		

X: The action plan submitted was supported by the ICAO - European Union (EU) Assistance Project on Capacity Building for CO2 mitigation for international aviation.*

FIGURE 2: List of State Action Plan Buddy Programme Partnerships.

Region	States Submitted	States Left to Submit	Percent Submitted
SAM	13	0	**100%**
EUR/NAT	50	6	**89%**
WACAF	21	3	**88%**
ESAF	17	7	**71%**
NACC	15	7	**68%**
MID	10	5	**67%**
APAC	24	15	**62%**
Global	**150**	**43**	**77.7%**

FIGURE 3: Regional breakdown of State Action Plan Submissions (in Percentages).

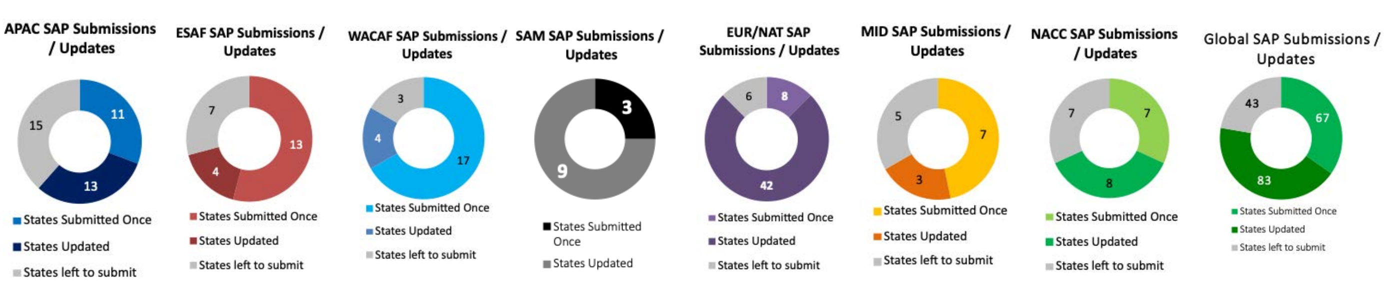


FIGURE 4: Regional breakdown of State Action Plan Submissions and Updates (in absolute numbers).

2 https://www.icao.int/environmental-protection/pages/BuddyPartnerships.aspx.

Celebrating the Success of the SAM Region

ICAO warmly acknowledges the significant milestone achieved by the ICAO South American (SAM) Regional Office, which has become the first ICAO Regional Office to have all its States submit their voluntary State Action Plans. This achievement highlights the dedicated efforts of the SAM States and the SAM Office. ICAO celebrates this collective progress as a vital step and encourages all other ICAO regions to follow towards the global response to climate change.

Looking Towards the Future

ICAO is looking forward to receiving new as well as updated State Action Plans and to reaching new milestones. As those submissions continue to increase, ICAO strongly encourages all Member States to maintain momentum and continue working towards the LTAG of net-zero emissions by 2050. The collaborative efforts of all States will be critical in achieving our collective, ambitious and vital goal for the future of aviation and the planet.

For more details on the ICAO State Action Plan initiative, including resources and support available to Member States, visit ICAO's Environmental Protection page[3].

3 https://www.icao.int/environmental-protection/pages/climatechange_actionplan.aspx

Chile's Actions to Enable Sustainable Aviation

By Martín Mackenna Rueda (Ministry of Transport and Telecommunications, Chile)

Introduction

In line with ICAO's Long-Term Aspirational Goal (LTAG) of achieving net-zero CO_2 emissions from international aviation by 2050, and with the global vision and the Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, adopted at the Third ICAO Conference on Aviation and Alternative Fuels (CAAF/3), Chile is advancing a forward-looking, collaborative strategy to reduce emissions and promote sustainable development in its civil aviation sector.

In 2022, Chile submitted its first State Action Plan (SAP) to the International Civil Aviation Organization (ICAO). This document was jointly developed by the Directorate General of Civil Aviation (DGAC); the Civil Aeronautics Board (JAC) of the Ministry of Transportation and Telecommunications; the International Economic Relations Undersecretary of the Ministry of Foreign Affairs; the Ministry of the Environment; and the Ministry of Energy, with the participation of the *"Vuelo Limpio"* (Clean Flight) program.

This report highlights the implementation of sustainability initiatives and standards across air operations, airport infrastructure and operations, and air traffic management. It also recognizes the potential of green hydrogen (H_2V) to decarbonize aviation, and describes how Chile, through the *Vuelo Limpio* program, is supporting the creation of a collaborative public-private alliance to develop this industry and advance the sector's energy sustainability. In addition, the report reflects Chile's ongoing engagement with ICAO capacity-building initiatives and regional dialogue on CORSIA, and highlights the development of a national study to assess the potential impacts and implementation pathways related specifically to the offsetting phase of the mechanism. It also acknowledges the growing involvement of national air operators in voluntary sustainability efforts.

Progress since the first State Action Plan

The *Vuelo Limpio* program

Since the publication of the SAP, *Vuelo Limpio* has consolidated itself as a leader program in the Chile´s sustainable air transport landscape. The *Vuelo Limpio* program promotes initiatives to decarbonize air transport through public-private collaboration in the sector. Led by the Energy Sustainability Agency, the Civil Aeronautics Board, and the Ministry of Energy, the program engages with the three main national airlines, as well as smaller companies including helicopter operators, and other associated organizations such as airports, aviation fuel distributors, and academia.

One of its key action areas is the promotion of energy efficiency through the development of a baseline for fuel consumption and CO_2 emissions per each air operator company. This baseline corresponds to the first year of reporting and it is monitored on a yearly basis to assess the sector's performance. The program also encourages operational improvements by identifying energy efficiency opportunities, promoting best practices, and facilitating participation in the *"Vuelo Verde"* (Green Flight) working group, a space for public-private cooperation.

In parallel, it fosters the development and adoption of SAF (Sustainable Aviation Fuel) through the creation of the SAF 2050 Roadmap, which addresses five key areas: capacity building, regulation, market development, technology, and the SAF ecosystem. These focus areas are designed to overcome both supply- and demand-side barriers in the market.

Operational – Air Navigation Domain

The DGAC and IATA have established the Vuelo Verde Working Group to promote collaborative decision-making on operational matters. Members include DGAC, JAC, IATA, the *Vuelo Limpio* program, Santiago airport concessionaire, the Chilean Association of Airlines (ACHILA), and national airlines JetSMART, LATAM and SKY Airline. This group has achieved notable outcomes:

- **Simultaneous Approaches Using RNP T:** The implementation of simultaneous approaches using Required Navigation Performance Tango (RNP T) technology at Santiago Airport (SCL) has optimized arrivals from the south, reducing deviations, flight times, fuel consumption, and CO_2 emissions. This initiative has yielded an estimated annual savings of 570,000 kg of fuel and 1,800 tonnes of CO_2, while improving punctuality and operational efficiency. Based on this success, new procedures are being developed to enable simultaneous approaches and departures on both runways, further enhancing operational sustainability amidst increasing air traffic. It is worth noting that during 2024, 99,2% of international and 43,2% domestic commercial flights operate from/to SCL Airport.
- **Airport Efficiency Publication:** A dedicated aeronautical publication was developed to implement an airport efficiency program at SCL. It focuses on reducing aircraft separation between arrivals and departures and optimizing runway occupancy times. This will also lower GHG emissions from aircraft idling during takeoff sequences.
- **Enhanced Airway Navigation:** Continental airway requirements have been updated to incorporate RNP 2 navigation specifications alongside the existing RNAV 5. This enables aircraft to maintain their routes during ATS surveillance system failures (e.g., radar), thanks to improved navigational precision. It also facilitates unrestricted use of all flight levels, enhancing airspace efficiency.
- **Noise Mitigation Adjustments at SCL:** Noise mitigation measures at Santiago Airport that previously restricted nighttime operations on runway 17R have been revised. New limitations based on aircraft noise levels were implemented in line with current environmental regulations. As a result, 17R can now operate 24/7, increasing operational capacity—especially for quieter, more efficient aircraft—while reducing noise impact.
- **Advanced RNP (A-RNP) Implementation:** Chile is progressively implementing Advanced RNP technology at airports, adapted to its mountainous geography. This technology enables more precise departure paths, lowering fuel consumption and enhancing efficiency. It also helps air traffic controllers anticipate flight paths, optimizing airspace capacity without compromising safety. A-RNP approaches have already been implemented in Concepción and Atacama, with upcoming deployments in La Serena and Iquique.

Airport Domain

Significant progress has been made in integrating sustainability criteria into the design and construction of airport infrastructure. Specific plans require contractors to use renewable energy, sustainable materials, and responsible waste management to reduce emissions and improve energy efficiency.

At SCL Airport, 400 Hz systems have been installed at all passenger boarding bridges, allowing aircraft to receive electrical power from the ground. This reduces fuel consumption, emissions, and noise while enhancing operational efficiency and supporting sustainable aviation.

Air Operators

There is growing commitment among national air operators to sustainability, as demonstrated through the implementation of concrete measures. Airlines such as JetSMART, LATAM Airlines and SKY Airline, have adopted strategies to improve operational efficiency, renew their fleets with lower-consumption aircraft, and employ cleaner technologies, resulting nationwide in one of the world's youngest fleets (6,2 years old on average).

These companies also actively participate in the *Vuelo Limpio* program, submitting annual fuel consumption data and implementing actions to improve energy efficiency. As a result, they received national recognition with the "Vuelo + Limpio" certification in 2024.

Research and Development

Green hydrogen (H_2V) is being promoted as a key resource for decarbonizing aviation sector. Led by CORFO (Chile's

Production Development Agency), several initiatives include international financing, technology programs, and the creation of a Technology Center in the Patagonia Region. Efforts are also underway to develop human capital and strengthen international positioning through events such as the Green Hydrogen Summit, establishing Chile as a regional leader.

Current projects have an expected production capacity exceeding 300,000 tons annually. According to the Ministry of Energy (2024), demand will grow toward 2050, driven mainly by international markets, while domestic demand will be led by transport, followed by mining and industry from 2030 onward.

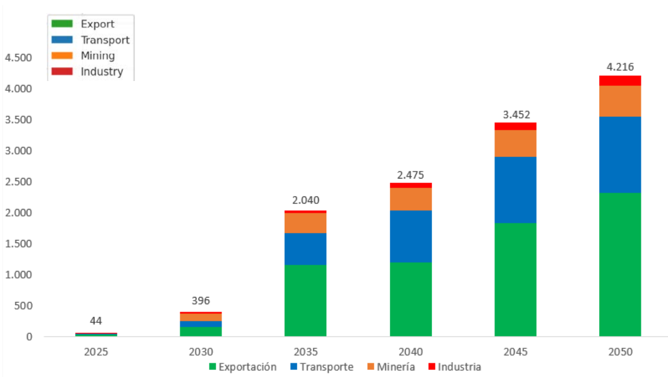


FIGURE 1: Projection of demand for H_2V (kTon H2), by destination, in a scenario consistent with carbon neutrality by 2050

CORSIA

Chile has not yet determined its voluntary participation in CORSIA's offsetting phase starting in 2027. In this context, the country is currently engaged in the ACT-CORSIA capacity-building program, supported by the United Kingdom, to evaluate the potential implications of such participation. This includes a comprehensive assessment of its expected impact on costs, air connectivity, and the competitiveness of the national aviation sector.

International Cooperation

Chile has established strategic partnerships with various countries to advance SAF development. A notable collaboration with the Netherlands focuses on joint research on e-SAF, launching pilot projects, and supporting the development of the Green Hydrogen Innovation Technology Center. It also facilitates information exchange on regulation, financial support, and investment.

In addition, partnerships have also been formed with Brazil and Colombia, strengthening regional integration.

The *Vuelo Limpio* program has actively participated in numerous initiatives, including working groups focused on pilot SAF and e-SAF projects, support for specialized human capital development, and promotion of R&D and innovation in Chile.

National Perspective from the SAF 2050 Roadmap

In 2024, Chile's aviation sector reached a historic milestone, exceeding 28 million passengers, with even more promising projections for the future. Fuel demand is expected to increase by 129% between 2019 and 2050, presenting a significant challenge for energy sustainability.

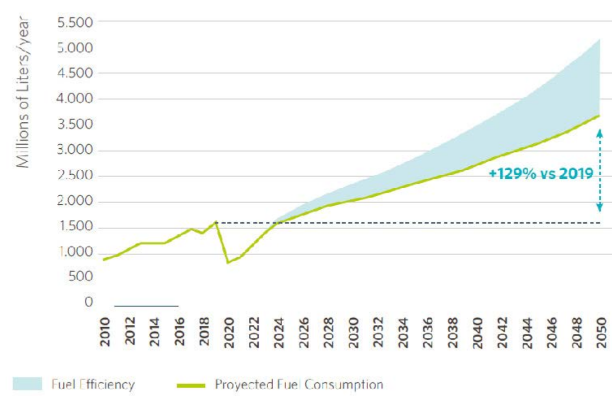


FIGURE 2: Projected aviation fuel consumption in Chile. Source: Chile's SAF 2050 Roadmap.

In this context, the energy transition toward SAF is essential. The SAF 2050 Roadmap, launched in 2024, stands as Chile's main public policy instrument for promoting SAF adoption, setting an aspirational goal of covering at least 50% of civil aviation fuel demand with SAF by 2050.The Roadmap aligns with key national climate policies, including the Long-Term Climate Strategy, the National Energy Policy, the National Green Hydrogen Strategy, and the Framework Law on Climate Change. Its development began in 2022, led by the *Vuelo Limpio* program and supported by the SAF Roundtable, a coalition of over 90 institutions from national, international, and academic sectors, creating a robust foundation for SAF development in Chile.

FIGURE 3: National SAF Ecosystem

The SAF 2050 Roadmap is fully aligned with the global framework for cleaner aviation energies adopted at CAAF/3. It embraces guiding principles such as flexibility, inclusiveness, and country-tailored approaches to scaling up SAF production, while respecting national capacities and promoting social, economic, and environmental sustainability.

This roadmap not only reflects this conceptual alignment with the Global Framework, but also translates it into concrete milestones that showcase Chile's tangible progress towards the aviation energy transition.

Key milestones include:

- **First Public-Private SAF Agreement (2024):** This agreement brought together 48 organizations that committed to supporting SAF development through voluntary actions. Signatories include airlines, the aviation fuel value chain, academia, and associations, with commitments ranging from capacity building to infrastructure development and pilot plant creation.
- **Feasibility Study for SAF Production:** Funded by the Netherlands and conducted through ICAO's ACT-SAF program, this study will assess Chile's available feedstocks—such as agricultural and forestry biomass, green hydrogen, used cooking oil, and captured carbon—for SAF production. It will also evaluate infrastructure, economic and environmental factors, and the potential use of green hydrogen to produce e-SAF, a key solution for aviation decarbonization.
- **Study on International SAF Regulation:** Funded by Chile's Ministry of Transport and Telecommunications, this study will review SAF regulations in countries such as the United States, Singapore, Brazil, and the EU. It will focus on storage, import, production, distribution, and export of SAF.

Next Steps

In 2025, Chile will update its SAP with the aim of presenting a high-quality document aligned with ICAO guidelines, targeting the 42nd ICAO Assembly for sharing its outcomes. National stakeholders have already begun coordinating this work and developed a plan to strengthen both the content and scope of the SAP. Key actions include incorporating projections for international aviation emissions over the coming decades to establish a robust baseline for assessing mitigation impact. Additionally, the plan will seek to quantify the effect of implemented initiatives in terms of CO_2 reduction, enabling more precise planning aligned with national climate commitments. These developments will reinforce the SAP as a strategic tool for decarbonizing Chile's aviation sector.

Moreover, the development of SAF in Chile presents a promising outlook, with initiatives such as *Vuelo Limpio* and the SAF 2050 Roadmap guiding the path toward sustainable aviation. Future efforts will focus on consolidating the SAF ecosystem, enhancing cooperation, and expanding the Public-Private Agreement to accelerate SAF development and adoption. Based on the Feasibility Study results, a Business Implementation Study will be launched to assess the technical and economic viability of SAF production projects, including green hydrogen-based e-SAF options and financing strategies. Simultaneously, work will be carried out to design a regulatory framework that facilitates permitting processes and addresses existing gaps in the development of this emerging industry.

These efforts reaffirm Chile's commitment and contribution to the LTAG, and its alignment with the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies.

Oman Vision 2040: A National Blueprint for Sustainable environment and Clean Energy

By Samah Al. Shibli (Oman Civil Aviation Authority)

Introduction

Oman's commitment to transitioning toward a low-carbon economy dates back to the mid nineties, when the Sultanate of Oman began taking deliberate steps to reduce its over-reliance on hydrocarbons. Oman Vision 2020 was the first strategic framework aimed at shifting away from this dependency, focusing on achieving macroeconomic stability by insulating the economy from oil price volatility and laying a strong foundation for economic diversification.

With the adoption of Paris Agreement, economic diversification has regained urgency in the Sultanate of Oman. In 2020, the Oman Vision 2040 was officially endorsed to guide the nation over the next two decades to an advanced nation's position by focusing on four keys themes: society of creative individuals, competitive economy, responsible state agencies and environment with sustainable components entails keeping a safe and well-preserved environment with effective and balanced ecosystems and renewable resources to support the National Economic.

Oman Vision 2040 outlines a strategic shift towards a diversified, sustainable economy driven by technology, innovation, and competitiveness. The plan aims to reduce the oil share of GDP to 16% by 2030 and 8.4% by 2040, while increasing the non-oil sector's contribution to 91.6% by 2040. Key targets include improving energy efficiency, with energy intensity rising from 6.92 in 2014 to 14.57 by 2030 and 17.3 by 2040. On the environmental front, Oman is striving to significantly enhance its performance in the Environmental Performance Index (EPI). By 2030, the goal is to rank among the top 40 countries worldwide. Looking ahead to 2040, Oman aims to secure a position among the top 20 countries globally.

Environment as a Priority in Oman Vision 2040

Environment and natural resources are key priorities under Oman Vision 2040. The government's strategic direction aims to create effective, balanced, and resilient ecosystems that protect the environment and ensure the sustainability of natural resources, ultimately supporting the national economy. Oman recognizes environmental preservation as a fundamental pillar for its social and economic development. By safeguarding its environment and resources, the country not only mitigates the economic costs associated with environmental degradation but also fosters a more sustainable economy.

The Vision outlines specific objectives to diversify non-conventional energy sources, enhance food and water security, and increase community awareness of environmental issues. These efforts are designed to align environmental, economic, and social priorities, reinforcing the country's commitment to the principles of sustainable development.

As Oman is rich in natural resources, including abundant wind and solar energy potential, which can be harnessed to produce clean energy, the optimal utilization and sustainability of these resources are critical in supporting the country's transition to clean energy and in fostering a green economy that reduces the dependency on fossil fuels.

Oman's commitment to sustainability is reflected in its impressive improvement in global environmental rankings. In 2024, the country rose 95 places to 54th globally (second in the Arab world) from 149th in 2022, showcasing the effectiveness of its environmental strategies and its growing leadership in sustainability efforts.

Net Zero plan 2050

Under the leadership of His Majesty Sultan Haitham bin Tarik, Oman announced in 2022 its commitment to achieve net-zero emissions by 2050, aligning with the Paris Agreement's objective of limiting global temperature rise to below 2°C compared to pre-industrial levels under the UNFCCC framework. This commitment positions Oman among the world's leading nations in shaping a sustainable future and reflects the country's ambition, as outlined in Oman Vision 2040, to overcome challenges, adapt to regional and global changes, seize opportunities, boost economic competitiveness, and enhance social well-being.

Oman has identified a comprehensive pathway that balances environmental, economic, and social priorities to ensure a smooth and sustainable transition. Six main decarbonization technologies would support an orderly transition: energy and resource efficiency, electrification and renewables, battery electric technology, sustainable hydrogen, carbon capture and storage and negative-emission solutions. Together, these technologies would cover ~90% of abatement to 2050. However, the decarbonization targets would require technology to mature, building new infrastructure, increasing adoption levels, introducing policies and legislation and market mechanisms.

Clean Energy Transition and Green Hydrogen Development

As part of its broader low-carbon transition, Oman is investing heavily in clean and renewable energy sources. The country's vast solar potential makes it an ideal location for large-scale solar power projects, particularly in its central and southern regions. Additionally, wind energy is being harnessed in specific southern areas, attracting significant investment and advancing the national clean energy agenda. Key targets include achieving a 20% renewable energy penetration by 2030, and further increasing this to between 35% and 39% by 2040.

A major milestone in Oman's clean energy journey is the establishment of Hydrogen Oman (Hydrom) in October 2022 which is a fully government-owned entity responsible for strategic planning and land allocation for hydrogen projects. By February 2023, over 65,000 square kilometers had been earmarked for renewable energy and clean hydrogen projects, including more than 50,000 square kilometers specifically for green hydrogen. The long-term goal is to produce over 1 million tons by 2030 and potentially 8 million tons by 2050. These ambitious goals solidify Oman's position as a global hub for renewable energy and green hydrogen, contributing significantly to its vision of achieving net zero emissions and transitioning to a sustainable economy.

Sustainable Aviation in Oman

The government's strong commitment to sustainability is reflected across all sectors, including aviation. Oman is dedicated to aligning its efforts to mitigate the environmental impacts of aviation industry with vision 2040 which places environmental sustainability at the core of the country's developmental agenda.

Oman has joined other countries in the adoption of the ICAO's Long-Term Aspirational Goal (LTAG) of achieving net-zero carbon emissions by 2050. This global initiative was developed to complement the goals of the Paris Agreement. In 2023, Oman has submitted its State Action Plan which outlines the expected future air traffic in Oman, the projected emissions from international civil aviation until 2050 as well as the mitigation measures.

Sultanate of Oman has taking proactive actions and efforts to address environmental issues in the aviation sector which will facilitate the reduction of emission. Key initiatives include:

- Fleet modernization,
- Enhanced data-driven aircraft performance monitoring for fuel savings.

- Adoption of industry best practices, such as single-engine taxiing, optimized fuel loading, use of minimized / or reduced flaps during takeoff and landing, minimizing reverses use and selecting aircraft best suited to the mission
- Route optimization and coordination with the CAA to enable shorter flight paths. Oman CAA is currently implementing a strategic national project known as "Ajwaa", aimed at enhancing the integration of air routes, air navigation systems, and operational procedures between the Sultanate of Oman and the airspaces of neighboring countries. This initiative seeks to ensure the highest standards of safety, security, and environmental protection.

The Sultanate of Oman was voluntarily participating in the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) from the pilot phase onward. Oman CAA has issued national legislation to implement CORSIA as a clear legal framework outlining the responsibilities of airline operators and the Authority in managing emissions from international aviation in compliance with the requirements of ICAO.

Oman CAA is working to enhance the Sultanate of Oman's benefits from the implementation of the CORSIA scheme and to maximizing the associated social and economic returns from emission offsetting. It is in close coordination with the Oman Net Zero Centre to ensure that national projects meet the CORSIA eligible units' criteria, to streamline the process of obtaining Letters of Authorization, and to prevent double counting of emissions in line with the requirements of Article 6 of the Paris Agreement on climate change.

As outlined in Oman Vision 2040 and the Net Zero Plan 2050, the country's strategic shift toward renewable energy and green hydrogen and use of different decarbonization strategy may provide a strong foundation for decarbonizing aviation. This includes the development and use of Sustainable and low carbon Aviation Fuels (SAF-LCAF) and green hydrogen-based aviation fuels. With large-scale investments in solar and wind energy, and the allocation of over 50,000 square kilometers for green hydrogen projects, Oman is positioned as a potential future supplier of clean aviation fuels aligned with international climate objectives.

The Sultanate of Oman is actively advancing the development of Sustainable and low carbon aviation Fuel (SAF-LCAF). In 2023, the Civil Aviation Authority hosted the Forum on Innovation Support in Sustainable and Low-Carbon Aviation Fuel and Clean Energies to raise awareness and explore investment and innovation opportunities. To institutionalize progress, a national SAF Taskforce was established in 2024, uniting stakeholders from government, industry, and academia to shape national policy, promote market development, and ensure infrastructure readiness. In 2025, an interactive policy workshop was held to explore potential pathways for SAF development in line with ICAO guidance. Given Oman's position as an oil-producing country, there are ongoing efforts to promote the production of Low-Carbon Aviation Fuel (LCAF) alongside SAF. These efforts will continue to ensure a supportive environment for the production and use of SAF and LCAF in the Sultanate. Nevertheless, the widespread availability and adoption of SAF must consider the challenges associated with its production and use. These include the economic costs, scalability, infrastructure requirements, and potential impacts on operators, producers and society. It is critical to ensure that SAF development does not compromise food or water security, or lead to unintended socio-economic consequences.

The Sultanate of Oman reaffirms its commitment to reducing the environmental impact of the civil aviation sector and contributing to the achievement of the International Civil Aviation Organization's Long-Term Aspirational Goals (LTAG), thereby supporting sustainable development across the sector's economic, environmental, and social dimensions in alignment with Oman Vision 2040.

Operational Benefits of the Implementation of Free Route Airspace in Kano Flight Information Region (Nigeria)

Oyetoun Foluwake Adegbesan (Nigeria Civil Aviation Authority), and Samson O. Akpore (Nigerian Airspace Management Agency)

Introduction

Nigeria has implemented various measures for the mitigation of CO_2 emissions in its efforts to contribute to the global targets set by ICAO. These measures and initiatives, which include improvement of airport operations and infrastructure, air navigation facilities and air traffic management system, and the acquisition of more fuel-efficient aircraft by Nigerian operators, etc. are all detailed in the updated State Action Plan (SAP) submitted by Nigeria to ICAO in November 2024.

As a key component of State Action Plans, the mitigation measures reflect the ongoing mitigation efforts, and in Nigeria's SAP it includes measures in areas such as modernization of fleet used by Nigerian airlines, improved operations/operational efficiency, improvement and modernization in airport infrastructure, improvement in air traffic management and infrastructure use, fuel conservation techniques, regulatory measures, and other cross-sector initiatives.

This article focuses on detailing with one such initiative—showcasing Nigeria's coordinated efforts to improve fuel efficiency and operational practices—while exemplifying how targeted interventions can deliver tangible environmental benefits and align with ICAO's Long-Term Aspirational Goal (LTAG) of net-zero emissions by 2050.

The implementation of the Performance Based Navigation (PBN) has continued to reduce flight times, fuel burn and CO_2 emissions and improve the air navigation and air traffic management within the Nigerian airspace.

The Nigerian Airspace Management Agency (NAMA) has continued to carry out Free Route usage with commendable results, some of which are highlighted as follows:

Highlights of regulatory measures put in place in Air Navigation Services are:

- Establishment of PBN procedures for flight operation across Kano FIR.
- Establishment of Free Route Airspace in the Kano FIR.
- Total Radar Coverage of Nigeria (Kano FIR and adjacent Airspace).
- Total VHF Radio Coverage to enhance Pilot-ATC communication in Kano FIR and adjacent FIRs.
- AIS Automation to enhance seamless flight operation.
- Deployment of New Navigational and Landing aids at Airports e.g. DVOR & ILS.
- Provision of voice and data links systems to enhance seamless flight operation e.g. CPDLC, ADS-B and ADS-C.

CO_2 emissions mitigation through Air Navigation Services (ANS) are:

- Through Direct routing/FRA.
- Establishment of SID and STARs procedures at Airports.
- Area Navigation (RNAV) flight procedures.
- Air Traffic Flow Management (ATFM).

- Enhanced Navigational and Landing Aids for precision operation at airports.
- Tremendous milestone transformation of ANS/ATC to enhance flight safety, expeditious and seamless flight operation.

Free Route Airspace (FRA) Usage and conventional fixed ATS route usage comparison analysis – First Quarter 2023 (Critical Aircraft – B737)

The conceptualization, development, charting, publication and successful implementation of Free Route Airspace – Local (FRA – Local) in Kano Flight Information Region (FIR) which commenced on the 2nd December 2021 was conducted as follows:

1. INITIAL IMPLEMENTATION: AS09/2021 effective date 2nd December 2021
2. FIRST PHASE INCREMENT: AS10/2022 effective date 19th May 2022
3. SECOND PHASE INCREMENT: AS16/2022 effective date 3rd November 2022
   Ref: ENR 4 (4.1 – 4.4) of the Nigeria AIP

Subsequent appraisals of FRA implementation show general operational benefits as follows;

a. Reduction in flight time
b. Reduction in fuel consumption
c. Reduction in carbon dioxide emission
d. Reduction in ATC / Pilot workload
e. Economic and flight efficiency advantages it portends for airspace users between the Kano FIR and Accra FIR.

Within the Kano FIR, specific FRA – Local implementation benefits as observed include the following;

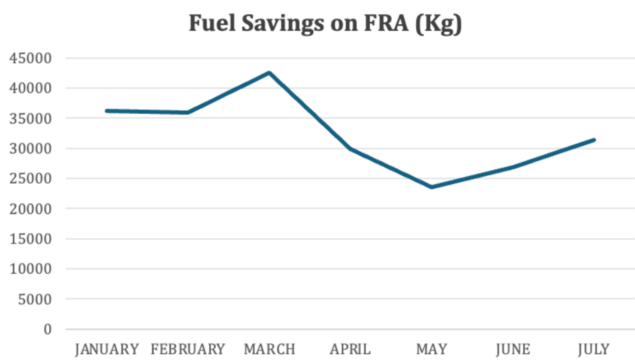
- **Savings in distance** from these improvements could be as much as 39 NM per route leg (route segment) per user, multiplied by number of users per day.
- **Time savings per Route Leg** (Minutes) could be as much as six minutes (6 minutes) per user, multiplied by number of users per day, while
- **Fuel Savings per Route Leg** could be as much as 289.21 Kg per user, multiplied by number of users per day.
- **CO_2 Savings per Route Leg** could be as much as 942.35 Kg per user, multiplied by number of users per day.

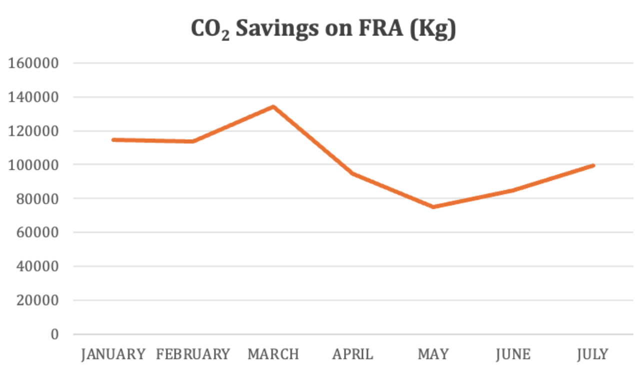
Find on the table in Appendix A, the statistical data for the 1st quarter 2023 (January – March 2023) on the actual **Fuel Savings per Route Leg (Kg)**, and **CO_2 Savings per Route Leg (Kg)** for the international airlines currently operating in the FRA – Local Kano FIR.

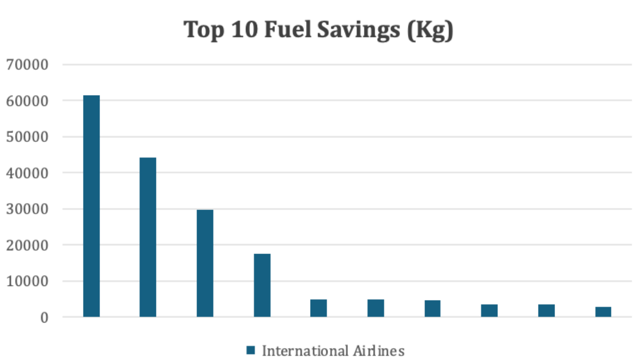
Appendix A

JANUARY 2023		**FEBRUARY 2023**		**MARCH 2023**	
AVIATION FUEL SAVED (KG)	CO_2 EMISSION SAVED (KG)	AVIATION FUEL SAVED (KG)	CO_2 EMISSION SAVED (KG)	AVIATION FUEL SAVED (KG)	CO_2 EMISSION SAVED (KG)
36200.54	**114731.56**	**35901.854**	**113787.206**	**42536.848**	**134415.736**
AVIATION FUEL SAVED (3 Months)		**114,639.242 Kg**			
CO_2 EMISSION SAVED (3 Months)		**362,934.502 Kg**			
AVERAGE MONTHLY AVIATION FUEL SAVED		**114,639.242 kg = 38,213.081 Kg (Prorated) 3 months**			
AVERAGE MONTHLY CO_2 EMISSION SAVED		**362,934.502 kg = 120,978.167 Kg (Prorated) 3 months**			

GRAPHICAL REPRESENTATION OF AIRCRAFT FUEL SAVINGS AND CARBON SAVINGS ON FREE ROUTE AIRSPACE (FRA)







These monthly data can be used as prorated from DECEMBER 2021 – APRIL 2024 (29 months) for FREE ROUTE AIRSPACE (FRA) USAGE / CONVENTIONAL FIXED ATS ROUTE USAGE

***KEY: Shorter distance travelled (FRA) = Reduced travel time = Amount of aviation fuel saved = CO_2 emission saved from entering the atmosphere**

From analysis of the statistical data on the table (Appendix A), the international airlines have saved the following since the implementation of FRA – Local in Kano FIR – **DECEMBER 2021 – APRIL 2024 (29 months);**

1. 38,213.081 × 29 = 1,108,179.349 Kg = 1,108.2 Tonnes

Over 1.1 tonnes of aviation fuel have been saved by international airlines usage of Free Route Airspace in Kano FIR

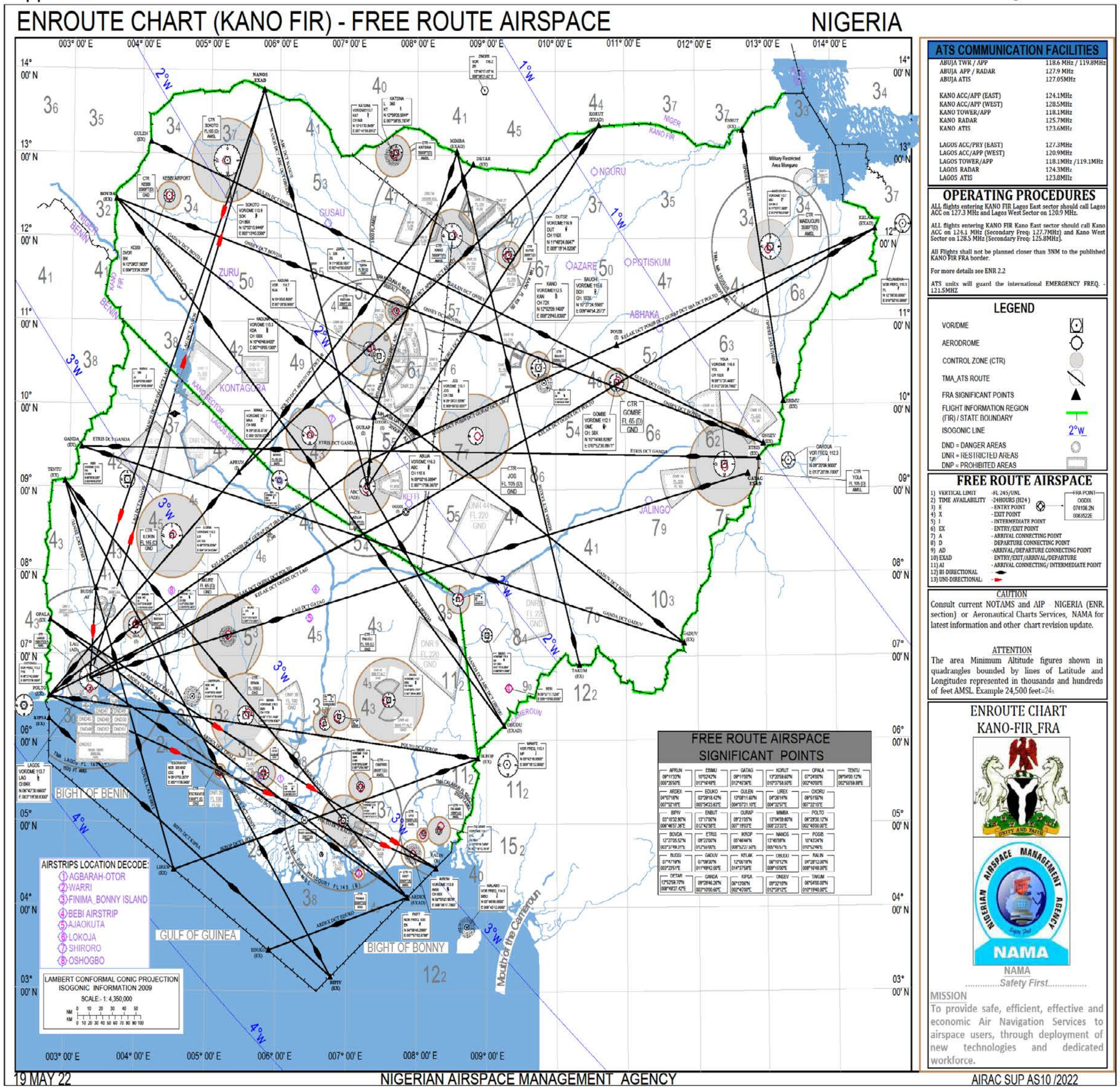
Consequently, from analysis of the statistical data on the table (Appendix A),

2. 120,978.167 x 29 = 3,508,366.843 Kg = 3,508.4 Tonnes

Over 3.5 tonnes of CO_2 emissions have been saved from being released into the atmosphere by usage of Free Route Airspace in Kano FIR

Appendix 5

Page 12 of 12



Assessing the Clarity of Net-Zero State Action Plans

By Supraja Kumar (ICCT)

Introduction

The International Civil Aviation Organization (ICAO) launched its State Action Plan (SAP) initiative in 2010 as a voluntary tool for Member States to report on their actions to reduce carbon dioxide (CO_2) emissions from aviation activity. The objective of SAPs is for Member States to develop strategies for emissions reductions and report on the impact of mitigation initiatives in their respective countries. After the adoption of the long-term aspirational goal (LTAG) at the 41st Assembly, the role of these SAPs becomes more important in monitoring progress towards the net-zero target.

Across aviation decarbonization roadmaps, some of the key mitigation measures for the sector are sustainable aviation fuel (SAF), new aircraft with significant fuel efficiency improvements, operational improvements, zero-emission planes (ZEPs), and market-based measures.[1] When considering various deployment timelines for mitigation measures, achieving the LTAG could result in a range of temperature increase pathways (Figure 1), from about 1.6°C to 2.3°C, depending on the exact emissions trajectory.[2] While the LTAG does not assign country-level emissions goals, it is clear from roadmaps that aggressive action will be needed from across the sector in order to reach net-zero CO_2 emissions by 2050.

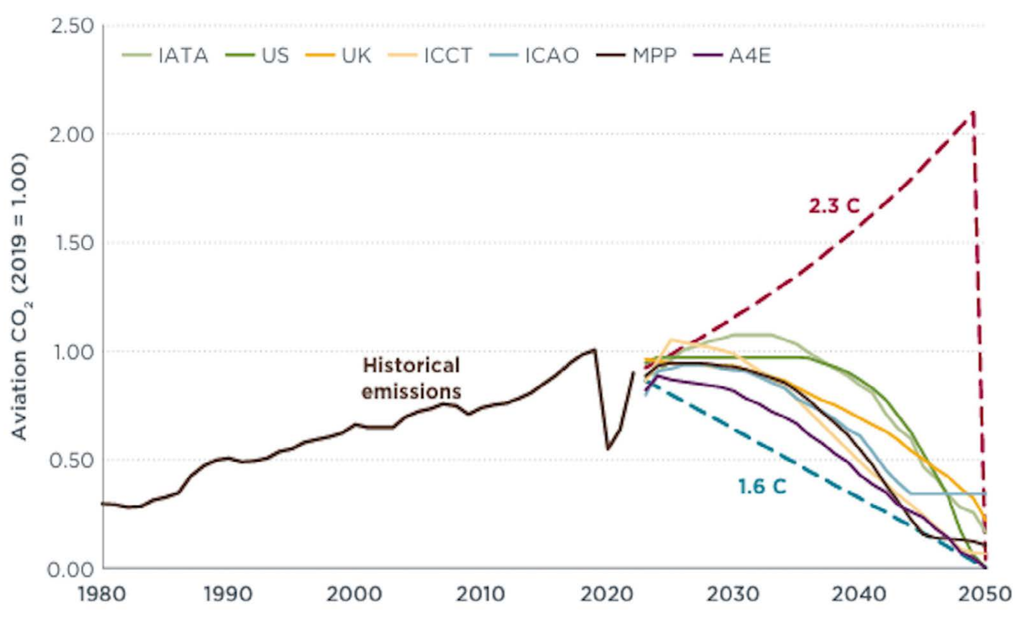


FIGURE 1: Historical and projected CO_2 emissions from aviation, 1980 to 2050, normalized to 2019 (Mithal and Rutherford, 2023).

1 IATA, "Aviation Net-Zero CO_2 Transition Pathways: Comparative Review," April 2024, https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/nz-roadmaps.pdf.

2 Shraeya Mithal and Daniel Rutherford, "ICAO's 2050 Net-Zero CO_2 Goal for International Aviation" (Washington, D.C.: International Council on Clean Transportation, January 5, 2023), https://theicct.org/publication/global-aviation-icao-net-zero-goal-jan23/.

Goal	Focus	Measure
Targets		Interim target (2030 or 2040)
		Long-term target (2050)
In-sector	Technical efficiency	Fuel efficiency improvements
	Operational efficiency	Airport-level initiatives, Air Traffic Control (ATC) improvements
	Sustainable aviation fuels	Blending (% share) or volumetric (gallon or L) target
		GHG reduction target
		Economic incentives for SAF uptake
	Zero-emission planes	Research programs and financial initiatives for ZEP introduction
Out-of-sector	Residual CO_2 emissions and controlling short-lived climate pollutants (SLCPs)	Emissions trading or carbon pricing
		Emissions offsetting
		Carbon capture, utilization, and storage
		Non-CO_2 impacts

TABLE 1: Summary of Focal Areas for SAP Assessment

ICAO recommends that SAPs be updated every three years to reflect new developments, as they could play an important role in understanding the trajectories of Member States towards the LTAG. In 2023, the International Council on Clean Transportation (ICCT) conducted a qualitative review of available SAPs and developed a set of criteria to assess their clarity, focusing on elements that could improve the ability for SAPs to be used in assessments of LTAG progress.[3] The findings of this analysis and recommendations for SAP development are detailed below.

Key Criteria for Assessing SAP Clarity

The ICCT analysis took elements from the SMART goal framework, focusing on assessing whether SAPs communicate *specific*, *measurable*, and *time-bound* mitigation measures in order to conduct a uniform review of their clarity.[4]

The first criterion, specific, refers to tangible reduction goals or policies that are defined by a Member State. The second criterion, measurable, outlines methods that would enable the monitoring and reporting of any goals. The last criterion, time-bound, defines a timeframe by which a given goal will be achieved. An example of a specific, measurable, and time-bound goal is to deploy 5% SAF by volume in all flights departing a given member state by 2030. SAPs that defined goals with these criteria were considered to be clear in our assessment.

Three categories were prioritized for specific, measurable, and time-bound language – targets, in-sector goals, and out-of-sector goals (Table 1).

The first category, targets, considered the inclusion of both an interim emissions reduction target (either 2030 or 2040) and a long-term target (2050). The in-sector goals category included four focal areas from decarbonization roadmaps – technical efficiency, operational efficiency, SAF, and ZEPs – and assessed relevant measures within each of them. The third category, out-of-sector goals, included any measures targeting residual CO_2 emissions or SLCPs, such as contrails.

SAPs are made publicly available at the discretion of Member States, and for this study, a set of 17 SAPs were selected, prioritizing the most recent submissions and

3 Daniel Rutherford and Shraeya Mithal, "Towards Net-Zero Aviation State Action Plans" (Washington, D.C.: International Council on Clean Transportation, October 25, 2023), https://theicct.org/publication/state-action-plans-oct23/.
4 Two other SMART criteria, being *achievable* and *relevant*, were deemed beyond the scope of the study.

capturing a diverse group of aviation markets across World Bank income groups.[5,6]

A review of 17 publicly available SAPs submitted through April 2023 was conducted, assessing clarity of measures using the above methodology. From this review, a few observations could be made:

- Most SAPs did not include clear interim or long-term emissions targets.
- Operational and technical efficiency measures were prioritized for in-sector goals.
- Clarity of SAPs on SAF and ZEP measures dropped dramatically between high-income countries and those in the upper-middle, lower-middle, and low-income country categories.
- Most countries detailed their participation in emissions offsetting measures, such as CORSIA.

ICAO has a number of resources available that Member States could use in their SAP development process. For example, the Environmental Benefits Tool (EBT) to aid in setting long-term and interim targets, the Fuel Savings Estimation Tool (ISFET) for assessing fuel efficiency and MBMs, and the ACT-SAF program to guide SAF deployment initiatives.[7,8]

As Member States continue to update their SAPs in the coming years to reflect their climate goals and progress, they could improve their clarity by communicating specific, measurable, and time-bound mitigation measures across key focal areas. This would enable SAPs to be used more widely to assess compatibility of the sector's activity with net-zero targets, which is a key priority of the ICAO Committee on Aviation Environmental Protection's (CAEP) LTAG Monitoring and Reporting Task Group (LMR-TG).

This effort is supported by the new edition of the *ICAO Guidance on the Development of State Action Plans on CO_2 Emissions Reduction Activities: Towards LTAG Implementation* (ICAO Doc 9988) which has been updated by ICAO in 2024. This Guidance reflects the adoption of the LTAG and emphasizes the pivotal role of SAPs in monitoring progress on the implementation of all elements of the basket of measures towards the achievement of the LTAG. It also encourages Member States to include specific activities regarding the development and deployment of SAF, LCAF and other aviation cleaner energies in their SAPS, in line with the ICAO Global Framework adopted by CAAF/3.

5 ICAO, "State Action Plans and Assistance," State Action Plans and Assistance, accessed April 29, 2025, https://www.icao.int/environmental-protection/pages/climatechange_actionplan.aspx.
6 World Bank, "World Bank Income Groups," 2025, https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
7 ICAO, "Environmental Tools (E-Tools)," Environmental Tools (E-tools), accessed April 30, 2025, https://www.icao.int/environmental-protection/Pages/Tools.aspx
8 ICAO, "ICAO Assistance, Capacity-Building and Training for Sustainable Aviation Fuels (ICAO ACT-SAF) ," ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ICAO ACT-SAF), accessed April 30, 2025, https://www.icao.int/environmental-protection/Pages/ACT-SAF.aspx

ICAO

CHAPTER EIGHT

Capacity Building and Implementation Support

ACT-SAF and ACT-CORSIA Programmes overview & recent developments

By ICAO Secretariat

ICAO ACT-SAF Programme

The achievement of the LTAG requires a robust, targeted and tailored capacity-building and implementation support programme, and that ICAO, industry, academia and other relevant stakeholders need to work together to deliver such a programme, taking into account different circumstances of States and regions, and in line with the ICAO's *No Country Left Behind* initiative.

Launched in June 2022, ICAO Assistance, Capacity-building and Training for SAF (ACT-SAF) Programme creates opportunities for States to develop their full potential in SAF development and deployment, as recognized by the ICAO Assembly Resolution A41-21, paragraph 18c), and is aligned with the ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies, adopted at ICAO CAAF/3.

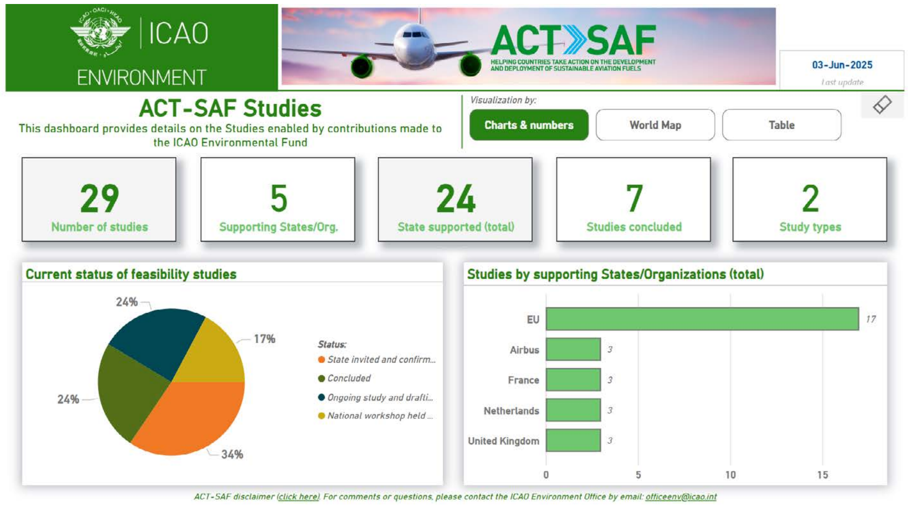
ACT-SAF aims to provide tailored support in multiple initiatives for States in various stages of SAF development and deployment, facilitate partnerships and cooperation on SAF initiatives under ICAO's coordination, and serve as a platform for knowledge sharing and recognition of all SAF initiatives globally.

ACT-SAF Training

A key component of ACT-SAF is the provision of targeted conceptual training on SAF. The ACT-SAF training series offers comprehensive coverage of key SAF-related topics, including sustainability certification, lifecycle emissions, production technologies, policy development, project financing, and downstream logistics. These sessions have benefitted from the valuable contributions of ACT-SAF partner States and Organizations, as well as insights from industry experts referred to ICAO. To date, nineteen training sessions have been delivered, all of which are accessible on ICAO.TV[1].

In addition to the virtual training series, ICAO has partnered with the United Kingdom to develop foundational SAF training content and policy implementation modules. These were delivered through in-person workshops held in Cameroon, Equatorial Guinea, and Tanzania in March and April 2024, with participation from representatives of Angola, the Democratic Republic of the Congo, and Gabon. Additional workshops have also been delivered in Mexico in coordination with the ICAO NACC regional office. ICAO is currently assessing further in-person training events through resources offered by Austria.

1 https://www.icao.tv/act-saf-series



SAF Feasibility and Business implementation studies

ACT-SAF feasibility studies[2] provide the initial steps for a State in realizing its SAF development potential. This is done through assessments on state-specific feedstock and corresponding conversion pathways, together with identifying financing, capacity building elements, and an action plan for establishing an efficient and sustainable value chain for SAF. Prior to ACT-SAF, support to States on feasibility studies have taken place within the framework of the ICAO and European Union assistance project - Capacity building for CO_2 mitigation from international aviation. Business implementation studies builds upon the work of the feasibility studies, with detailed analysis of the shortlisted feedstock/pathway, supplemented with sustainability and life-cycle assessments, assessments of SAF production costs, market supply/demand, and technical-economic analysis.

To date, seven studies have concluded, and 21 additional studies have commenced, or are in planning stages, thereby operationalizing contributions by France, Netherlands, United Kingdom, Airbus, and the European Union. More studies are projected in coming years.

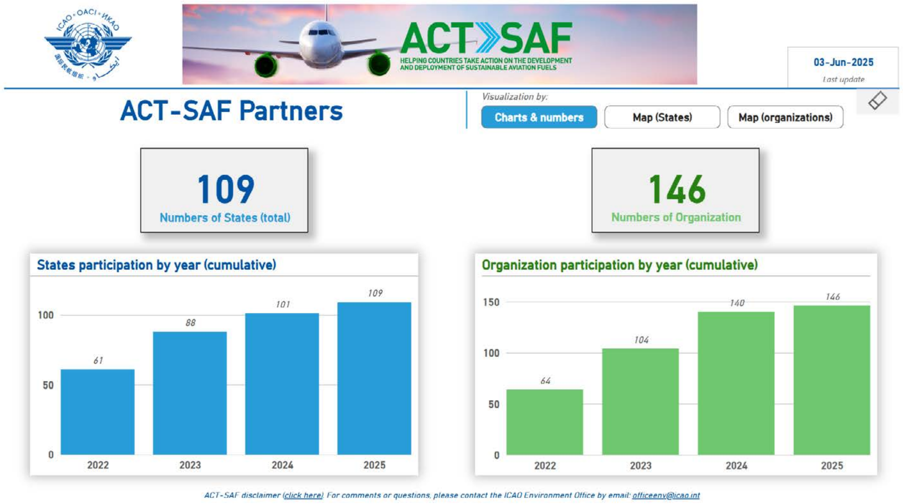
Templates and Guidance for SAF feasibility and business implementation studies

ICAO has also developed templates and guidance documents, used by consultants working on the above-mentioned feasibility and business implementation studies. This sets out a consistent approach towards their development. In addition, it also supports self-funded States, embarking on similar work, in detailing key elements expected.

Information Sharing - ACT-SAF Platform

The ACT-SAF platform[3] recognizes the many ways partners and stakeholders are supporting the implementation of cleaner energies for aviation, including SAF. With the aim of facilitating the coordination of efforts globally, and avoiding overlaps of efforts, ICAO compiles a list of feasibility studies, training/outreach, as well as events.

2 https://www.icao.int/environmental-protection/Pages/act-saf.aspx
3 https://www.icao.int/environmental-protection/Pages/act-saf.aspx



Updates on ACT-SAF are disseminated to partners through regular newsletters, updating on recently concluded/upcoming trainings, progress on feasibility/business implementation, key SAF developments globally, as well as ICAO events.

ACT-SAF Accelerator

This project provides support to accelerate the analysis and approval of life cycle values for new fuel sources and pathways. With resources provided by France, the first ACT-SAF accelerator project will support the analysis of feedstocks with potential to be used for SAF production (cassava/cashew), as identified on the ACT-SAF feasibility study for Cote d'Ivoire. Support has also been extended regarding the inclusion of SAF in the national bioenergy code.

Participation in ACT-SAF – all are welcome!

ICAO States and organizations interested in taking action to develop SAF initiatives are welcome to participate in ACT-SAF – this can be done by agreeing to the ACT-SAF Terms and Conditions[4]. To date, more than 250 States and organizations are recognized as ACT-SAF partners. ICAO welcomes more participation from Member States (civil aviation authorities, fuel or energy-related authorities), aviation industry (manufacturers, aeroplane operators), fuel producers/industry, academia, financial institutions (e.g., development banks), civil society organizations and associations interested in aviation-related climate change action.

Beyond ACT-SAF – what's next?

With the successful operationalization of the ACT-SAF programme, ICAO plans to extend the work towards an ACT-LTAG programme – building upon the ACT-SAF approach, and connecting ICAO initiatives on capacity building related to technology and operations.

ICAO ACT-CORSIA Programme

Launched in 2018 and also as part of ICAO's *No Country Left Behind* initiative, the ACT-CORSIA (Assistance, Capacity-building and Training for the Carbon Offsetting and Reduction Scheme for International Aviation) Programme aims to ensure that all States are equally equipped to implement CORSIA, the first global market-based measure developed for any industry sector. More information on CORSIA is in Chapter 6 of this Report.

4 https://docs.google.com/forms/d/e/1FAIpQLSf28JBcRZNR9Xdj-LGB4XCZuhfwflBSmsl9zjqeBGz5fGoUZA/viewform

The ACT-CORSIA Buddy-Partnerships

The "Buddy-Partnerships"[5] initiative lies at the center of ACT-CORSIA, matching supporting and recipient States to enable practical, hands-on support for the implementation of the CORSIA Monitoring, Reporting, and Verification (MRV) system. These partnerships have proven to be an efficient mechanism for knowledge transfer and institutional strengthening. As of 2025, over 119 recipient and 16 supporting States are engaged in Buddy-partnerships activities, which include training sessions, technical assistance, and the use of tools such as the ICAO CO_2 Estimation and Reporting Tool (CERT) and the CORSIA Central Registry (CCR). In addition, ACT-CORSIA supports States in developing the legal and regulatory frameworks needed for robust CORSIA implementation, including the collection, verification, and reporting of emissions data.

The Buddy-partnerships consider the States' specific needs to develop appropriate capacity-building and training activities. These activities have been designed in a flexible manner to adjust the delivery of training, offering tailored solutions while maintaining a coordinated approach, with an annual Training of Trainers event hosted by ICAO aimed at keeping the ACT-CORSIA trainers from all Supporting States aligned with the general developments and most pressing matters on CORSIA implementation.

ACT-CORSIA Outreach material

Over the years, ACT-CORSIA has developed and made available several elements to support capacity building, such as brochures and leaflets[6]; model regulations[7]; and recordings of seminars[8]. It also maintains the CORSIA Frequently Asked Questions (FAQs)[9] and monthly issues the CORSIA Newsletter[10], with a view to continuously inform Member States and the wider public on the status of CORSIA implementation.

Navigating CORSIA and Training Courses

"Navigating CORSIA - A guide to the scheme's design and implementation"[11] is an initiative consisting of a package of pre-recorded presentations on CORSIA, prepared for an audience interested in CORSIA but not fully conversant with the scheme's design and implementation features. The material, which can be accesses through the ICAO TV platform, was updated in 2023 and consists of the following videos:

- Introduction to 2023 Navigating CORSIA[12];

5 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Buddy-Partnerships.aspx
6 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-communication.aspx
7 https://www.icao.int/environmental-protection/CORSIA/Pages/ICAO_model_regulations.aspx
8 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Seminars.aspx
9 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx
10 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIANEWSLETTERS.aspx
11 https://www.icao.tv/navigating-corsia
12 https://www.icao.tv/navigating-corsia/season:1/videos/introduction-to-navigating-corsia-by-ms-jane-hupe-deputy-director-environment

- Session 1 – CORSIA Overview[13]
- Session 2 – CORSIA's Monitoring, Reporting and Verification and related tools[14]
- Session 3 – CORSIA Eligible Fuels[15]
- Session 4 – CORSIA Eligible Emissions Units[16]

ICAO, under the Global Aviation Training (GAT) programme, continues to provide courses on CORSIA; the CORSIA Verification Course, launched in 2019 to train verification bodies, was updated in September 2023 to align its contents with the Second Edition of Annex 16, Volume IV. In light of the increasing interest on aspects of CORSIA implementation such as CORSIA Eligible Fuels and CORSIA Eligible Emissions Units, it is expected that three more courses on CORSIA will be available in the last quarter of 2025.

The future of ACT-CORSIA

By strengthening institutional capacity, enhancing technical expertise, and promoting cooperation, ACT-CORSIA ensures that all States can actively contribute to addressing the climate impacts of the international aviation sector by facilitating CORSIA implementation. As more States join the effort and new phases of CORSIA unfold, ACT-CORSIA continues to build the foundation for a globally consistent and transparent implementation of this landmark climate measure.

13 https://www.icao.tv/navigating-corsia/season:1/videos/corsia-overview
14 https://www.icao.tv/navigating-corsia/season:1/videos/corsia-s-monitoring-reporting-and-verification-system-and-related-tools
15 https://www.icao.tv/navigating-corsia/season:1/videos/corsia-eligible-fuels
16 https://www.icao.tv/navigating-corsia/season:1/videos/corsia-eligible-emissions-units

Regional Perspectives on Progress from ICAO Regional Officers towards the Long-Term Global Aspirational Goal (LTAG)

By Peter Dunda (APAC Region), Chinga Mazhetese (ESAF Region) Blandine Ferrier (EUR/NAT and WACAF Regions), Radhouan Aissaoui (MID Region), Luis R. Sanchez (NACC Region), Jorge Armoa (SAM Region)

Environmental Protection Activities in ICAO's Regional Offices: Progress and Outlook

ICAO continues to make significant advancements in promoting environmental sustainability within the international aviation sector. As part of its commitment, ICAO's Regional Offices play a crucial role in implementing environmental initiatives and supporting Member States in meeting ICAO's ambitious environment and climate goals. This section focuses on the efforts and achievements of all of ICAO's Regional Offices in advancing ICAO's environmental objectives. Through a range of activities, including enhancing regional development of State Action Plans, assisting States with their involvement in the ACT-SAF Programme, and supporting States with the implementation of CORSIA, the Regional Offices are actively driving progress toward reducing aviation's carbon footprint and ensuring a sustainable future for international aviation. This report highlights the key initiatives, challenges faced, and the future outlook for continued success in the region.

Asia and Pacific (APAC) Regional Office

Introduction

The ICAO Asia and Pacific (APAC) Regional Office is committed to promoting the environmental sustainability of international civil aviation across the APAC region. To achieve this objective, the APAC Regional Office has identified five key tasks that are essential for driving meaningful progress:

- Implementation Support for ICAO Standards: Assisting States in implementing the requirements of ICAO Annex 16 – Environmental Protection - Volume IV – Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and other Environment guidance materials, with a particular focus on addressing the development and update of State Action Plans (SAPs) to reduce CO_2 emissions and fulfilling the requirements of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).
- Stakeholder Engagement: Facilitating cooperation between Member States and international and regional organizations through external conferences, seminars, and meetings, amongst others.

- Monitoring Progress: Tracking implementation progress, identifying common challenges, and addressing support needs of Member States.
- Promote Research and Awareness: Promoting the dissemination of knowledge on climate change impacts on aviation and increasing awareness across the APAC region.

Sustainable Aviation Fuels (SAF)

In the area of SAF, the APAC Regional Office is actively engaged in supporting the advancement of ICAO's Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF) Programme. The Regional Office's activities include facilitating the implementation of ACT-SAF, organising environment-focused events in the region, participating in relevant regional and international forums, and promoting collaboration on ICAO's environmental policies. The APAC Regional Office also coordinates the registration of additional States and organizations that have expressed their intention in participating in the ACT-SAF Programme. In this regard, between January 2023 and May 2025, the APAC Regional Office has organized a number of internal events to further promote SAF initiative and the ACT-SAF Programme.

As part of its efforts to support States in implementing ICAO's environmental objectives, the APAC Regional Office has organized regional environmental seminars as described below:

- **2023 APAC Environmental Regional Seminar** – This seminar focused on encouraging stronger commitment among States in working towards achieving the outcomes of the 41st ICAO Assembly. The event focused on the implementation of the Long-Term Global Aspirational Goal (LTAG), including providing updates on the ACT-SAF Programme and financing for aviation cleaner energy initiatives.
- **2024 APAC Regional Seminar on Environment** – This seminar was aimed at raising awareness and facilitating the exchange of views on the implementation of the LTAG and the Global Framework on SAF, Lower Carbon Aviation Fuels (LCAF) and other aviation cleaner energies. The discussions during the seminar addressed recent developments in aviation cleaner energy policies, State Action Plans, the role of CORSIA eligible fuels, implementation challenges, updates on the ACT-SAF Programme, as well as financing mechanisms.

In addition, between January 2022 and May 2025, the APAC Regional Office has actively promoted the ACT-SAF Programme by participating in various international and regional events, in collaboration with international organizations such asIATA, ACI and organisations in the AFI Region; regulatory authorities including the FAA and ASEAN; and industry stakeholders such as Honeywell, Airbus, and Mitsui.

Looking ahead, the 2025 APAC Environment Regional Seminar will aim to strengthen compliance with the CORSIA offsetting requirements, foster regional collaboration on SAF, LCAF, and other aviation cleaner energies, and continue to support the ACT-SAF Programme.

State Action Plans (SAP) on CO_2 Emissions Reduction

With respect to the implementation and advancement of State Action Plans, the APAC Regional Office undertakes a range of activities to support Member States in aligning with ICAO's environmental objectives. This includes maintaining regular engagement with designated State Focal Points to facilitate continuous implementation support. The Regional Office also organizes and delivers technical assistance activities, including tailored support for Pacific Small Island Developing States (PSIDS), supporting the development and submission of their State Action Plans and the incorporation of relevant mitigation measures to support the implementation of the LTAG.

In addition, the APAC Regional Office supports States in incorporating quantified data into their SAPs, highlighting their individual contributions toward the achievement of ICAO's global aspirational goals. These efforts are further complemented by APAC's participation in and support of various environmental events held in the region, as well as representation in relevant regional and international forums to promote further collaboration on ICAO's environmental policies and objectives. In this regard, below are some notable events:

- **2022 Webinar on the State Action Plan Initiative for CO_2 Emissions Reduction:** This event aimed at sharing updates on new ICAO activities related to SAPs, highlighting the outcomes of the 2022 ICAO Stocktaking and the High-Level Meeting on the Feasibility of a Long-Term Aspirational Goal for International Aviation CO_2 Emissions Reductions (HLM-LTAG).
- **2023 Workshop for Pacific Small Island Developing States (PSIDS) on State Action Plans (SAPs) for CO_2 Emissions Reduction in International Aviation:** The primary objective of this workshop was to provide PSIDS with direct support in preparing and submitting their SAPs to ICAO, while also raising awareness on ICAO's updated environmental protection initiatives.
- **2025 Webinars on the State Action Plan Initiative for CO_2 Emissions Reduction**: These webinars will focus on emphasizing the importance of the SAP initiative in achieving the LTAG and will provide valuable insights into SAP implementation progress across the APAC region.

As of the latest update, 24 of the 39 APAC States have submitted their State Action Plans to ICAO, while 15 States have yet to submit their Action Plans. In this regard, the primary mitigation measures selected by APAC States include advancements in aircraft technology, operational improvements, the adoption of SAF , cleaner energy solutions, and market-based measures. Notably, operational improvements have emerged as the most widely utilized mitigation measure, with 23 APAC States incorporating these measures.

Moreover, the APAC Regional Office has also facilitated the SAP Buddy Programme, whereby Indonesia, as a supporting State, has provided assistance to Timor-Leste, a receiving State, in the development of its State Action Plan. The outcome of this initiative is to encourage greater commitment among APAC States to develop and update their SAPs, with a focus on incorporating quantified data and relevant mitigation measures.

Looking ahead, the upcoming SAP events for 2025 will include a workshop tailored to South Asia and Pacific Small Island Developing States (PSIDS). The primary objective of this workshop will be to provide technical assistance in the preparation, updating, and submission of State Action Plans to ICAO, while also fostering regional collaborations and capacity-building to advance aviation environmental protection initiatives across these regions.

CORSIA

Regarding CORSIA, the APAC Regional Office undertakes several activities to ensure continuous engagement and support for its implementation across the region. These activities include regular communication with State Focal Points to maintain engagement in CORSIA implementation, organizing and conducting assistance activities to help APAC States align with ICAO's global aspirational goals, and providing targeted information and support to encourage States that have not yet done so to notify ICAO of their intention to participate in the CORSIA offsetting requirements.

Furthermore, the APAC Regional Office actively participates in relevant events to represent and promote collaborations on ICAO's environmental protection initiatives, including CORSIA. The APAC Regional Office also supports environmental protection events organized by ICAO HQ within the APAC region, monitors States' implementation of CORSIA-related requirements, and coordinates the delivery of ICAO assistance to ensure the fulfilment of the requirements under ICAO Annex 16 – Volume IV.

Additionally, the APAC Regional Office supports and monitors the progress of the ACT-CORSIA Buddy Partnerships, facilitating the delivery of ICAO support to these partnerships, and ensuring the inclusion of new States in the ACT-CORSIA Programme to receive the necessary capacity-building assistance. Between January 2022 and May 2025, the APAC Regional Office has organized several internal events related to the CORSIA Initiative, including:

- **2022 Webinar on CORSIA**: This event focused on sharing updates regarding the CORSIA Monitoring, Reporting, and Verification (MRV) System**,** the CORSIA Central Registry (CCR)**,** and the offsetting requirements.
- **2025 Webinar on CORSIA Implementation (7 May 2025):** The objective of this event is to provide updates on key implementation elements, including the 2025 MRV requirements, and to discuss the status of CORSIA implementation within the APAC region.

The APAC Regional Office has actively encouraged States within the region to voluntarily participate in the CORSIA and ACT-CORSIA Programmes, reaching out to those States that have not yet joined. In 2024, APAC further disseminated information on CORSIA at various workshops, including those organized by international organizations such as the African Civil Aviation Commission (AFCAC) and the Association of Southeast Asian Nations (ASEAN), as well as aviation authorities like the European Union Aviation Safety Agency (EASA).

As of now, 25 out of 39 APAC States have voluntarily joined CORSIA, and 31 out of 39 APAC States have participated in ACT-CORSIA. The role of the APAC Regional Office is to assist with the increase of the number of APAC States engaged in CORSIA and ACT-CORSIA, in addition to ensuring their compliance with CORSIA requirements and constantly updating States with ICAO's environmental policies and objectives related to CORSIA.

Looking ahead, an upcoming event in 2025 will include a workshop on CORSIA, alongside continued support for the ACT-CORSIA Buddy Partnership . For instance, Singapore will be providing ACT-CORSIA training to its partner States, including Cook Islands, Kiribati, Marshall Islands, Palau, Tonga, and Tuvalu.

Conclusion

The APAC Regional Office will continue to play a role in advancing ICAO's environmental objectives across the APAC region. Through sustained collaboration and capacity-building, the APAC Regional Office will continue to support States in achieving meaningful progress. Looking ahead, the focus remains on strengthening implementation and fostering regional action toward ICAO's global environmental goals.

Eastern and Southern Africa (ESAF) Regional Office

Introduction

The ICAO Eastern and Southern Africa (ESAF) Regional Office, established in Nairobi, Kenya in 1983, is the youngest among the seven ICAO Regional Offices. It encompasses 24 Member States, representing 34% of the world's Landlocked Developing Countries (LLDCs) and approximately 8% of the world's Small Island Developing States (SIDS). These nations are particularly susceptible to the impacts of climate change. Recognizing the global challenge of climate change, the aviation sector has actively engaged in mitigation efforts. The ESAF Region has also experienced significant impacts from climate change. In recent years, the region has experienced significant events such as cyclones Eleanor (2024) and Garance (February 2025), which led to airport closures in Mauritius. Southern Africa endured its most severe drought during the 2023/2024 El Niño episode, leading to States like Lesotho, Malawi, Namibia, Zambia and Zimbabwe declaring national drought disasters and seeking aid. On the other hand, the East African region faced severe flooding, which disrupted airport operations. For instance, in April 2024, heavy rains and poor visibility forced flight diversions at Kenya's Jomo Kenyatta International Airport (JKA). At that time, UNICEF reported that nearly 1 million people in Kenya, Burundi, Tanzania, and Somalia were affected by these unprecedented rains. The ESAF Regional Office continues to support its Member States in implementing ICAO policies on environmental protection, aiming to enhance the environmental sustainability of civil aviation at the regional level.

Collaboration

Each year, the ESAF Regional Office leverages the annual Director Generals Civil Aviation (DGCA) and the Africa-Indian Ocean Region (AFI) Aviation Week events to raise awareness and showcase work on environmental protection to both States and stakeholders. Panel discussions are carefully selected based on the latest topics in environmental matters, ensuring relevance and engagement. We have seen that these discussions have a profound impact as they promote regional collaboration on activities towards achieving our environmental aspirational goals.

In the last triennium, the ESAF Region established new collaborations with the two Regional Safety Oversight Organisations (RSOOs) in the region—the East African Civil Aviation Safety and Security Oversight Agency (CASSOA) and the Southern African Civil Aviation Safety Organization (SASO), which have traditionally focused on safety. Since 2022, joint activities have been conducted where RSOOs have invited their Partner States, and ICAO has facilitated the training of Focal Points. For RSOO SASO, this has become an annual event held around October each year. Additionally, the Region has worked with the African Union Commission (AUC), particularly the Infrastructure and Energy Department and the African Civil Aviation Commission (AFCAC).

Regarding industry partners, annual joint activities have been conducted by the ESAF and WACAF Regional Offices with organizations such as the Africa Airlines Association (AFRAA), the International Air Transport Association (IATA) Africa & Middle East, Airports Council International (ACI) Africa, the International Sustainability and Carbon Certification (ISCC), EASA on SAF and the Roundtable on Sustainable Biomaterials (RSB). These efforts ensure that States and industry are not left behind in the journey towards enhanced environmental sustainability of civil aviation at the regional level. Topics for these sessions have included the implementation of CORSIA, SAF, the development and update of State Action Plans SAP, and innovations in environmental practices.

The ESAF and WACAF Regions also created new relationships with other UN Agencies like the United Nations Economic Commission for Africa (UNECA). As the continent's Economic Commission, UNECA and ICAO leverage their expertise to support the implementation of the Agenda 2030 and Africa's Agenda 2063. For instance, in 2024, ICAO and the UNECA hosted a virtual side event during the 10th Session of the Africa Regional Forum on Sustainable Development (ARFSD10) under SDG13 on Climate Change. During this event, ICAO has emphasized CORSIA as the globally recognized Market-Based Measure (MBM) standard for international aviation. In 2024, the ESAF Office delivered a presentation on SAF and its role in ICAO's global environmental aspirational goals at the World Food Programme's (WFP) 3rd Humanitarian Aviation Environmental Summit (HAES) in Nairobi, Kenya.

In 2025, the ESAF Office also coordinated with the East African Community's (EAC) RSOO CASSOA and jointly participated in the UNECA's 11th Session of the Africa Regional Forum on Sustainable Development (ARFSD11) under SDG17 on Partnerships for the Goals. Moreover, the ESAF Office also participated in the UNECA 6th Africa Climate Talks which build up to the 2nd Africa Climate Talks to be conducted later in 2025. The ESAF Region's Member States are at the forefront of African climate initiatives, with Kenya hosting the inaugural Africa Climate Week in 2023 and Ethiopia set to host the second event in 2025.

Implementation Support

With respect to implementation support, several activities were also conducted by the ESAF Regional Office. In this regard, the ESAF Office collaborates closely with the WACAF Regional Office to organize workshops, seminars, and meetings. Following the adoption of the LTAG in 2022, both Regional Offices have made significant efforts to enhance the capacity of their Member States to contribute to the achievement of LTAG.

CORSIA

Over the past three years, ESAF States have actively embraced the role of CORSIA in achieving the Carbon Neutral Goal (CNG) for international aviation. The number of States voluntarily joining CORSIA has increased, surpassing the region's triennial target, with many participating in the ACT-CORSIA Buddy Partnerships. Additionally, in line with Resolution A41-22, which encourages the purchase of Emissions Units benefiting developing States, the Region has conducted activities with Civil Aviation Authorities (CAAs) and national environmental agencies. These activities focused on policies regarding CORSIA Eligible Emissions Units and provided an overview of the application and approval process for potential programs. Notably, some projects from the region, such as the Kenyan BURN Project under the Gold Standard Programme, are part of the approved programs under CORSIA.

However, the development of CORSIA regulations is progressing slowly, as indicated by the limited number of States that have completed the Annex 16 Volume IV Compliance Checklists (CCs) on the ICAO Universal Safety Oversight Audit Programme (USOAP) Continuous Monitoring Approach (CMA) Online Framework.

Sustainable Aviation Fuels (SAF)

ESAF States have eagerly adopted the ACT-SAF Programme, with over 50% joining within its first year. Currently, 71% of ESAF States are ACT SAF Partners. This swift uptake is partly due to proactive measures by Member States like

Ethiopia and South Africa, who explored the potential of Sustainable Aviation Fuels (SAF) before the programme's launch. Ethiopia identified potential feedstock, while South Africa used the Solaris tobacco plant for Africa's first biofuels flight in 2018. The region has conducted the highest number of Feasibility Studies under the ICAO ACT-SAF Programme, with three Business Implementation studies currently underway. Additionally, ESAF States such as Angola and Zambia have shown further commitment by independently securing funding for their own SAF feasibility studies outside of the ACT-SAF Programme. In addition to the environmental benefits of SAF, ESAF States recognize the social and economic advantages that come with its adoption.

The Regional Office actively supports the implementation of activities aligned with the four Building Blocks of ICAO's Global Framework for SAF, LCAF, and other aviation cleaner energies. Following the launch of the Global Framework, a virtual workshop was held to raise awareness among States. This initiative was further reinforced during an in-person 2024 Regional Seminar conducted in collaboration with the ICAO Environment Branch.

State Action Plans (SAP) on CO_2 Emissions Reduction

ESAF States have made significant progress in developing their State Action Plans SAPs. All Small Island Developing States (SIDS) in the ESAF region have created initial Action Plans, demonstrating their commitment to environmental protection. Currently, assistance is being extended to Somalia, Eswatini, South Sudan, and Comoros for the development of their SAPs. Additionally, support is being provided to Uganda, Namibia, Angola, Rwanda, and South Africa as they update their SAPs. At present, only four States have successfully updated their SAPs.

Following the update of ICAO Doc 9988"Guidance on the Development of State Action Plans on CO_2 Emissions Reduction Activities: Towards LTAG Implementation" , extensive efforts have been made by the ESAF and WACAF Regional Offices to ensure that State Focal Points (FPs) are well-informed of the latest developments incorporated in the SAP guidance material. Among the measures outlined in the ICAO Basket of Measures, operational measures are the most popular in Africa. These measures include enhancements to Air Traffic Management (ATM) systems and operational improvements aimed at achieving a sustainable aviation system. All SAPs submitted in the ESAF Region incorporate these operational measures.

Assistance Missions

Numerous assistance missions were carried out to aid States in implementing CORSIA and developing their State Action Plans SAPs. For example, in 2023, Malawi and Somalia received guidance on formulating their SAPs, while Seychelles received support on CORSIA Implementation Elements. As a result of this assistance, Malawi successfully submitted their SAP in 2023, becoming the 17th ESAF State to do so.

Challenges

Despite these successes, the ESAF region continues to face challenges such as a lack of expertise in environmental science, absence of government policies to support SAF development, and financial constraints for research and development in innovation and SAF. The regional office remains committed to prioritizing environmental protection and will continue to leverage collaboration and dedication to achieve environmental goals.

Looking ahead to the next triennium, the Regional Office is committed to promoting and encouraging States to report on activities related to the Building Blocks of the CAAF/3 Global Framework. The office will continue to support Member States and will aim to increase the number of States with established regulations on CORSIA. Additionally, efforts will be made to assist in the development and update of SAPs in alignment with the latest edition of ICAO Doc 9988. This initiative will also encompass supporting States in implementing ICAO's LTAG monitoring and reporting mechanisms.

Western and Central Africa (WACAF) Regional Office

Established in 1963, the ICAO Western and Central Africa (WACAF) Regional Office was the second ICAO regional office to be established globally, and the first one in Africa. Initially, the WACAF Office served the States in both the WACAF and ESAF Regions. However, in 1983, the office was divided to create the ESAF Office. Over the past three years, the WACAF region has faced significant climate change impacts, including rising temperatures, droughts, and sudden onset events like floods. For instance, in 2023, heavy rains and floods caused dams and rivers to overflow in Cameroon. Other severely affected countries include the Democratic Republic of Congo, the Republic of Congo, Niger, and the Central African Republic. Flooding and heavy rains can disrupt aviation operations by reducing visibility, worsening runway conditions, affecting aircraft performance, causing delays, posing safety risks, and damaging airport infrastructure.

The Office serves 24 accredited States across the Western and Central African region. Established to ensure a safe, secure, efficient, and environmentally sustainable civil aviation system, the WACAF Regional Office plays a pivotal role in coordinating and supporting various environmental initiatives. In this regard, the ICAO WACAF Regional Office supports the advancement of ICAO's environmental objectives across the region, providing technical support, capacity building, and strategic coordination with States and partners. Over the past triennium, key progress has been made on State Action Plans SAP development, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) implementation, and in sustainable aviation fuels (SAF) supported by enhanced partnerships and awareness activities in the WACAF region.

Collaboration

The WACAF Regional Office collaborates with numerous industry partners, and, together with the ESAF Regional Office, it has undertaken joint activities with organizations such as the Africa Airlines Association (AFRAA), IATA Africa & Middle East, ACI Africa, the International Sustainability and Carbon Certification (ISCC), and the Roundtable on Sustainable Biomaterials (RSB). The topics addressed during these sessions included the implementation of CORSIA, SAF, the development and update of SAP, and innovations in environmental protection.

Over the past year, the WACAF Regional Office has initiated new collaborations with key Regional Safety Oversight Organisations (RSOOs) such as the Economic Community of West African States (ECOWAS) and the Banjul Accord Group Aviation Safety Oversight Organisation (BAGASOO). Many RSOOs are institutionally linked to Regional Economic Communities (RECs), which can facilitate coordinated action across States. This is particularly relevant for advancing ICAO's environmental goals, as RSOOs can help promote harmonized approaches to environmental protection and support States in implementing relevant ICAO initiatives at the regional level.

Furthermore, the ESAF and WACAF Regions have established new partnerships with other UN entities such as United Nations Economic Commission Africa (UNECA) that are active in the AFI Region and with whom potential synergies are being explored. For example, in 2024, both regions and UNECA organized a virtual event on the sidelines of the 10th Session of the Africa Regional Forum on Sustainable Development (ARFSD10) focused on SDG13, Climate Change. It was an opportunity for ICAO to highlight CORSIA as the internationally recognized Market-Based Measure MBM standard for global aviation.

Implementation Support

The WACAF Office conducts several implementation support activities including annual meetings, workshops, seminars and webinars to support Member States in implementing environmental standards and policies. Some of these activities are jointly organized in close collaboration with the ESAF Regional Office. Since the adoption of the LTAG in 2022, both Regional Offices have made significant efforts to enhance the capacity of their Member States to contribute to achieving LTAG.

State Action Plans (SAP) on CO_2 Emissions Reduction

The WACAF Regional Office maintains continuous engagement with States to ensure timely development and updates of State Action Plans SAPs to reduce CO_2 emissions from international aviation. It actively promotes the inclusion of new mitigation measures aligned with the Global Framework on SAF, LCAF, and other aviation clean energies endorsed at CAAF/3.

To date, 21 WACAF States have developed a State Action Plan on CO_2 emissions reduction, reflecting significant progress in this area. Only three States are yet to develop their initial State Action Plans. Among the mitigation measures outlined in ICAO Doc 9988, operational measures are the most selected by WACAF States. These operational measures include enhancements to Air Traffic Management (ATM) systems and operational improvements aimed at achieving a sustainable aviation system. Regional partnerships continued to played a key role, through cooperations with IATA, AFRAA, and ACI Africa. In addition, SAP-related topics were also integrated into seminars and events held in Dakar in 2023 and 2024 as well as during webinars with States SAP Focal Points. Two virtual workshops were held this year to support the States Focal Points with the implementation of the updated Fourth Edition of ICAO Doc 9988. In this regard, extensive efforts have been made by ESAF and WACAF Regional Offices to ensure that Focal Points are well-trained and informed.

CORSIA

With respect to CORSIA, the ACT-CORSIA Buddy Partnerships have been a great success, evidenced by the increased number of WACAF States voluntarily joining CORSIA. Partnerships have been established with France and Canada supporting for Francophone States, and with Nigeria supporting Anglophone States. The Regional Office plays a pivotal role in organizing both onsite and virtual meetings to ensure that all recipient States are well-trained on CORSIA requirements as per Annex 16 volume IV as well as on the CORSIA Central Registry (CCR). Currently, in the WACAF Region, 23 out of 24 States are engaged in a Buddy partnership under ACT CORSIA.

In addition to ACT CORSIA, States in the region have been actively encouraged to participate in CORSIA through ICAO State Letters and have gained practical insights during regional workshops and seminars where CORSIA was a key focus. Notably, these include the annual environment meeting organized with the ESAF Regional Office for all the African States.

The number of States that have voluntary joined CORSIA continues to grow reaching 13 States in 2024 with additional States envisaging to join.

Sustainable Aviation Fuels (SAF)

Aligned with ICAO's Global Framework for SAF, LCAF and other aviation cleaner energies, and the ACT-SAF Programme, the WACAF Office has actively disseminated information and promoted implementation efforts among States. This includes organizing a series of high-level capacity-building events, such as the Seminar on environment held in Dakar in 2024 and webinars organized with the ESAF Office, AFRAA and IATA Africa in 2023 and 2024. In addition, the WACAF Office contributes to teleconferences and technical exchanges, facilitating dialogue on SAF and the LTAG.

The ACT-SAF Programme has accelerated regional efforts towards Sustainable Aviation Fuels in the WACAF Region. Currently, more than half of the WACAF States are participating in the ACT-SAF Programme.

The impact of ACT-SAF is clearly reflected through the following concrete activities:

- In Cote d'Ivoire, a feasibility study was conducted under Phase II of the ICAO-EU Project on the development of State Action Plans. Cote d'Ivoire is currently receiving support with regulation amendments to ensure recognition and inclusion of SAFs. In addition, with the financial support from France, a Business Implementation study will soon be launched;
- In 2025, a feasibility study was initiated for Ghana with funding from the United Kingdom;
- Feasibility studies are also underway for Mauritania and Senegal with funding from the European Union.

Looking ahead, the WACAF Office will expand SAF-related capacity-building efforts in coordination with industry partners, will continue to support feasibility studies in selected WACAF States, and promote ICAO's FINVEST platform in the region.

Assistance Missions

The WACAF Region recognises the importance of assistance missions to support States in implementing CORSIA and developing their State Action Plans. For instance, in 2024, Mauritania received support to develop their SAP and as a result, Mauritania became the 21st WACAF State to submit its SAP to ICAO.

Conclusion

Looking ahead, the WACAF Regional Office will continue to prioritize its support for States in advancing their environmental sustainability efforts and building on the commendable progress that many States have already made. This progress includes actively engaging in the development of robust monitoring mechanisms for the implementation of their SAPs and measuring progress towards the achievement of the LTAG. Recognizing the crucial role of SAF in decarbonizing the aviation sector, the WACAF Office will intensify its multifaceted activities under the ACT-SAF program. In parallel, it remains committed to support States in the adoption and implementation of CORSIA through the ACT-CORSIA Partnership with continued training and assistance on Monitoring Reporting and Verification (MRV) of CO_2 emissions data in CORSIA, as well as the CORSIA eligible fuels and emissions Units. The WACAF Regional Office will also continue to strengthen collaborations with various stakeholders and regional partner organizations to enhance its capacity building strategy to better respond to evolving needs of its Member States.

European and North Atlantic (EUR/NAT) Regional Office

Introduction

The ICAO European and North Atlantic (EUR/NAT) Office, located in Paris, France, was the first Regional ICAO Office to become established, in 1947. The EUR/NAT Office serves 56 accredited States across Europe and the North Atlantic region. Established to ensure a safe, secure, efficient, and environmentally sustainable civil aviation system, the Office plays a pivotal role in coordinating and supporting various environmental initiatives across the region. The Office's accreditation area (EUR/NAT area) is characterized by its diverse aviation landscape, encompassing both highly developed and emerging aviation markets, as well as its wide variety of geographical features, which necessitates tailored approaches to promote environmental sustainability.

The EUR/NAT Regional Office plays a pivotal role in providing assistance to its Member States in the implementation of ICAO's environmental standards and policies. In this regard, the Office has launched its activities related to environmental protection in 2018 with the establishment of the Environmental Task Force. This Task Force aims to provide more targeted support to the States in the regions and foster regional collaboration among the States and key stakeholders. The EUR/NAT Regional Office provides implementation support on environment-related matters through workshops, on-site technical assistance missions and regular follow-up calls with designated State Focal Points.

The EUR/NAT Environment Task Force further supports implementation efforts by raising awareness on the latest ICAO developments at the global, regional and national levels as well as the sharing of experience and best practices amongst States and stakeholders.

Aligned with the strategy of the EUR/NAT Regional Office to be more collaborative, State centric, more risk based and actions and results oriented, the Environment Task force support a collaborative work with the ICAO Member States and partner organization to avoid duplication and enhance synergies. An example of collaboration is the two events with ACI EUROPE on Green Airports: a webinar organized in 2023, and a regional seminar held in Almaty, Kazakhstan in 2024. The latter follows up on the global ICAO seminar to present a more regional approach.

In addition to its direct work with the ICAO Member States, the EUR/NAT Office collaborates with various stakeholders, including industry partners to advance environment initiatives and promote the ACT SAF Programme. These collaborations foster knowledge sharing and innovation, helping States overcome barriers that they might encounter with SAF deployment.

State Action Plans (SAP) on CO_2 Emissions Reduction

The State Action Plan initiative has become a key element of the ICAO's comprehensive capacity-building and assistance strategy to support Member States with the implementation of a broad range of CO_2 emissions mitigation measures selected from the ICAO "basket of measures". While SAPs remain a key mechanism for communicating national action plans for international aviation, they also play a critical role in enabling ICAO to assess Member States' progress toward achieving the sector's LTAG. In this regard, States are encouraged to include in their SAPs more detailed long-term strategies for reducing carbon emissions from international aviation, including through the use of innovative technologies, improved operational measures, and SAF. Furthermore, States are urged to incorporate the latest advancements in aviation technologies and cleaner energy sources, supported by relevant policies, implementation roadmaps, and long-term projections.

To date, 50 out of 56 EUR/NAT States have developed and submitted to ICAO their State Action Plans which represents 89% of the States from the EUR/NAT area. In addition, 19 EUR/NAT States have submitted updated to their SAP through the Action Plan Emissions Reduction (APER) website in 2023 and 2024.

Implementation Support: The ICAO EUR/NAT Regional Office provides comprehensive support to States in developing and updating their State Action Plans for CO_2 emissions reduction. This includes organizing annual webinars, workshops, and onsite meetings through the Environment Task Force, where States receive guidance on the ICAO Document 9988 and on the mitigation, measures selected to reduce CO_2 emissions from international aviation.

The EUR/NAT Regional Office collaborates with regional organizations such as the European Commission European Union Aviation Safety Agency (EASA), Arab Civil Aviation Organization (ACAO) and the European Civil Aviation Conference (ECAC) to facilitate the development of the SAPs. These partnerships ensure that States receive the necessary support and resources to effectively develop and implement their selected measures incorporated into their action plans. The EUR/NAT Office organizes annual meetings with ACAO and ECAC on State Action Plans. In addition, every year since 2022, the Regional Office and ACAO organize assistance missions to States from the EUR/NAT Region to provide assistance with the development and update of their State Action Plans.

CORSIA

CORSIA has been widely recognized as the only global market-based measure (MBM) for the international aviation sector. It is crucial to understand that the transboundary nature of international aviation operations requires a globally harmonized MBM.

In addition, CORSIA has been recognized as a policy instrument to incentivise the development and deployment of SAF and LCAF on a global scale, including through the adoption of sustainability criteria, life-cycle emissions values, and certification for such fuels, thus allowing for the reduction of offsetting requirements for aeroplane operators.

The EUR/NAT Regional Office actively supports States in implementing CORSIA requirements. This includes providing technical assistance, organizing capacity-building activities, and facilitating the submission of CO_2 emissions data and other necessary documentation to ICAO. To date, 46 States from the EUR/NAT area have voluntarily joined the CORSIA scheme, representing 82% of the EUR/NAT States.

In addition, the EUR/NAT Regional Office facilitates ACT CORSIA webinars and onsite meetings with donors States such as Canada, France and Germany. This has enabled the EUR/NAT Office to support 14 EUR/NAT States. The Office organizes several webinars per year to ensure that States receive the necessary support they need to implement CORSIA requirements.

The office works closely with regional and international organizations to streamline CORSIA implementation. The Office organizes annual joint events with regional organizations like ECAC and ACAO to avoid the duplication of efforts and enhance the effectiveness of capacity-building activities.

Sustainable Aviation Fuels (SAF)

In alignment with ICAO's Global Framework for SAF, LCAF and other aviation cleaner energies and the ACT-SAF programme, the EUR/NAT Regional Office has actively disseminated the related information and promoted implementation efforts among States.

This included organizing a series of high-level capacity-building events, such as the webinar on the SAF Roadmap held in April 2025, a regional seminar on LTAG and SAF in Samarkand, Uzbekistan (September 2024), and joint webinars in 2023 on SAF with ECAC to promote the ICAO guidance document on potential policies and coordinated approaches for the deployment of SAF. In addition, during his official visits to States, the Regional Director regularly promotes the ICAO ACT SAF programme to States Officials, explaining the benefits for States to join ACT SAF. The Regional Director also reached out to leaders from the energy sector to discuss plans to start producing SAF, LCAF and other aviation cleaner energies.

To date, 23 States from the EUR/NAT area have joined the ICAO ACT SAF programme, along with partner organizations such as the European Union, EUROCONTROL, EASA, ECAC and Joint Aviation Authorities Training Organisation (JAA-TO).

Through the ACT-SAF programme, the EUR/NAT Regional Office assists States in developing and deploying SAF. This includes promoting the development of feasibility studies, providing policy development support, and facilitating partnerships with industry stakeholders. The Office has initiated coordination and enhanced discussions with national fuels producers from several member States.

Looking ahead, the EUR/NAT Regional Office will continue to expand SAF-related capacity-building efforts in coordination with industry, explore funding opportunities for further feasibility studies, and promote ICAO's FINVEST platform across the EUR/NAT area.

Conclusion

For the next triennium, the Regional Office will continue assisting States to develop and update the State Action Plans in accordance with the latest edition of ICAO Doc 9988. The EUR/NAT Regional Office will continue supporting Member States in implementing CORSIA requirements. Additionally, the Regional Office will support States in implementing ICAO's LTAG monitoring and reporting mechanisms.

The ICAO EUR/NAT Regional Office continues to play a crucial role in advancing environmental sustainability in aviation across its accreditation areas. Through dedicated support, addressing challenges, and fostering collaboration, the EUR/NAT Regional Office ensures that States are well equipped to meet their environmental goals and contribute to global efforts in reducing aviation's impact on the environment.

Middle East (MID) Regional Office

Advancing Environmental Sustainability in the MID Region

The ICAO Middle East (MID) Regional Office is guiding the region toward a cleaner more resilient aviation sector. While the MID Region hosts some of the world's busiest airports and fastest-growing airlines, it also grapples with extreme heat, water scarcity, frequent sandstorms and a heavy dependence on long-haul flights. To reconcile this rapid growth with the urgent need for climate action, ICAO MID partners with its 15 Member States to deliver practical solutions across three main areas: SAF, State Action Plans SAPs and CORSIA implementation.

Strategic Initiatives and Regional Collaboration

Sustainable Aviation Fuels (SAF)
Sustainable Aviation Fuel is a "drop-in" alternative to conventional jet fuel that can cut lifecycle carbon emissions by up to 80%. In the energy-rich MID Region, deploying SAF requires new supply chains and certification processes, but it also offers a chance to modernize the existing fuel infrastructure. To fast-track SAF adoption, the MID Regional Office has made its development a top priority, drawing on local expertise and forging strategic partnerships to support feasibility studies, certification efforts and early commercial trials.

- Saudi Arabia's first SAF delivery (October 2024): In line with Vision 2030 and the Kingdom's Net Zero 2060 goal, the Arabian Petroleum Supply company (APSCO) and General Authority of Civil Aviation (GACA) successfully delivered and stored SAF at Red Sea International Airport. This landmark event provides a model for future SAF handling and distribution.
- UAE's Air-CRAFT consortium (2024): This pioneering research alliance unites regulators, fuel producers, airlines and academia to scale up SAF technologies across the value chain.
- ACT-SAF projects (2024–2025): ICAO MID facilitated feasibility studies and sustainability-certification support in Jordan (funded by the Netherlands) and Egypt (supported by the European Commission), strengthening local capacities to produce, certify and eventually commercialize SAF.

State Action Plans (SAP) on CO_2 Emissions Reduction
State Action Plans enable Member States to set clear emissions-reduction targets, select mitigation measures and integrate the aviation section into national climate strategies. The MID Office delivers workshops, training on data-collection tools and technical assistance missions to Kuwait, Oman, Bahrain and Saudi Arabia to ensure each State's Action Plan is both realistic and measurable.

As a result of these tailored capacity-building activities, significant progress has been achieved, by early 2025, ten out of the 15 Member States in the MID region, representing two-thirds of the region, had submitted draft State Action Planss. In 2025, Bahrain led the way with submitting their first quantified State Action Plan update, detailing specific targets such as airport carbon accreditation and optimized flight paths. Moreover, in collaboration with the Arab Civil Aviation Organization, the MID Regional Office has also delivered SAP workshops to Arab Civil Aviation Organization ACAO Member States, broadening access to technical support and strengthening regional cooperation.

CORSIA

To assist MID States with meeting their CORSIA commitments, the MID Regional Office offers Monitoring, Reporting, Verification (MRV) training and targeted in-country assistance. These Collaborative platforms also foster knowledge-sharing on carbon-market mechanisms, enabling States to exchange insights and best practices.

The MID Region's strong CORSIA engagement is evident, with seven Member States having voluntarily joined the pilot and first phases, and twelve submitting their 2024 emissions reports on schedule. In addition, under ACT-CORSIA Buddy Partnerships, Qatar has partnered with Oman, Iraq, Libya, Iran, Kuwait and Jordan to deliver capacity-building and training activities, sharing valuable expertise throughout the region.

Partnerships for Progress

Collaboration plays a crucial role in enhancing the impact of ICAO's efforts in the MID Region. The MID Office works closely with ACAO and IATA's Middle East and Africa divisions to pool expertise, leverage resources, and strengthen partnerships across the region. Regional seminars, technical workshops and symposiums provide ongoing forums for stakeholders to exchange best practices and maintain momentum between formal meetings.

Conclusion

The MID Region stands at a pivotal point in its development, where its role as a global aviation hub requires a focus on both growth and a strong commitment to environmental responsibility. By advancing SAF, shaping robust SAPs and fully embracing CORSIA, Member States are demonstrating that aviation growth and sustainability can go hand in hand. With ICAO's guidance and strong regional cooperation, the Middle East is charting a clear course toward net-zero skies, where aviation connects people and economies without costing the planet. As ICAO's global climate framework evolves, the MID Office remains committed to ensuring no State is left behind in this journey toward sustainable flight.

North American, Central American and Caribbean (NACC) Regional Office

Introduction

The NACC Regional Office supports and addresses the diverse needs and priorities of its 22 Contracting States and 19 Territories. These States and Territories represent varying levels of aviation development, ranging from large and complex systems to smaller and developing systems. While the NACC Regional Office's mandate covers a broad spectrum of aviation activities, environmental protection has emerged as a critical and growing priority. The NACC Office recognizes the fundamental importance of air connectivity in Latin America and the Caribbean, essential for overcoming geographical challenges, limitations of land infrastructure, and boosting socioeconomic progress. Balancing this vital connectivity with environmental sustainability is a key challenge and a central focus of the NACC Regional Office's work. ICAO, in close collaboration with its Member States, has established a global framework to guide action, recognizing the diverse capabilities and national circumstances of States, to effectively address climate change and promote a sustainable future for aviation. With reference to the NACC Region, this involves close collaboration and coordination with key players such as the European Union (EU), Latin American and Caribbean Air Transport Association (ALTA), the Airports Council International – Latin America and Caribbean (ACI-LAC) (ACI-LAC), the Regional Association IV of the North American, Central America and the Carribean - World Meteorological Organization (RA-IV WMO), International Air Transport Association (IATA), and Civil Air Navigation Services Organisation (CANSO).

The NACC Regional Office integrates ICAO's environmental program into its various activities, ensuring that sustainability is a key driver in all areas of assistance. This involves actively promoting ICAO's Strategic Objectives with a strong emphasis on environmental sustainability. The approach includes facilitating the development and update of State Action Plans SAPs for the reduction of CO_2 emissions, supporting operational improvements to reduce emissions, promoting the development and deployment of SAF, and advancing the implementation of the CORSIA. One of the main forums for these efforts is the annual meeting of civil aviation directors, which includes a dedicated session to address ICAO's environmental policy and review States' annual work plans.

CORSIA

The NACC Regional Office facilitates the implementation of CORSIA through the ACT-CORSIA Programme, via virtual seminars to promote CORSIA, improve understanding of its requirements, and support implementation efforts. A crucial component of ACT-CORSIA is the assistance to States in fulfilling their Monitoring, Reporting, and Verification (MRV) obligations. Vital support to ACT-CORSIA Programme is provided by Canada, Spain, the United Kingdom, and the United States through implementation support. The region demonstrates a strong commitment to CORSIA, evidenced by a high voluntary participation rate of 90.9% of States (20 out of 22). The ACT-CORSIA Programme directly supports 15 States (68.2%) in their implementation efforts. Furthermore, ICAO promotes valuable State-to-State training programs and the exchange of best practices. Examples of these initiatives include Spain's cooperation with Costa Rica and the Dominican Republic to update their national regulations related to Annex 16, Volume IV, as well as with Central American States to provide on-site training on CORSIA implementation. Spain is also assisting Mexico in resolving questions regarding MRV implementation and States' emissions reports. Similarly, Canada is cooperating with Eastern Caribbean Member States and with Trinidad and Tobago to provide on-site training, address questions related to MRV implementation and States' reports, and expedite the drafting and promulgation of national regulations. Currently, it is necessary to develop training programs focused on Eligible Fuels and Eligible Emissions Units under CORSIA.

Sustainable Aviation Fuels (SAF)

The NACC Regional Office promotes the deployment and utilization of SAF as a fundamental pathway to decarbonize the aviation sector and to achieve the LTAG . This advocacy takes various forms, with the Regional Office's activities under the ACT-SAF Programme being multifaceted. For example, the NACC Regional Office organizes virtual seminars to ensure the engagement of each State, raise awareness about the benefits of SAF, and promote ICAO's sustainability objectives.

In July 2024, the Central American Corporation for Air Navigation Services (COCESNA) played a key role in co-organizing the international webinar *"Impulsando un Futuro Sostenible en la Aviación Civil Internacional."* The webinar brought together experts from multiple States, including Belize, Ecuador, El Salvador, Spain, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, and the Dominican Republic. Following this, an ACT-SAF Workshop was held in Mexico City on 7 November 2024, which led Mexico to seek additional support from ICAO, explore potential partnerships with other Contracting States, and engage in co-processing discussions. Later, in April 2025, a teleconference focused on the Dominican Republic centered on their SAF progress and strong interest in ICAO's ACT-SAF program. During the call, they outlined specific needs for support and information, which led to a formal request to pursue a business case study.

It also disseminates the ACT-SAF Series guidance material to assist States develop and implement their initiatives. In addition, the NACC Regional Office fosters strong collaboration between States and relevant national stakeholders to drive SAF working groups, conduct feasibility studies, and the integration of SAF as a mitigation measure in State Action Plans. In this regard, active collaboration and coordination with entities such as the EU, ALTA, and ACI-LAC, which continuously deploy regional efforts to promote the development and deployment of SAF and cleaner aviation energies, is essential.

To demonstrate the region's commitment, 77% of accredited States (17 out of 22) actively participate in the ACT-SAF Programme. In 2017, Two States in the region, the Dominican Republic and Trinidad and Tobago, successfully completed feasibility studies with the assistance of the EU-ICAO program. The Dominican Republic continues to successfully advance the implementation of its SAF roadmap. Similarly, in Mexico, SAF working groups continue to develop and improve the comprehensive SAF roadmap, in both cases with the support of ICAO's ACT-SAF Programme. Among the Regional Office's priorities is to continue promoting regional SAF production by addressing regional challenges, supporting the formulation of policies that stimulate such production, as well as encouraging new countries and air operators to continue adhering to the terms and conditions of ACT-SAF. The Regional Office is currently focusing on securing funding for two additional feasibility and business case implementation studies. Furthermore, the NACC Regional Office emphasizes the need to study the potential of sargassum and other locally available raw materials for SAF production in small island States and States with coastlines on the Caribbean Sea.

State Action Plans (SAP) on CO_2 Emissions Reduction

The NACC Regional Office plays a vital role in supporting States in the development and update of their SAPs. NACC States have indicated that ICAO's assistance has been crucial in assisting States with defining their strategic approaches to CO_2 mitigation measures, fostering collaboration among stakeholders, and tracking progress toward achieving the LTAG and national sustainable development goals.

To facilitate this process, the NACC Regional Office, in cooperation with the SAM Regional Office, has conducted NAM/CAR/SAM workshops and seminars to progressively involve the States and promote ICAO's environmental program. The ICAO Regional Seminar on International Aviation and the Environment, hosted by the Dominican Republic in April 2023, aimed to inform States about the preparations for the third Conference on Aviation and Alternative Fuels (CAAF/3). Discussions centered on implementing aspirational goals for net-zero carbon emissions in aviation, including developments in the ACT-SAF Programme, and additionally addressed clean energy financing, implementation challenges, and policies. Another Regional Environment Seminar was conducted in Asunción, Paraguay, in August 2024, focused on raising awareness and exchanging views on the implementation of the LTAG, and the Global Framework on SAF, LCAF, and other aviation cleaner energies. Furthermore, teleconferences were organized with Central American States in August 2024, and with the Eastern Caribbean Civil Aviation Authority (ECCAA) and the Organisation of Eastern Carribean States (OECS) in November 2024, focused on navigating the Action Plan on Emissions Reduction (APER) website, ensuring access to the web-based SAP platforms, and outlining the next steps for drafting Member States' SAPs. This includes the dissemination of information on ICAO Document 9988, "Guidance on the Development of State Action Plans on CO_2 Emissions Reduction Activities: Towards LTAG Implementation", and the promotion of the State Action Plan online Training Course.

With respect to the numbers of State Action Plan submission within the NACC region, 68% of the States (15 out of 22) have submitted their initial SAPs. Among these 22 States, 9 have submitted quantified Action Plans and 8 have submitted updates to their initial SAPs. The NACC Regional Office remains dedicated to supporting the remaining 32% of the States (7 out of 22) with the development and submission of their action plans. Currently, our office is facilitating the development of the first Multi-State SAP for the six member States of the Eastern Caribbean Civil Aviation Authority (ECCAA), with support from Canada, promoting a collaborative effort among the participating States.In the NACC Region, SAPs incorporate a variety of mitigation measures adapted to regional circumstances. These measures may include the adoption of new aircraft technologies and fleet renewal, the deployment and increased use of SAF, and operational improvements to reduce fuel consumption and optimize flight times. Regarding fleet renewal, ALTA recently published that the airlines integrating ALTA have managed to reduce the average age of their fleets by 18%, which underscores the importance of maintaining this modernization trend to continue with emissions reduction. A focus area is operational improvements, the region has intensified its efforts through two task forces: the Air Traffic Flow Management Task Force, focused on optimizing the efficiency and capacity of airspace; and the Airspace Optimization Task Force, which works to improve the efficiency and flexibility of traffic flows through initiatives such as Free Route Airspace (FRA) and Performance-Based Navigation. Both initiatives, including the implementation of FRA facilitated by regional collaboration through the CIIFRA initiative (CANSO, IATA, ICAO Framework for Regional Collaboration), represent key efforts to improve airspace efficiency and reduce CO_2 emissions.

The increase in turbulence and other severe meteorological phenomena associated with climate change represents a regional concern. This issue has been addressed in various forums, including the CAR/SAM Planning and Implementation Regional Group (GREPECAS), the Regional Association IV of the North American, Central America and the Carribean - World Meteorological Organization (RA-IV WMO), the Latin American and Caribbean Air Transport Association (ALTA), the Airports Council International – Latin America and Caribbean (ACI-LAC), and International Air Transport Association (IATA). The integration of Aircraft Meteorological Observations (ABO) constitutes a fundamental technology to significantly improve the collection of meteorological data in airspaces lacking in-situ observation systems. These technologies have the potential to optimize both flight route planning and the operational efficiency of air navigation systems. The NACC Regional Office will continue to address these critical concerns as part of operational improvements in upcoming regional events, including the workshop on severe meteorological phenomena and aviation, among others.

Future outlook

Looking ahead, the Regional Office will continue to prioritize its support for States in advancing their environmental sustainability efforts. This includes actively engaging in the development of robust monitoring mechanisms for the implementation of their SAPs, ensuring effective tracking of progress towards the LTAG and facilitating data-driven decision-making, building upon the current momentum where 68% of States have already submitted initial SAPs. Recognizing the crucial role of SAF in decarbonizing the sector, the office will intensify its multifaceted activities under the ACT-SAF Programme, aiming to expand the 77% participation rate and support more States in conducting feasibility studies and implementing SAF roadmaps. Furthermore, the office remains committed to the widespread adoption of CORSIA through the ACT-CORSIA Programme, building on the strong 90.9% voluntary participation, by providing crucial MRV assistance and developing targeted training on Eligible Fuels and Emissions Units. To strengthen its capacity to support these activities effectively, the Regional Office is promoting the enhancement of stakeholder engagement and strategic partnerships, fostering a collaborative approach to environmental protection within the NACC Region.

South American (SAM) Regional Office

Introduction

The ICAO South American (SAM) Regional Office continues to support the advancement of ICAO's environmental objectives across the region, providing technical support, capacity building, and strategic coordination with States and partners. Over the past triennium, key progress has been made in SAF, State Action Plans , and CORSIA, supported by enhanced partnerships and awareness activities.

Sustainable Aviation Fuels (SAF)

In alignment with ICAO's Global Framework for SAF and the ACT-SAF programme, the SAM Office has actively disseminated information and promoted implementation efforts among States. This included organizing a series of high-level capacity-building events, such as the Seminar on LTAG and SAF in Santiago, Chile (April 2023), and a regional seminar on the environment in Asunción, Paraguay (August 2024), delivered jointly with the NACC Regional Office. The Office also partnered with EASA to organize the Regional Workshop on deploying SAF, LCAF, and other aviation cleaner energies (August 2024), and hosted a workshop in Armenia, Colombia (April 2024) to disseminate ICAO's environmental protection measures. Additionally, the environmental panel held during the RAAC/18 meeting in São Paulo in February 2025 further reinforced the region's commitment to sustainability.

Technical assistance has been a cornerstone of the Office's SAF work. In this regard, support was provided to Bolivia, Colombia, and Panama in establishing SAF ecosystem roundtables and organizing feasibility studies. The SAM Office also contributed to teleconferences and technical exchanges, facilitating dialogue on SAF and LTAG. Moreover, partnerships were instrumental, with collaboration involving stakeholders such as IATA, ALTA, Airbus, Avianca, LATAM, GOL, EASA, and the Inter-American Development Bank (IDB).

Currently, there are two SAF feasibility studies being conducted in Chile and Peru. Argentina's study is expected to begin by mid-2025, and Panama is also preparing to launch its study. In total, seven States have installed SAF ecosystem discussion platforms, and 11 have formally joined the ACT-SAF Programme.

Looking ahead, the SAM Office will expand SAF-related capacity-building efforts in coordination with industry, explore funding opportunities for further feasibility studies (including in Argentina and Panama), and promote ICAO's FINVEST platform in the region.

State Action Plans (SAP) on CO_2 Emissions Reduction

The SAM Regional Office maintains continuous engagement with States to ensure timely development and updates of State Action Plans to reduce CO_2 emissions from international aviation. It actively promotes the inclusion of new mitigation measures aligned with the Global SAF Framework, LCAF, and other aviation cleaner energy pathways endorsed at CAAF/3. Technical assistance has been provided through both teleconferences and in-country missions. In addition, Support for first-time SAP submissions was offered to Panama, Paraguay, and Peru, while updates were facilitated for Colombia, Ecuador, Venezuela, and Paraguay. The Office also collaborated with Bolivia, Suriname, and Venezuela in advancing their SAP development through remote support.

Importantly, the South American Region is the first ICAO region in which all States have submitted a SAP. Currently, five States are updating their action plans, with a focus on integrating more robust mitigation actions and aligning with ICAO's long-term goals. Regional partnerships again played a key role, with cooperation from IATA, ALTA, and EASA. SAP-related themes were also integrated into broader seminars and events held in Colombia and Paraguay. A virtual workshop is being planned to support the implementation of the updated Fourth Edition of ICAO Doc 9988, guiding States through the latest developments contained in their edition.

CORSIA

The SAM Regional Office continues to support CORSIA implementation through a blend of awareness-raising efforts, technical coordination, and capacity building under the ACT-CORSIA Programme. States in the region have been encouraged to participate in CORSIA through ICAO State Letters and have gained practical insights during regional workshops and seminars where CORSIA was a key focus. In this regards, technical support missions were undertaken in Paraguay, Panama, and Colombia, with virtual follow-up provided as needed. As of early 2025, 12 States in the SAM Region have adopted CORSIA-related regulations, and 10 have submitted their reports to the CORSIA Central Registry. Four States are formally participating in the CORSIA scheme.

As part of the efforts to support CORSIA implementation, EASA has contributed to capacity-building activities through dedicated webinars that strengthened States' understanding of the reporting and verification processes under Annex 16, Volume IV. Looking ahead, future efforts will focus on deepening CORSIA capacity-building activities for the States that are not yet fully engaged, and continuing to follow-up on 2024 emissions reporting obligations to the CORSIA Central Registry.

Greening Aviation through Global Aviation Partnerships – the contribution of the European Union

By Delphine Micheaux Naudet (EU Representative to ICAO) and Thomas Rousing-Schmidt (DG MOVE, European Commission)

Global aviation connects continents, economies, and people. The significant upsides of global aviation are obvious to an ICAO readership. At the same time, ambitious climate action is needed, and aviation must play its part. Global aviation faces the double challenge of ensuring its continued growth whilst significantly reducing its environmental footprint to meet the global Long-Term Aspirational Goal (LTAG) of net zero carbon emissions by 2050.

A global and widespread use of Sustainable Aviation Fuels (SAF), Lower-Carbon Aviation Fuels (LCAF), and other cleaner energy sources will be essential to achieve the LTAG. And it cannot succeed without global cooperation. No state, no matter how advanced or resource-rich, can decarbonise global aviation alone. That's why international partnerships, capacity building, and solidarity are vital components in the journey towards substantial decarbonisation.

In the 27 Member States of the European Union (EU), the ReFuelEU Aviation Regulation has set a minimum supply mandate, on fuel producers, for SAF in Europe, starting with 2% in 2025 and increasing to 70% in 2050. Various measures have been put it place to support the implementation of these new rules, including several financial incentives, a European Clearing House, research programmes and international cooperation.

This article focuses on the international cooperation dimension and explores how the EU is cooperating with Partner States across Africa, Asia, Latin America, and the Caribbean, with the support of ICAO and of the EU Aviation Safety Agency (EASA), to incentivise SAF production across the world, thereby helping to shape a future where climate action, green jobs, and sustainable growth in aviation go hand in hand. The EU is committed to ICAO's "No Country left Behind" Strategic Objective and contributes to its implementation. And it's not just the EU alone: Since 2022, European entities have committed more than €20M to support environmental protection initiatives in civil aviation across Africa, Asia, Latin America and the Caribbean.

International aviation operates across borders, but the emissions it generates know none and therefore require global efforts. The LTAG and ICAO's associated objective to achieve a 5% reduction in CO_2 emissions through the use of SAF, LCAF, and other cleaner energies by 2030 set the trajectory and will need inclusive, collaborative action in line with the Global Framework adopted at CAAF/3.

Many developing countries hold significant potential for SAF development and production, and this can support their local economic development.

EU funded ACT-SAF project in Africa-India: A Strategic Investment in Climate and Development

The EU is supporting numerous capacity building activities on the transition to cleaner energy in aviation, including in the framework of ICAO ACT-SAF programme with the EU funded ACT-SAF Africa-India project, a flagship initiative supporting 14 African States and India in laying the foundations for sustainable aviation fuels. This programme forms part of ICAO's wider ACT-SAF umbrella and is co-implemented by ICAO (€1,6 M) and EASA (€2,4 M), making it the largest multi-partner efforts of its kind. The following map shows the participating States:

EU-funded ACT-SAF Africa-India Project, Partner States

This project exemplifies how the EU is supporting Partner States not just with funding, but with tailored technical assistance, capacity building, and long-term planning.

In the period 2018-2023 the EU also funded SAF feasibility studies in seven States, of which five in Africa (Kenya, Rwanda, Burkina Faso, Zimbabwe, Cote d'Ivoire) and two in the Caribbean (Dominic Republic, Trinidad and Tobago).

Building the SAF Ecosystem

A major output of the ACT-SAF Africa-India initiative is the delivery of Feasibility Studies and Business Implementation Studies in participating States. These studies help States to understand their domestic SAF feedstock potential, assess infrastructure and logistical gaps, identify suitable conversion technologies, map policy, regulatory developments, and financing needs, deal with certification issues, and build direct supply lines.

By producing this country-specific intelligence, the project helps de-risk future investments and pave the way for real industrial development. The goal is not simply to produce reports, but to create the conditions for financially viable SAF production projects that facilitate final investment decisions.

These efforts are fully aligned with the EU's Global Gateway strategy, which supports sustainable infrastructure development and economic partnerships in regions like Africa, Latin America/Caribbean and Asia-Pacific. Green energy and aviation are strategic sectors within this strategy, and SAF lies at their intersection.

Empowering Partner States:

A key design principle of the ACT-SAF Africa-India project is local ownership. Instead of a one-size-fits-all model, the project focuses on national priorities and fosters domestic leadership. This approach has led to tangible progress, including:

- Country Consultations to engage national stakeholders and to identify SAF potential and priorities
- Capacity-Building Workshops that strengthen local institutions and expertise
- Regional Knowledge Sharing events that encourage peer-to-peer learning

The project's First Annual Workshop, held in Mombasa, Kenya in September-October 2024, convened over 220 participants to discuss SAF project de-risking and regional cooperation. In early May 2025, a Second Annual Workshop took place in Abuja, Nigeria, focused on SAF financing and risk management, core topics for turning feasibility into reality.

These events help create communities of practice that will outlive the projects themselves, ensuring the sustainability of capacity built.

SAF as a Development Catalyst

Beyond emissions reduction, SAF represents a powerful opportunity for economic transformation. The diverse feedstock base (for example used cooking oil, agricultural waste) as well as green hydrogen could create demand for local supply chains. The development of SAF infrastructure offers the potential for green jobs, skills training, and rural development.

In this way, SAF can serve not only as a decarbonisation solution, but also as a vehicle for green industrialisation, especially in developing countries, in line with ICAO "No Country left Behind" Strategic Objective. Countries can position themselves as energy exporters in the future SAF market, boosting trade while reducing dependence on imported fossil fuels.

Recognising this potential, the EU is supporting, via its Global Gateway Initiative, countries to move from analysis to investment.

Supporting CORSIA Implementation

Another important element of the global basket of measures to address aviation emissions is the Carbon offsetting under CORSIA, a key mitigation measure to reduce emissions and incentivise the use of SAF.

The initiatives of European entities, either through the ICAO ACT-CORSIA programme or through dedicated technical cooperation projects, have contributed to the increasing numbers of States volunteering to take part in CORSIA during the Pilot Phase (2021-2023) and First Phase (2024-2026). By facilitating the implementation of CORSIA's Monitoring, Reporting and Verification (MRV) process, and in some cases the development of their national accreditation process, this has helped enable over 100 countries to effectively participate in the scheme. Technical assistance has also contributed to the development or update of State Action Plans for CO_2 emissions reduction in 18 States, reinforcing national ownership and institutional capacity.

Partner States supported by European funded international cooperation initiatives on CORSIA.

In addition, the "EU-CORSIA Africa and Caribbean Project", implemented by EASA and financed by the EU (€5,5 M), has been ongoing since 2019 and is due to end in October 2025. The project covers 54 States and has facilitated the engagement of Partner States in CORSIA. It has also helped more States adopt a domestic legal framework on CORSIA, including a national MRV framework. The project has increased knowledge sharing on the ICAO emissions unit criteria and eligible emissions units.

As CORSIA progresses toward its offsetting phase, EU-backed efforts help countries to strengthen their implementation systems and align their domestic climate goals with global aviation commitments.

The Path Forward: Coordination and Strategic Scaling

While progress on SAF is clear, major challenges remain:

High SAF costs, infrastructure gaps, policy uncertainty, financing constraints. Regulatory incentives and long-term targets are needed, and projects need de-risking.

To address these, the EU and its partners in the Aviation Environmental Protection Coordination Group (AEPCG) play a key role in aligning EU institutions, States, and stakeholders around shared objectives. This forum facilitates collective planning, efficient resource use, and a more coherent EU presence in international environmental cooperation.

Additionally, greater cooperation between donors - multilateral development banks, climate funds, and bilateral partners - can help ensure that funding streams complement each other and are matched to the priority needs of Partner States.

Conclusion: From Ambition to Action, Together

The fight against climate change requires global resolve, and this is especially true for the aviation sector. Through international partnerships, global climate diplomacy can translate into local impact.

By supporting countries across Africa, Asia, Latin America, and the Caribbean, the EU is contributing to decarbonise aviation globally. Whether through capacity-building, feasibility studies, or financing readiness, these efforts are equipping Partner States to shape their own clean aviation futures.

In doing so, they are also shaping a more inclusive, resilient, and sustainable global aviation system - one that leaves no country behind on the journey to net-zero emissions in international aviation.

Kenya's Role in the Global Effort on Aviation Environmental Protection and Sustainable Aviation Fuels (SAF) development, Strengthened by International Support and Collaboration

By Francis Mwangi (Kenya Civil Aviation Authority - KCAA)

a) Kenya's Environmental Initiatives in Aviation

Kenya, through its Civil Aviation Authority, has for a long time understood the need to balance the growth of its aviation sector with the needs of environmental protection. In the wake of global climate change, KCAA has put in place policies that will ensure that the aviation sector complies with both local and international environmental standards (Annex 16). At the core of these efforts is a desire to minimise the carbon emissions of aviation and encourage sustainable economic growth.

KCAA's environmental management system functions on an integrated basis, where economic, environmental, and social objectives are balanced. This approach guarantees that the aviation industry does not hinder the development of the country at the expense of future generations' ability to meet their needs. Notably, Kenya has been a proactive player in the global efforts to mitigate aviation emissions, in line with ICAO's vision of achieving net-zero carbon emissions for international aviation by 2050. This ambitious goal can be also achieved through partnership with international partners, attendance in high-level climate conferences such as COP28, CAAF/3 and active participation in ACT-CORSIA and ACT-SAF Programmes.

b) Key Achievements from 2022 to 2025

KCAA's environmental successes have been a continuation of its efforts to minimise the carbon footprint of aviation. One of the main areas of attention has been the reduction of carbon emissions from aircraft and airports, an area that it actively promotes through various international forums.

i. CORSIA participation

As a contribution to the global efforts to combat climate change, Kenya actively participated in the CORSIA pilot phase (2021-2023) and submitted carbon emissions data for Kenyan operators through the CORSIA Central Registry, as required. Kenya remains engaged in the CORSIA first Phase (2024-2026) and continues to implement the measures outlined in its State Action plan (2022-2028).

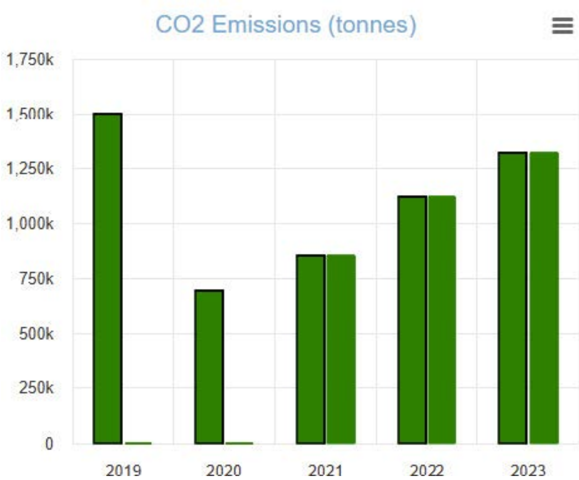


FIGURE 1: CO_2 emission for international flights from 2019-2023

FIGURE 2: ACT-CORSIA with EU 2025

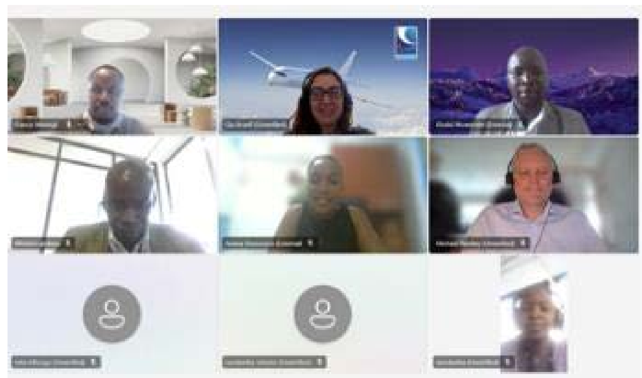


FIGURE 3: ACT-CORSIA under buddy programme 2025

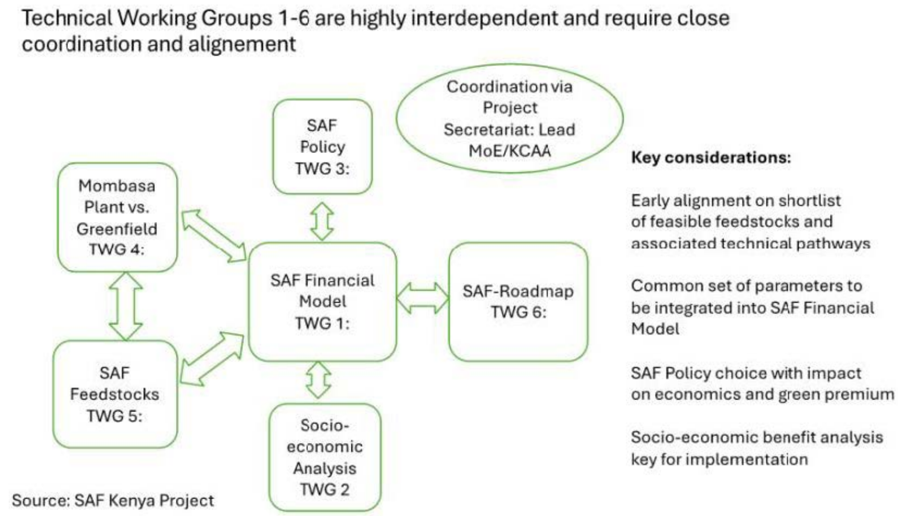
ii. ACT-CORSIA initiative

Kenya and UK CORSIA Experts continued to provide training to CORSIA Buddy Partnership countries namely: Ethiopia, Seychelles, South Sudan, Tanzania, and Uganda. The training was delivered in physical, online, and hybrid formats, with monthly meetings held with each country through March 2025. Key topics covered included: Updates to the CORSIA Regulatory Framework, CERT 2024, CCR Reporting for 2025, CEF, CAAF/3, and ACT-SAF materials, CEEEU and TAB 2025 review. Further Kenyan Stakeholders received training from EASA ACT-CORSIA during the review period.

iii. SAF Initiative

Kenya has played a significant role in advancing the development and promotion of Sustainable Aviation Fuels (SAF) that is one of the key measure established in the State action plan. As a promising alternative to conventional jet fuel, SAF offers substantial reductions in lifecycle greenhouse gas emissions. A major milestone was achieved in 2018 when Kenya participated in a SAF feasibility study funded by the International Civil Aviation Organization (ICAO) and the European Union. This study marked an important step toward building domestic SAF production capacity. In support of this initiative, the Kenya Civil Aviation Authority (KCAA) has organized workshops aimed at disseminating findings, engaging stakeholders, and harmonizing policy frameworks. These efforts underscore Kenya's commitment to a collaborative, multi-stakeholder approach to SAF development. To further institutionalize this effort, Kenya has established a national SAF Steering Committee. This committee is overseeing SAF implementation through specialized Technical Working Groups (TWGs), which focus on key areas including:

a) SAF Finance Case for Kenya
b) Socio-Economic Benefits Study
c) SAF Policies (Energy Policy)
d) Mombasa Refinery and Fuel Blending, and Certification
e) Feedstock Sourcing Assessment
f) SAF Roadmap



These TWGs are working in coordination to develop a comprehensive and actionable strategy for SAF deployment in Kenya. The global drive for decarbonization has triggered innovation, whereby there are improvements in cleaner technologies and alternative fuels. **By collaborating and with support from ICAO, GIZ, WB, FAA, Netherland, EASA, Hasselt University and MIT through Ascent 93 and other international organisations, Kenya has a chance to lead the way in sustainable aviation practices in Africa.** The establishment of local SAF production capacities, as well as the increase of renewable energy projects at airports, can make Kenya a regional center for sustainable aviation.

FIGURE 4: 1st SAF workshop Aug 2022

FIGURE 5: Second SAF workshop, October 2023

FIGURE 6: Stakeholder engagement with KPC on SAF agenda

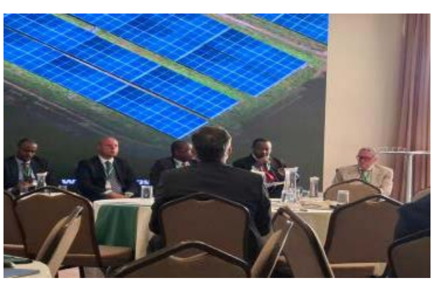


FIGURE 7:ENI-AFI conference April 2025

FIGURE 8: Visit to Geothermal Plant for feasibility on SAF supported by ICAO through Netherlands funding

FIGURE 9: 1st Regional workshop and 3rd Kenya workshop under EASA ACT_SAF in Mombasa, Kenya in 30 Sept-2nd Oct 2024

FIGURE 10: 1st SAF Steering Committee meeting on 29th May 2024

FIGURE 11: 2nd SAF NSC meeting in Mombasa, Kenya- 2nd to 4th October 2024

FIGURE 12: TWG Meeting April 2025

FIGURE 13: 3rd SAF NSC meeting in Naivasha- 19-21st May 2025

vii. CAEP Participation

Kenya continues to actively participate in the CAEP Meeting and currently holds the position of the Vice Chairperson for the region. Kenya has also been actively participating in the COP meetings under UNFCCC to push the agenda on Article 6 and CORSIA.

viii. Solar at the gate project.

A pilot project was implemented in at the Moi International Airport, Mombasa, Kenya with strong support from the International Civil Aviation Organisation (ICAO). This initiative targeted 14 African and Caribbean states. Twelve (12) States were from the African Region and two from the

FIGURE 14: COP 28 participation in Dubai, 2023

FIGURE 15: CAEP participation in Japan

FIGURE 16: kenya key negotiators on climate change

FIGURE 17:CAEP participation in Montreal 2025

FIGURE 18: Hosting of CAEP WG4 in Nairobi in 2024

Caribbean Region. This project was implemented by the Kenya Civil Aviation Authority (KCAA) and the Kenya Airport Authority (KAA). It was funded by the European Union and the Government of Kenya at a cost of USD 1,501,132.22 which was part of the €6.5 million initiative, entitled "Capacity Building for CO_2 Mitigation from International Aviation". It consisted of a ground-mounted photovoltaic system of 507kW solar power generation facility and mobile airport gate electric equipment and was launched on 12th December 2018. This solar farm not only helps in carbon reduction but also leads to significant savings in electricity bills for the airport, which is an average of USD 25,000 (Ksh 2.5 million) per month. These initiatives have made MIA a model for sustainable airport operations in Africa. The project continues to generate Solar energy for use in the Airport.

https://archives.greenairnews.com/www.greenaironline.com/news5633.html?viewStory=2557.

FIGURE 19: Solar panel at MIA

FIGURE 20: Dashboard for usage and generation

ix. State Action Plan and progress

Kenya is focused on environmental sustainability as a key aspect of its operations. The establishment of a specialised Environmental Protection Department in the CAA is one of the most important developments. In accordance with its obligations to CORSIA and other international agreements, Kenya has been attending high-level forums like the ICAO Conference on Aviation Alternative Fuels (CAAF/3) in Dubai in 2023. These international engagements are essential for knowledge sharing, the development of new technologies, and global cooperation. KCAA is also dedicated to promoting Kenya's overall environmental objectives. In accordance with the national goal of planting 15 billion trees by the year 2032, the KCAA Board has committed to planting 32,500 trees every year. During the 2023/24 period, the Authority managed to plant more than 52,000 trees in different parts of Kenya, helping in reforestation and carbon sequestration, and this year, 100,644 trees have been planted and in is a work in progress.

FIGURE 21:CAAF/3 participation in Dubai

FIGURE 22: Tree planting in 2024

Conclusion

By taking part in global initiatives such as CORSIA, promoting SAF, and introducing renewable energy projects, KCAA has made Kenya a leader in the drive for sustainable aviation in Africa. However, the problems that the industry faces are significant, and there is a lot to be done to achieve the global goal of net-zero emissions by 2050. Further international collaboration, innovation, and investment in sustainable technologies will be critical for the aviation industry to contribute to climate change mitigation. As Kenya continues to move forward, it is an example of how a developing country can be a leader in environmental stewardship in the aviation industry.

By actively participating in global initiatives such as CORSIA and ACT-SAF, promoting Sustainable Aviation Fuels (SAF), and investing in renewable energy projects, Kenya is positioned as continental leader in the pursuit of sustainable aviation. Despite this progress, the aviation sector still faces substantial challenges on the path to achieving the global target of net-zero emissions by 2050.

Realizing this ambition will require not only continued international collaboration, innovation, and investment in sustainable technologies but also clear and trusted partnerships that foster inclusive progress. Strengthening collaboration with stakeholders, locally and globally, is essential to ensure that climate action in aviation also delivers tangible socio-economic benefits to communities and enhances energy security. As Kenya moves forward, it stands as a compelling example of how a developing country can lead by example in environmental stewardship, demonstrating that sustainability and inclusive development can go hand in hand in the global transition to net zero by 2050.

Lessons Learned from Capacity Building Sessions in the Caribbean

By Ashan Edoo (Transport Canada)

Introduction

In 2014, the International Civil Aviation Organization (ICAO)'s Council considered how to better communicate with and assist its Member States in terms of Capacity Building and Implementation. One of the major points considered was with respect to discrepancies in how ICAO Standards and Recommended Practices (SARPs) were being implemented and that ICAO itself should provide more assistance including by playing a more active role on coordinating between States to build capacity.

Consequently, the Council decided that ICAO should review what it can do to better encourage States that have the capacity and resources to provide more comprehensive assistance to States that require support in various areas. Therefore, the No Country Left Behind (NLCB) initiative was endorsed to help coordinate and publicize any Organization-wide activities consistent with these priorities.[1]

ICAO's ACT-CORSIA Programme

In 2018, after the adoption of Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the Standards and Recommended Practices (SARPs), the ICAO Council endorsed the ICAO ACT-CORSIA (Assistance, Capacity-building and Training for the CORSIA) Programme which recognized that many ICAO Member States would need targeted assistance in order to prepare for CORSIA implementation.[2]

Canada has been an active supporter of the ACT-CORSIA programme since its inception, including providing support to Francophonie States in Africa in a partnership with France and more recently supporting Caribbean States through direct coordination with the ICAO North America and Caribbean (NACC) office and Regional Focal Points.

Importance of Aviation In the Caribbean Region

Air connectivity is key for the movement of people and transport of goods for the small island nations of the Caribbean. While there has been traffic growth overall for aviation within the region, this has been driven by extra regional traffic while intra-regional traffic has decreased.[3] This means that in many cases passengers need to take multiple flights to get between two States given that there may be limited or no routes available.

In a working paper to the 40th Session of the ICAO Assembly, the Caribbean Aviation Safety and Security Oversight System (CASSOS) outlined the value that had been provided from the ACT-CORSIA programme including invaluable training and partnerships alongside assistance with domestic regulations.[4]

1 https://applications.icao.int/postalhistory/the_no_country_left_behind_initiative.htm
2 https://www.icao.int/environmental-protection/pages/Assistance.aspx
3 https://www.caribank.org/sites/default/files/publication-resources/Air%20Transport%20Competitiveness%20and%20Connectivity%20in%20the%20Caribbean_0.pdf
4 https://www.icao.int/Meetings/a40/Documents/WP/wp_339_en.pdf

ACT-CORSIA Workshop – Trinidad and Tobago (2024)

Overview

Ahead of this session, Canada coordinated with the ICAO Secretariat, NACC Regional office and Host State before settling on a date and location for the training. As per the ICAO ACT-CORSIA program, the training was tailored to Trinidad and Tobago (Figure 1) as per their needs and several virtual meetings were held prior to the in-person training to understand the circumstances there and expected attendees to ensure a timely productive workshop. This approach allowed the State to benefit from training that was tailored to their circumstances which is a key part of ICAO's ACT-CORSIA capacity building program.

The training covered a wide range of topics related to CORSIA and provided participants with information on ICAO's work on the Environment, Key Components of CORSIA and latest developments on Sustainable Aviation Fuels. An opportunity was also provided during the workshop to allow for an update from the Trinidad and Tobago Civil Aviation Authority on airspace improvements to improve fuel efficiency of flights in the Piarco Flight Information Region.

Overall, the workshop was well attended with participants from the Civil Aviation Authority, various multiple Government Departments, a fuel producer and a regional airline.

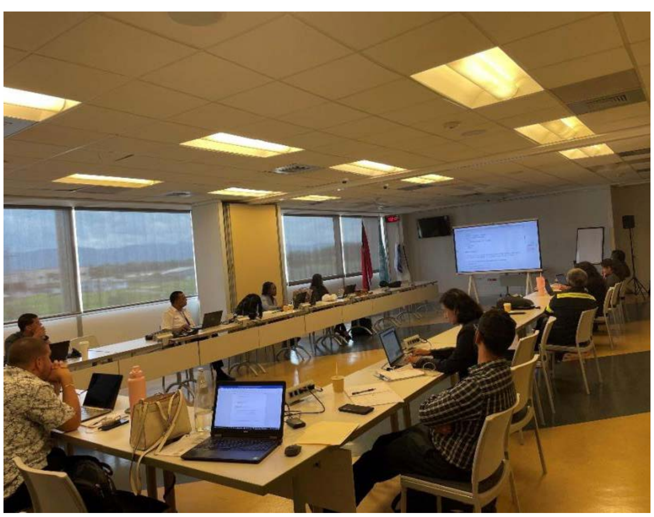


FIGURE 1: ACT-CORSIA Workshop – Trinidad and Tobago.

Key takeaways

- Given that participants had a varied understanding of ICAO's work on the Environment and CORSIA, it was important to provide a high-level overview before diving into the specifics of the scheme and to provide ample time for answering questions.
- It was valuable to have the largest regional airline, Caribbean Airways in attendance as they were able to share their own experiences with CORSIA with participants.
- One challenge was that participants had varying levels of understanding and exposure to the Environment file. Moreover, it was mentioned that representatives have difficulty building up and maintaining a high level of expertise on environmental matters when training is provided to the State only once per year. This was relayed to the ICAO Secretariat.
- Participants discussed setting up future meetings to further discuss Environmental matters to continue making progress, as well as options for updating a SAF Feasibility study.

ACT-CORSIA and State Action Plan Workshop – Antigua and Barbuda (2025)

Overview

This workshop was provided in coordination with the Eastern Caribbean Civil Aviation Authority (ECCAA) and attended by its 6 Member States (Figure 2):

- Antigua and Barbuda
- Saint Lucia
- Saint Vincent and the Grenadines
- Grenada
- Dominica
- Saint Kitts and Nevis

Similar to the first workshop, Canada coordinated closely with the ICAO NACC regional office to tailor the agenda to the needs of the Eastern Caribbean States. Along with providing Capacity Building on CORSIA, training was also provided on ICAO's State Action Plan initiative.

FIGURE *2*: ACT-CORSIA and SAP Workshop – Antigua.

- It was important to understand that while some measures may work for larger ICAO Member States and airports, they may not be a good fit for smaller island States with smaller airports and lower levels of traffic.
- Another key point was the impact of extreme weather events on airport infrastructure and that this should be considered for future planning.
- The lack of direct intra-regional flights was also noted in discussions, and this results in higher emissions due to longer itineraries. For example, instead of a short flight to get from one island to another island, travellers may instead have to fly through a larger airport like Miami international and face an overnight layover.

Key takeaways

- As the Eastern Caribbean States are not members of ICAO's Committee on Aviation Environmental Protection, it was valuable for them to have access to a Canadian expert both at the workshop and then afterwards. For example, there were specific questions on how ICAO's CO_2 estimation tool worked and how specific aircraft types are accounted for, and the instructor was able to provide answers and reference material at the workshop on it.
- While a regional air operator had ceased operations during the covid pandemic, it is possible that a new operator may surpass the CORSIA threshold in future years and therefore it was important to have an understanding of CORSIA now and how to prepare for compliance.
- Discussions for the 2nd half of the workshop focused on developing the first State Action Plan for the ECCAA Member States. In particular, there were productive discussions on availability of data and selection of mitigation measures.

Next Steps

Canada is continuing to support the ECCAA Member States virtually as they work on their first Aviation Action Plan.

Conclusion

The provision of Capacity Building to requesting States is key to ensuring that they can contribute to Aviation's green transition and ICAO's No Country Left Behind Initiative. Such training should be tailored to each State's individual circumstances to ensure they are impactful while also coordinating with ICAO's regional offices as appropriate. It is also important that ICAO Member States are aware that there are virtual opportunities for increasing their expertise on Environment such as Webinars organized by the ICAO Secretariat.

Participation of the Dominican Republic in the EASA Assistance Projects with the European Union Funding

By Judit De Leon (IDAC) and Eleonora Italia (EASA)

INTRODUCTION

The Dominican Republic notified its official entry into the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) on October 5, 2018, with the aim of participating from the outset in the process of adapting CORSIA implementation elements to the national context. On July 16, 2020, through communication 2054, and during the pandemic, the CORSIA Aviation Capacity Building Project for Africa and the Caribbean was notified of its interest in participating in the project. This took into account the positive results obtained in the first ICAO-EU project, completed in 2018, and the challenges faced by the Dominican State as a Small Island Developing State (SIDS).

The project provided support for the harmonization, and where necessary, the design, of the national legal framework necessary to address the impact of aviation on climate change, including the dissemination of ICAO Annex 16 Volume IV, which creates the legal basis for CORSIA implementation.

The EU-CORSIA Africa and Caribbean project activities included:

- Promote knowledge and understanding of aviation's impacts on climate change and related policy measures through (regional) workshops and dedicated training

IDAC

Instituto Dominicano de Aviación Civil

"Año de la Consolidación de la Seguridad Alimentaria"

2054

Santo Domingo, D.N.

16 JUL 2020

Señora,
Caroline Beth,
Technical Cooperation Project Assistant
European Union Aviation Safety Agency
Su Despacho.

Muy cortésmente le saludo, en ocasión de dirigirme a usted en referencia a su comunicación No. devco.c.6 (2020)3460873, de fecha 24 de Junio de 2020, sobre el lanzamiento de la creación de capacidad para la mitigación de CO2 a nivel internacional, proyecto de aviación África y el Caribe (CORSIA África y el Caribe).

En tal sentido, me complace informarle que el Estado Dominicano está interesado en participar, en aras de contribuir con los esfuerzos mundiales para reducir las emisiones de CO_2 provenientes de la aviación internacional. Por tanto, anexamos el formulario "Focal point identification-Response form" con los datos del punto focal para CORSIA de la República Dominicana.

Atentamente,

Dr. Alejandro Herrera Rodríguez
Director General

Anexo: Formulario de identificación-respuesta de punto focal "Focal point identification-response form"

AHR/yl

FIGURE 1: Official Correspondence from the Dominican Republic's Civil Aviation Authority (IDAC)
Formal letter issued by IDAC expressing interest in international collaboration on aviation environmental matters.

courses, while promoting collaboration with national transport, aviation, and environment and climate entities;

- Regional workshops and training on environmental management systems;
- Regional workshops and training on the importance of using monitoring and evaluation (M&E) procedures and indicators to track climate adaptation initiatives, plans, and actions at the project and sectoral levels;

The objective of this project was to mitigate greenhouse gas emissions from the civil aviation sector and, more specifically, to assist selected States in complying with their measures under the Chicago Convention in relation to United Nations Sustainable Development Goal (SDG) No. 13: "Adopt urgent measures to combat climate change and its impacts". The project was planned to run from 2020 to 2022. As the project phases were completed and its impact was evaluated, the project has been extended until the 12 October 2025.

CORSIA entered the pilot phase from 2021 to 2023. This phase required airline operators eligible for CORSIA to submit an emissions monitoring plan. The Instituto Dominicano de Aviación Civil (IDAC) had to approve it. The following year, after approval, the plan had to be verified by a verifier accredited under the CORSIA scheme by the national accreditation body, in this case the Organismo Dominicano de Acreditación (ODAC).

To comply with the scheme, the following tasks were carried out:

1. July 2021: Signing of the IDAC-ODAC Interinstitutional Agreement. The ODAC will create a scheme that allows for the accreditation of national or international validation and/or verification bodies that meet the requirements contained in the ISO 14065:2013 Standard entitled "Greenhouse Gases."

2. In 2020, we started with only one Emissions Monitoring Plan (EMP), and by 2023, five were submitted (EMP). This is due to the increase in the number of airline operators eligible for the CORSIA scheme, as can be seen in Chart 1.

3. In January 2023, Dominican Aeronautical Regulation No. 16 (RAD16) on environmental protection was published, in compliance with the recommendations of the International Civil Aviation Organization (ICAO) under Annex 16 Vol. 4 CORSIA. It describes, based on compliance with the Carbon Offset and Reduction Plan, Implementation Phases of the International Aviation Carbon Offset and Reduction Plan, Emission Offset and Reduction Requirements, Administration of the Offset Plan, among others.

Chart No. 1
Number of Airlines Applicable to CORSIA
(Number of AOs)

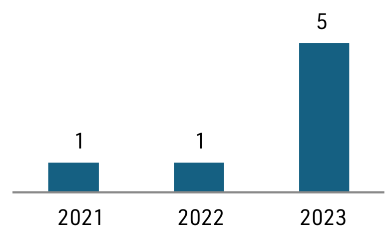


FIGURE 2: Number of airlines applicable to CORSIA.
Source: Prepared by the authors, with data from the approval of the EMP.

IMPLEMENTED ACTIVITIES AND EVOLUTION

1. From March 9-10, 2022, a CORSIA MRV Virtual Seminar was held: Key Concepts of ICAO ANNEX 16, Volume IV, "First Edition." Sixteen airline operators were invited, with the participation of 16 people from different organizations.

2. From April 28-29, a workshop was held on Accreditation to ISO 14065:2013—The Foundation for CORSIA Program Implementation by National Accreditation Bodies (NABs) and Verification Bodies (VBs). This workshop was coordinated with the Dominican Accreditation Body (ODAC). Sixteen people from the accreditation team, a technical expert, and verifiers participated.

3. From May 17 to 19, 2022, the first regional seminar on CORSIA was held in Antigua under the framework of the project, with the participation of an 8-person delegation, including: the Accreditation Body, the Air Operator, the Ministry of Environment and Natural Resources, the Climate Change Council and the Clean Development Mechanism, and the IDAC.

FIGURE 3: Regional Seminar on CORSIA held in Antigua.

4. From September 1st to 2^{nd} 2022, the workshop "ISO 14064-1:2006 TRAINING" was held, taught virtually by a Project Expert in Accreditation, Standardization, Conformity Assessment and Greenhouse Gases, with the participation of 24 people representing ODAC, INDOCAL, IDAC, Ministry of Environment, Verification Body and Council of Climate Change and Clean Development Mechanism.

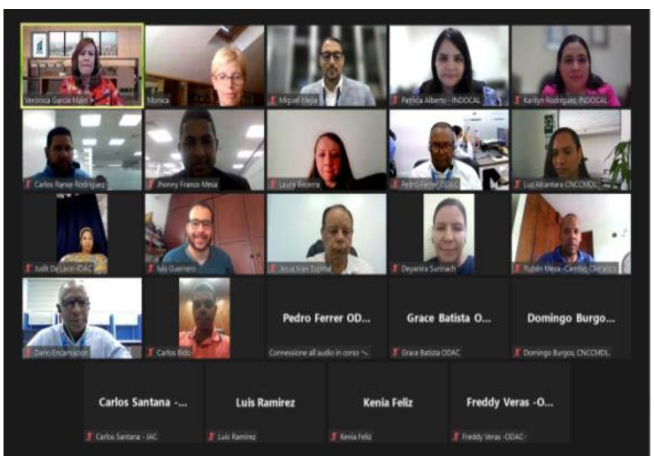


FIGURE 4: ISO 14064-1:2006 Training.

5. On October 25 and 26 2022, the ISO 14064-3 and ISO 14065 training workshops were held, with 14 participants. The objective of this training was to expand knowledge in conformity validation/verification. The entry requirement was identified as preferably auditors or individuals with knowledge of conformity verification or validation.

6. On October 2-4, 2023, the 2nd regional seminar on CORSIA was held at the Higher Academy of Aeronautical Sciences (ASCA), where the Dominican delegation had a representation of 20 people, including ministries and air operators, which increased from 1 to 5. The procedures created by the ODAC for the accreditation scheme of the verifying body were presented as a result of this seminar.

FIGURE 5: 2nd Regional Seminar on CORSIA held at the Higher Academy of Aeronautical Sciences (ASCA) in Dominican Republic.

7. In September 2023, a compliance audit was conducted on the verifier to accredit the validation/verification processes in CORSIA.

8. On November 9, 2023, the CI-ATABEY Foundation was accredited as the first national and Caribbean verifier for CORSIA with accreditation number 011/OVV-001.

9. The session on terminology related to SAF (Sustainable Aviation Fuel) and CEF (CORSIA Eligible Fuel) was held on April 9, June 25, and June 28, 2023. Technical Certification and Sustainability Certification were attended by 64 people from different institutions, including the SAF panel.

FIGURE 6: Session on terminology related to SAF and CEF.

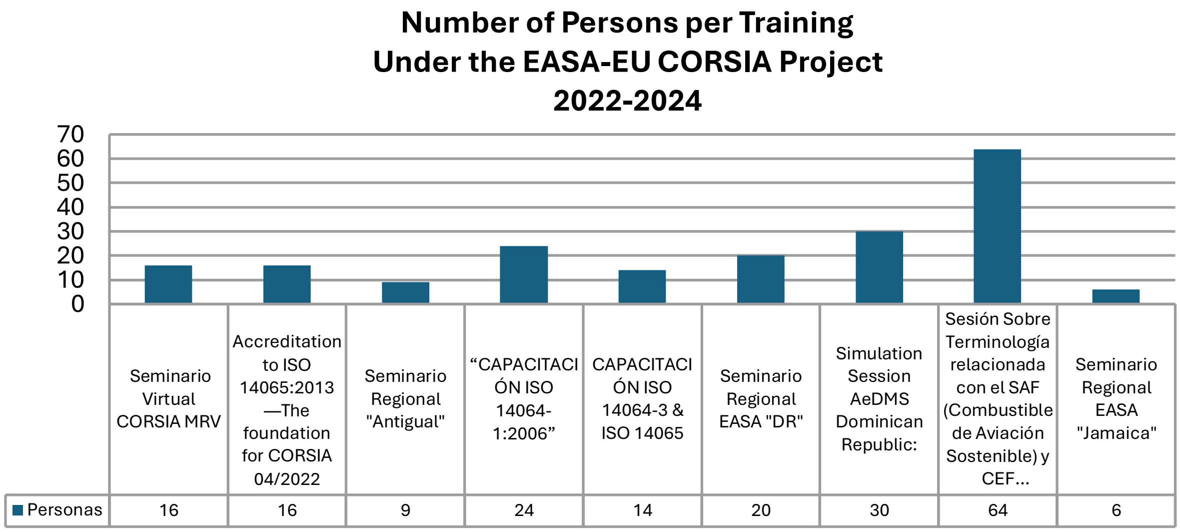


FIGURE 7: Number of persons per training under the EASA-EU CORSIA Project 2022-2024. Source: Prepared by the authors, obtained from the participant list and other records.

CONCLUSIONS

A total of 199 people were trained in the various training courses provided under the project framework (Figure 7).

The impact of the training can be represented in the following graph (Figure 8): 30% was provided to national and international airline operators, 64% to public institutions such as the Civil Aviation Board, the Airport Department, ODAC, INDOCAL, the National Council for Climate Change and Clean Development Mechanism, and the Ministry of the Environment, among others; and 6% to the private sector, such as ground service operators, airport managers, and verification bodies other than the public sector, among others.

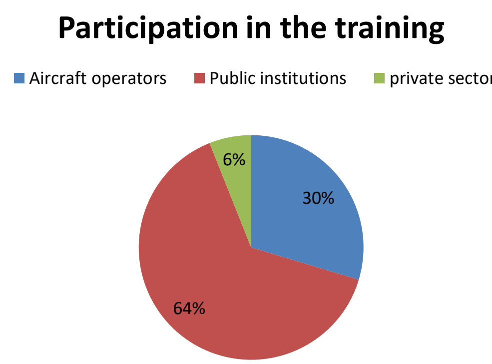


FIGURE 8: Participation in the capacitation per type of organization. Source: Prepared by the authors, obtained from the participant list and other records.

Ramping up roadmaps under ICAO's ACT-SAF initiative: experience from Boeing and partners

By Boeing

Boeing and partners are developing country-specific roadmaps that lay the foundation for scaling SAF

The International Civil Aviation Organization (ICAO) has been at the forefront of aviation decarbonization including its adoption of a long-term aspirational goal for international aviation to achieve net-zero emissions goal by 2050, as well as its aspiration to reduce carbon emissions by 5% for international aviation by 2030 using sustainable aviation fuels (SAF), Lower Carbon Aviation Fuel (LCAF) and other aviation cleaner energies.

Boeing supports ICAO's efforts and in 2023 the company joined the ICAO Assistance, Capacity-building and Training for Sustainable Aviation Fuels (ACT-SAF) initiative. ACT-SAF creates opportunities for countries to develop their full potential in SAF development and deployment.

In support of ICAO's initiative, Boeing has helped develop region-specific roadmaps and SAF feedstock analyses together with local partners to help scale SAF production locally to drive regional energy resilience and help meet demand globally. These roadmaps help to identify which feedstocks are the most cost-effective and politically and technically achievable in any country.

Boeing supported studies span the UK, Ireland, India, UAE, Australia & New Zealand, Brazil, South Africa, Ethiopia, Japan and a recently launched SAF feedstock assessment for Southeast Asia.

"These roadmaps inform three things," said Brian Moran, Chief Sustainability Officer at Boeing. "They inform policy, including incentives and other measures, such as revenue certainty mechanisms that de-risk investment in SAF facilities for producers. They inform technology, and which feedstock and production pathways are the most promising to scale up. And thirdly, they inform financing and opportunity for investors."

In the charts below, further fidelity on country and regional paths towards net zero is provided by the Boeing Cascade Climate Impact Model, a digital tool that quantifies the potential of commercial aviation's strategies to reduce carbon emissions.

Key takeaways from a few Boeing-sponsored SAF roadmaps:

Japan

- A SAF feedstock study in Japan[1], undertaken by strategic consultancy firm ICF and led by Boeing, Mitsubishi Heavy Industries and SMBC Aviation Capital, identified potential for Japan to produce up to 441 million gallons (1.67 billion liters) of SAF by 2030.
- Promising feedstocks include woody biomass, municipal solid waste and renewable electricity.
- Scaling up local production of SAF could allow Japan to nearly meet its 2030 goal of using 10% SAF for international flights.

Southeast Asia

- RSB's report on Southeast Asia[2] noted the region boasts significant potential to produce SAF due to its abundant bio-based feedstock resources such as agricultural residues, sugars, municipal waste and some energy crops.
- The region's bio-based feedstock capacity could produce 34.2 billion gallons (129.4 billion liters) of SAF annually by 2050, or about 12% of global SAF demand.
- 75% of the potential SAF feedstock can be sourced from post-consumer and agricultural waste.
- Making up 37% of total feedstock contribution, the most voluminous feedstocks are rice husks and straw.

Australia

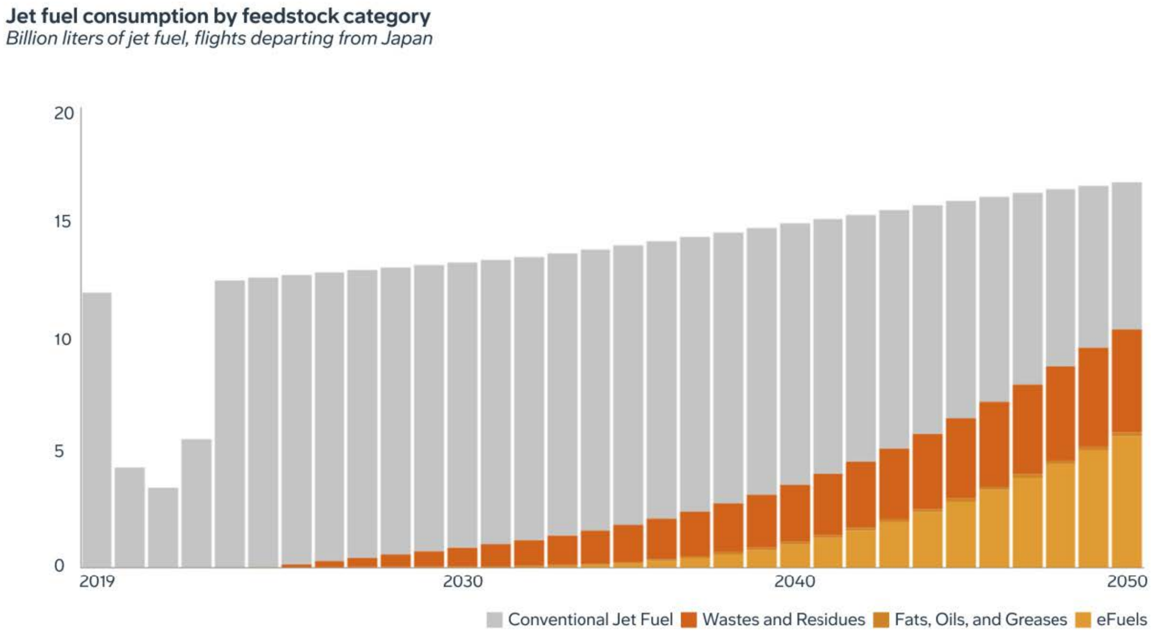
- CSIRO's report on Australia[3] illustrates that through a combination of feedstocks and technologies, local feedstocks can meet a large and growing portion of Australia's jet fuel demand. Australia will have enough feedstocks to produce 60% of local jet fuel demand, growing to 90% by 2050, according to the forecast.
- In November 2024, Boeing and CSIRO published an update called the SAF State of Play[4]. The study found several projects are progressing towards SAF blending and production, including Boeing's investment into Wagner Sustainable Fuels[5] to build Australia's first blending facilities.
- Federal and State government action is driving policy development and de-risking investment, while Australia's finance sector is increasingly engaged in developing innovative funding approaches to scale SAF.

Brazil

- A RSB report on Brazil[6] determined huge potential in sugarcane bagasse and wood residues, particularly in the south-eastern part of the country.
- The main findings suggest the potential for SAF production from the mapped residues in Brazil is up to 2.4 billion gallons (9.08 billion liters), which is around 125% of the current fossil kerosene (Jet A) consumption in Brazil.

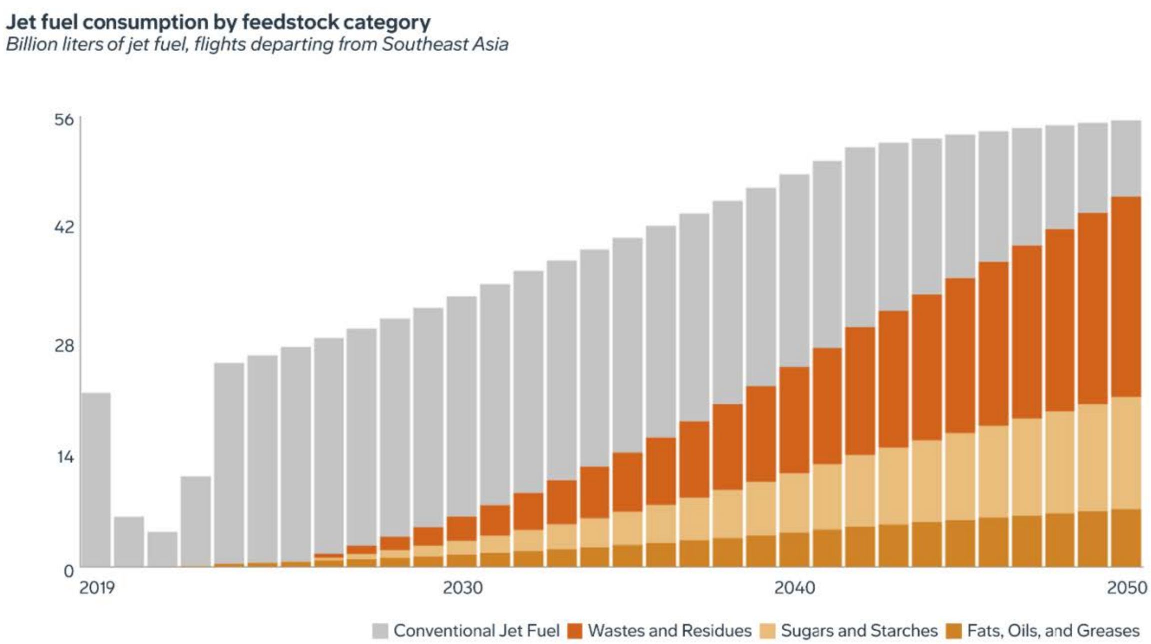
"Scaling SAF sustainably is not one size fits all, so these roadmaps are incredibly important to guide these investments," said Moran. "They unlock learnings as to where we should put precious resources while guiding governments on national priorities they can help advance."

1 https://www.icf.com/insights/aviation/saf-ecosystem-in-japan
2 https://rsb.org/wp-content/uploads/2024/09/rsb-sustainable-feedstock-assessment-saf-in-southeast-asia.pdf
3 https://www.csiro.au/safroadmap
4 https://www.boeing.com.au/content/dam/boeing/en-au/pdf/boeing-and-csiro-saf-state-of-play-report-2024.pdf
5 https://www.boeing.com.au/news/2024/boeing-invests-in-australian-sustainable-aviation-fuel-productio
6 https://rsb.org/programmes/projects/fuelling-the-sustainable-bioeconomy/



Data Source: *Charting the Path: SAF Ecosystem in Japan. ICF. April 2024. Jet fuel demand estimated using the Boeing Cascade Climate Impact Model.*

FIGURE 1: Boeing's Cascade digital tool examines the possible pathways to produce SAF in Japan and reduce the country's carbon emissions from aviation. (Boeing graphic)



Data Source: *Sustainable Feedstock Assessment for Sustainable Aviation Fuel Production in Southeast Asia. Roundtable on Sustainable Biomaterials (RSB). 2024. Jet fuel demand estimated using the Boeing Cascade Climate Impact Model.*

FIGURE 2: A chart from Cascade illustrates the pivotal role agricultural waste and residues could play in locally developed SAF in Southeast Asia. (Boeing graphic)

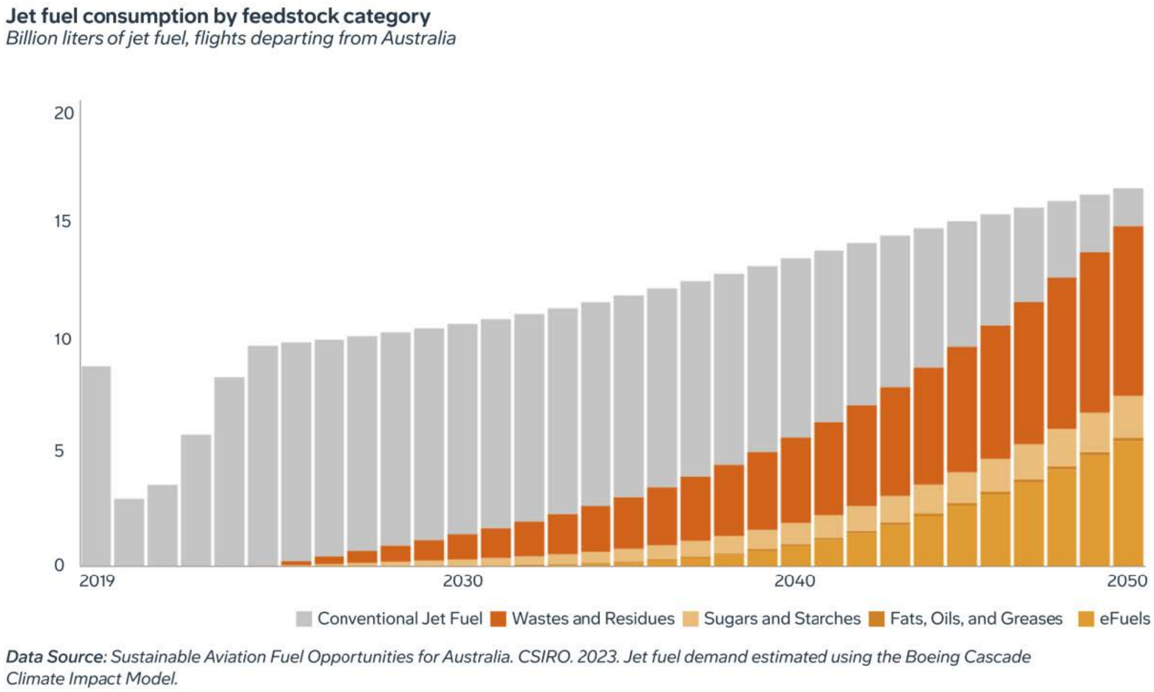


FIGURE 3: A chart from Cascade outlines the opportunities to develop SAF from local feedstocks in Australia, which could produce 60% of local jet fuel demand today, growing to 90% by 2050, according to a CSIRO report. (Boeing graphic)

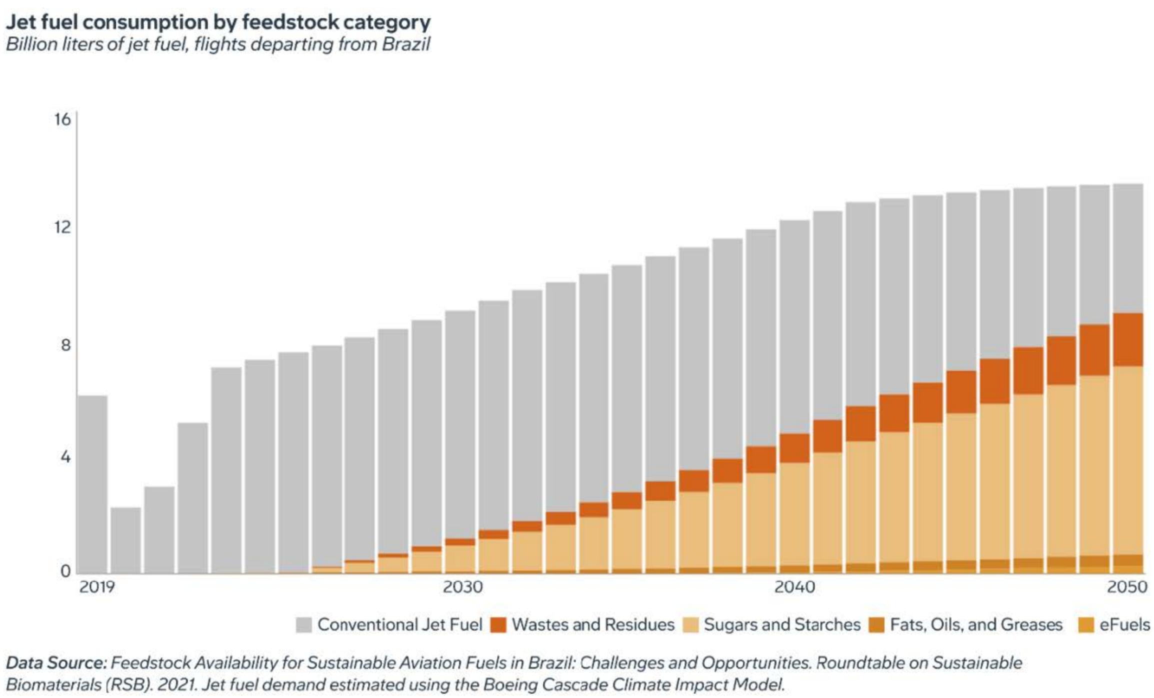


FIGURE 4: A chart from Cascade outlines the various paths for local SAF production in Brazil, including the potential of sugarcane bagasse and wood residues. (Boeing graphic)

ICAO

CHAPTER NINE

Climate Financing

Mobilizing Financing for a Net-Zero Aviation Sector

By ICAO Secretariat

Financing is a cornerstone of aviation's transition to net-zero carbon emissions, enabling the deployment of cleaner energies and other aviation decarbonization measures, as well as necessary infrastructure upgrades. Yet, securing the scale of investment required, (especially in developing regions) remains a major challenge and demands coordinated action across government, industry, and the financial sector.

The achievement of ICAO's Long-Term Aspirational Goal (LTAG) of net-zero carbon emissions by 2050 for international aviation requires not only transformative technological change but also a massive mobilization of financial resources. The scale of investment needed is unprecedented: approximately USD 3.2 trillion by 2050, primarily to scale up the deployment of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF), and other cleaner energy sources. Facilitating that all States, particularly developing countries and States with particular needs, have access to the financing necessary for this transition has become a central focus of the ICAO's environmental strategy.

Advancements since the LTAG adoption – Advocacy and Outreach

Following the adoption of LTAG by the 41st Session of the ICAO Assembly in 2022, ICAO intensified its efforts to bridge the financing gap through structured dialogues, strategic planning, and the development of targeted tools and partnerships. Assembly Resolution A41-21 recognized that ambitious climate goals cannot be realized without the means of implementation commensurate with the level of ambition. Paragraph 18 of that Resolution specifically tasked the ICAO Council with initiating concrete measures to enhance access to private investment and funding from financial institutions (A41-21, paragraph 18. a) and to explore the establishment of a climate finance initiative or funding mechanism under ICAO (A41-21, paragraph 18. b).

In response, ICAO launched an extensive dialogue process with both financial institutions and Member States, starting with a series of regional consultations in late 2022. These early exchanges brought together major public and private financial actors and development banks across all ICAO regions, providing an initial platform to assess opportunities, risks, and gaps in the financing ecosystem for cleaner aviation energy. In 2023, this engagement deepened with two informal high-level meetings of the ICAO Council — first with multilateral development banks and later with private investors — where discussions centered on unlocking investment for SAF scale-up and improving bankability of aviation decarbonization projects.

One key finding that emerged from these interactions was the urgent need for predictable, long-term regulatory frameworks and strong sustainability criteria — both of which are prerequisites for unlocking institutional investment. Many actors expressed interest in supporting SAF but noted high capital costs, policy uncertainty, and a lack of familiarity with aviation-specific risks as major deterrents. ICAO's convening role has proven vital to bridging this information gap and aligning stakeholders across aviation, energy, and finance sectors.

Financing was established as one of the foundational Building Blocks of the Global Framework adopted at the Third ICAO Conference on Aviation Alternative Fuels (CAAF/3) held in November 2023, which established the 2030 global aspirational Vision and Global Framework for cleaner aviation fuels and sustainable aviation financing.

This recognition reflects the critical role that access to public and private capital plays in enabling the deployment of SAF, LCAF, and other cleaner energy sources. By designating financing as one of its core elements, the Global Framework underscores the need for coordinated action to mobilize investment and de-risk projects, particularly in support of developing countries and States with particular needs, to ensure the effective and equitable implementation of the LTAG.

Facilitated by the adoption of the Global Framework, a number of outreach activities have been conducted also by the ICAO Secretary General in 2024. This includes meetings in Washington D.C. and London with representatives of the financial sector (multilateral development banks, private banks and investment funds) in order to raise awareness on the establishment of the ICAO Finvest Hub.

A key aspect of that outreach was to provide clarity on the ICAO Finvest Hub, where the intention is not to manage any funds, but instead to attract interest from the financing community for SAF, LCAF and other cleaner energy projects and other aviation decarbonization measures. More information on the ICAO Finvest Hub, which is part of the Organization's response to Resolution A41-21, paragraph 18. a) is available below and detailed in other articles under this Chapter.

The ICAO Secretariat also continued working directly with States to understand their financing challenges and needs. Through the ICAO ACT-SAF programme, more than 50 exploratory interviews and surveys were conducted, with a clear take-away message: over two-thirds of participating States cited access to financing as a critical barrier to SAF deployment. ICAO responded by dedicating substantial attention to financing at the 2023 and 2024 editions of the LTAG Stocktaking event and during its global series of environmental regional seminars, offering practical guidance and showcasing opportunities for financing cleaner aviation energy projects.

To support Member States in identifying and attracting investment, ICAO has also enhanced its technical assistance tools. These include updates to the *Guidance on State Action Plans* (Doc 9988) with improved sections on financial needs assessments and investment communication, and the development of a harmonized template for SAF feasibility studies, designed in collaboration with ACT-SAF partners. This template aims to make SAF project proposals more transparent and comparable, thus facilitating investor engagement and due diligence.

While these efforts have laid important groundwork, ICAO is also responding to the Assembly's specific request for even deeper consideration. In 2024, a Small Group of Council Representatives was established to oversee a consultancy study regarding the possible establishment of a climate finance initiative or funding mechanism under ICAO, as requested by Resolution A41-21, paragraph 18. b). The study, guided by detailed Terms of Reference, evaluated a range of options, assessing their financial, institutional, and legal feasibility, and as well as ICAO's potential role in implementation. The consultancy delivered its study in early 2025, to support the Council's consideration of its report to the 42nd Session of the ICAO Assembly.

ICAO Finvest Hub Initiative

As requested by the Assembly and the CAAF/3 Global Framework, ICAO has been preparing for the launch of the "Finvest Hub", a platform designed to facilitate access to climate finance and to connect States and project developers with funding opportunities.

In October 2024, ICAO and the International Renewable Energy Agency (IRENA) signed a Memorandum of Cooperation to allow for partnerships to operationalize the ICAO Finvest Hub. This cooperation will be further detailed in an IRENA article in this Chapter.

The conceptual foundation of the Finvest Hub is aligned with ICAO's broader financing strategy: to create an enabling environment where investments in aviation cleaner energy can flourish, particularly in parts of the world most in need of support.

Together, these activities form a coherent response to one of the most complex and urgent aspects of the global aviation decarbonization challenge: financing the transition. ICAO's work since 2022 represents a strategic shift toward implementation support, capacity-building, and financial mobilization, which are essential pillars of international aviation's efforts to reach net-zero carbon emissions by mid-century.

The ICAO Finvest Hub

By ICAO Secretariat

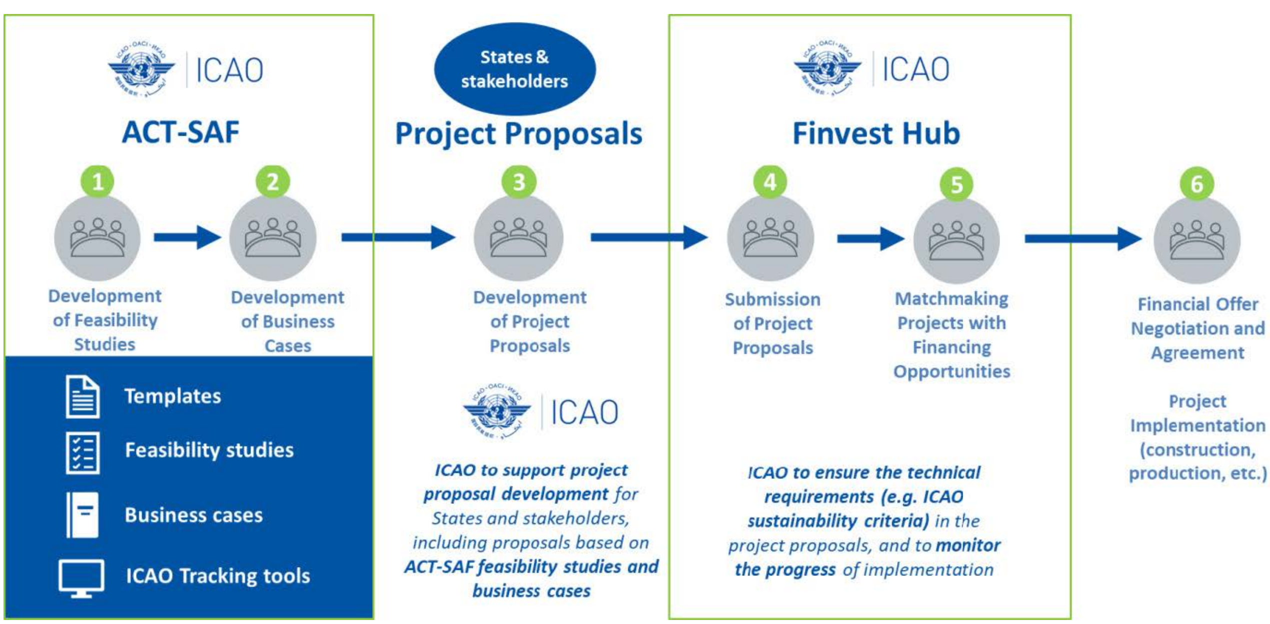
As the international aviation sector continues to progress towards the LTAG, the need for substantial financial investment in sustainable aviation technologies and cleaner energies has never been greater. Recognizing the critical role of finance, ICAO has introduced the Finvest Hub—a platform designed to bridge the gap between aviation sustainability projects and the financial resources necessary to bring them to fruition.

The Finvest Hub focuses on accelerating the transition of aviation towards cleaner energy solutions. At its core, this initiative aims to provide a dedicated space for the aviation industry to connect with investors, policymakers, and other key stakeholders. The hub supports the scaling of sustainable aviation fuel (SAF) production, the deployment of clean energy infrastructure, and the development of technologies that reduce aviation's carbon footprint. It also facilitates the creation of financial structures that can attract significant investment, particularly in emerging markets.

One of the defining features of the ICAO Finvest Hub is its inclusivity. The platform prioritizes the needs of developing countries, which often face significant barriers in securing financing for aviation sustainability projects. By providing targeted support, such as capacity-building initiatives, technical assistance, and access to a network of global investors, the Finvest Hub aims to enable developing countries and States with particular needs to actively participate in the global transition to a sustainable aviation sector.

In partnership with a broad range of governments, financial institutions, and the private sector, ICAO is fostering a collaborative environment that enables the aviation industry to innovate, scale, and implement solutions to reduce emissions. The Finvest Hub not only supports the aviation sector's immediate needs but also lays the groundwork for long-term, sustainable growth. Through these efforts, ICAO is reinforcing its leadership in driving the international aviation sector's decarbonization and facilitating the necessary financial flows to support the achievement of overall global climate objectives.

This initiative also complements ICAO's broader sustainability agenda, which includes the adoption of international standards for fuel efficiency, emissions



The ICAO Finvest Hub

reductions, and the use of SAF, LCAF and other aviation cleaner energies. By providing a comprehensive platform for the financing of aviation sustainability projects, the Finvest Hub represents a critical step forward in ensuring the aviation industry can meet its collective environmental goals and contribute meaningfully to global climate action.

One example of partnership towards the operationalization of the Finvest Hub is the Memorandum of Cooperation signed between ICAO and the International Renewable Energy Agency (IRENA) in October 2024 to explore partnership arrangements to facilitate the identification of financial resources for scaling up SAF, LCAF and other aviation cleaner energy solutions. ICAO looks to explore partnerships of this nature with other suitable players from governments, financial institutions, and the private sector.

Discussions between ICAO and IRENA explored the collaboration through IRENA's Energy Transition Accelerator Financing (ETAF) platform, which currently facilitates the funding and de risking services for renewable energy projects, through the submission of project proposals and their technical and financial assessments, towards the matchmaking with 14 ETAF Funding Partners.

ICAO and IRENA are working towards the establishment of a Finvest Hub module for the IRENA ETAF platform (IRENA ETAF – ICAO Finvest Platform) which will provide the concrete means to:

1) receive SAF project proposals;

2) assess the technical and financial aspects of the submitted SAF project proposals; and

3) bring the assessment results of the SAF project proposals, for consideration by the ETAF Funding Partners.

Further discussions are ongoing between ICAO and IRENA towards the operationalization of the Platform, while considering the appropriate roles and responsibilities between the two organizations, as well as necessary technical, infrastructural, legal and funding arrangements.

Partnering for Aviation Decarbonisation: The ICAO-IRENA Approach

By Haliru Audu (International Renewable Energy Agency - IRENA)

The aviation sector is vital to global connectivity and trade but remains one of the hardest to decarbonise. In 2024, aviation (both domestic and international) emitted 915 million tonnes of CO_2, accounting for approximately 2.5 percent of global emissions and 12 percent of transport-related emissions[1]. With air traffic expected to double by 2045, emissions could increase substantially without mitigation.

Sustainable Aviation Fuel (SAF) offers a promising solution, capable of reducing lifecycle emissions by up to 80 percent compared to conventional jet fuel[2]. However, SAF accounted for less than 0.1 percent of global aviation fuel use as of 2021[3], limited by high production costs, policy gaps, and restricted access to finance.

To help close this investment gap, the International Renewable Energy Agency (IRENA) is leveraging its Energy Transition Accelerator Financing (ETAF) platform, a multi-partner climate finance mechanism focused on clean energy investments in developing countries. In partnership with the International Civil Aviation Organization (ICAO), IRENA is now extending the platform for the ICAO's Finvest Hub, a specialized module to mobilise capital for bankable SAF projects.

Leveraging a Proven Platform: IRENA and the ETAF Approach

Initially launched with a target of USD 1 billion, IRENA's ETAF platform has grown to over USD 4.15 billion in pledges from 14 partners[4], including multilateral development banks, insurers, and sovereign institutions. The platform is designed to mobilise capital and reduce risk for renewable energy projects.

ETAF supports project development through a structured facilitation process. This includes sourcing and evaluating proposals, providing feedback to improve bankability, and linking developers with financing and de-risking solutions offered by its partners. Since its launch, the platform has supported a broad mix of technologies, such as solar PV, wind, hydro, geothermal, bioenergy, and e-mobility.

This approach is now being extended to Sustainable Aviation Fuel (SAF) through a collaboration with ICAO. By applying the same investment-oriented framework, the partnership aims to help overcome the financial and technical hurdles that continue to limit SAF deployment.

A Strategic Collaboration to Accelerate SAF Investment

Building on this effort, ICAO and IRENA formalised their collaboration in 2024 through a Memorandum of Cooperation to explore pathways to operationalize the ICAO Finvest Hub. The partnership combines ICAO's technical expertise in aviation standards and carbon reduction mechanisms, including the Carbon Offsetting and

1 International Energy Agency (IEA), Aviation Sector Analysis, 2024. https://www.iea.org/energy-system/transport/aviation
2 World Economic Forum – Clean Skies for Tomorrow: https://www.weforum.org/reports/clean-skies-for-tomorrow-implementation-manual/
3 IATA – SAF Factsheet: https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/
4 https://etafplatform.org/Partners

Reduction Scheme for International Aviation (CORSIA)[5], with IRENA's experience in project facilitation, bankability assessment, and capital mobilisation.

The two organisations bring complementary strengths. ICAO provides global reach and oversight on SAF sustainability certification and regulatory alignment, while IRENA focuses on evaluating the financial and commercial viability of projects, coordinating due diligence, and offering technical assistance to improve project readiness.

This combined approach aims to close the gap between technical viability and investment readiness, helping to bring more SAF projects to the market.

Structuring Support: Building a Viable SAF Pipeline

The FinvestHub applies a structured process to identify SAF projects that meet both climate and investment criteria. Projects are assessed for sustainability, technical readiness, regulatory compliance, and credible offtake arrangements, including in light of relevant ICAO policies and technical requirements such as those such as CORSIA.

Once qualified, projects may benefit from support measures available through ETAF's partners, including:

- Blended finance to reduce the cost of capital
- Equity to fill early stage funding gaps
- Guarantees and insurance to mitigate political, credit, or technology risks

These de-risking instruments are particularly important for first-of-a-kind SAF projects, which often encounter hesitation from investors due to limited operational data and evolving market dynamics.

Operationalising the Finvest Hub

Several developers have already expressed interest in accessing support through the Finvest Hub, and the foundation is being laid. The Hub is currently under development, with screening criteria in the final stages of design.

Once operational, it will guide projects through a structured process, from registration and eligibility screening to due diligence and financing engagement. The Hub will facilitate the initial review, match eligible projects with financing partners, and provide a framework for tracking progress through to financial close.

Early expressions of interest from both public and private sector actors reflect the growing demand for structured support to advance SAF projects toward investment readiness.

Turning SAF Commitments into Bankable Projects

The urgency to decarbonise aviation is intensifying as global policy momentum builds and demand for Sustainable Aviation Fuel continues to grow. Initiatives such as the European Union's ReFuelEU Aviation[6] and the United States' SAF Grand Challenge[7] signal increasing international ambition to scale up production and adoption.

Yet ambition alone is not enough. Unlocking finance for SAF at the scale required will demand coordinated efforts across institutions, the private sector, and governments.

The ICAO-IRENA partnership, through the Finvest Hub, offers a practical response to this challenge. By providing structure, credibility, and a pathway to capital, the Hub can help advance SAF projects from concept to investment readiness. As part of the broader ETAF platform, it serves as a timely instrument for aligning the aviation sector with global climate goals.

5 ICAO CORSIA: https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
6 European Commission, ReFuelEU Aviation Initiative, https://transport.ec.europa.eu/transport-modes/air/refueleu-aviation_en
7 U.S. Department of Energy, SAF Grand Challenge Roadmap, https://www.energy.gov/eere/bioenergy/sustainable-aviation-fuel-grand-challenge

Combining and sequencing public-private levers can increase the likelihood of SAF project financing

By Giorgio Parolini (World Economic Forum)

Introduction

Scaling sustainable aviation fuel (SAF) production requires significant investment, which can only materialise through strong collaboration across industries and governments. As part of its flagship "Airports of Tomorrow" initiative, the World Economic Forum's latest white paper on SAF financing, "Case Studies and Implications for Investment[1]," developed in partnership with Kearney, outlines how multiple levers can come together to accelerate SAF deployment.

This article highlights insights from the report, building on the latest regional developments and early industry success stories, and explores their implications for SAF financing and international cooperation.

En route to 2030

Keeping in mind ICAO's vision for a 5% reduction in international aviation emissions by 2030 through the use of SAF, Lower Carbon Aviation Fuels (LCAF) and other aviation cleaner energies (compared to zero cleaner energy use), as well as individual government targets and regulations aimed at boosting SAF use by then, the Kearney analysis underpinning the report identifies over 5 Mt of SAF production gaps to 2030. Yet production is rapidly scaling, SAF market prices are reducing, and confidence in producers' ability to supply the SAF volumes needed to get to 2030 is increasing, especially in Europe.

Most of this production continues to come from used cooking oil, with technology and financial hurdles – over $20billion by 2030, according to the report - that need to be overcome to scale alternative pathways. New production clusters, in particular in Asia and South America, have started to emerge, affecting feedstock trades to Europe and the United States, where project developers had predominantly concentrated to date, and creating pressure to scale SAF locally to improve domestic energy security even where regions may not possess competitive advantages.

Multiple levers to scale SAF

This is where the levers identified by the report can play a role in helping countries scale domestic production. Ten levers were identified to attract capital for SAF commercialisation, with developers, governments, airlines and OEMs, airports, private investors, and multilateral development banks (MDBs) all playing critical roles.

Government-led levers and other sources of public funding

Governments are essential in providing a clear and futureproof direction to industry in the forms of mandates

1 https://www.weforum.org/publications/financing-sustainable-aviation-fuels-case-studies-and-implications-for-investment/

and targets, avoiding U-turns and backtracking when market circumstances change, and creating a level playing field for domestic and international players to facilitate SAF offtakes.

To spur production, a number of incentives can be introduced to support SAF market stability. Grants and direct subsidies can lower production costs and encourage technological innovation. The UK Government, for example, has allocated £165 million for SAF projects through its Advanced Fuels Fund, with companies like Alfanar benefitting from the grant as part of their early plant development.

Yet grants only cover part of the CAPEX needed to scale a facility, which can exceed $1bn, and as plant development progress, capital is needed to achieve financial investment decision, and even afterwards when the plant is completed some technology challenges might arise, impacting fuel volumes and quality. These have an impact on the OPEX that affects the price of the fuel produced, and thus the revenue of the future SAF facility. This is why loan guarantees to manage technology risks, as well as revenue certainty mechanisms, also explored in the UK to complement mandates and grants – can support SAF producers, help mitigate financial risks and lower the cost of capital.

Governments are not the only source of cheaper capital. Multilateral development banks can also play a key role in kick-starting feasibility studies and early-stage plant development. This is particularly vital in countries which have a less substantial regulatory frameworks in place, to support a more global pipeline of projects across regions so that more countries and regions can leverage the industrial opportunities of SAF plants and value chains, in line with the objectives of ICAO's ACT-SAF Programme with which the World Economic Forum has been collaborating.

New business models and market-driven mechanisms

Beyond government, corporate buyers can also play a major role in scaling SAF. It is becoming more frequent to see corporations voluntarily looking to reduce their travel emissions (Scope 3) through the SAF certificates. Book-and-claim mechanisms that allow to separate the environmental attributes from the actual volumes of SAF are advantageous for airlines, as customers with higher willingness to pay may be able to take over some of the price premium of greener molecules, and lower the cost of capital for developers. This is because Scope 3 offtakes increase the number of counterparties involved with the transaction, reducing buyers' credit risks as a result of the higher creditworthiness than corporates typically have compared to airlines.

More and more organisations are developing their own platforms that customers can use independently to purchase credits or deliver SAF via book-and-claim mechanisms, such as World Energy, American Express Global Business Travel and Shell, DHL, SkyNRG, and World Kinect. Others are partnering directly across the value chain, such as HSBC which signed a partnership with Cathay Pacific and Ecoceres in 2024, and Microsoft and OMV.

Book-and-claim partnerships are a way for developers to increase the chances of project financing, but it is often through direct equity investments from strategic parties that the likelihood of progressing to construction and commercialisation can be boosted further. Equity holders can consider taking higher level of risk when this can bring strategic returns, other than financial returns – for instance the ability of an airline to get priority access to the fuel produced or the reputation of investing in sustainable products to keep a licence to operate. Examples of these include the investments from MUFG and All Nippon Airways in LanzaJet, the capital raised by Ineratech to expand its operations, and the strategic agreement between Infinium, International Airlines Group and Brookfield Asset Management that could unlock up to $1.1 billion of funding. Both Ineratech and Infinium were selected among the winners of the World Economic Forum's 2024 UpLink Sustainable Aviation Challenge[2] aimed at identifying highly-scalable start-ups in the sustainable aviation space.

The private sector can therefore play a key role in supporting the nascent SAF market, while benefitting from the carbon emissions reductions that can be claimed by using SAF or SAF certificates and supporting plant development. Yet greater understanding is needed for businesses to

2 https://uplink.weforum.org/uplink/s/uplink-issue/a002o0000174PRGAA2/sustainable-aviation-challenge

become more familiar with the reporting, accounting, sustainability and procurement options and implications of such mechanisms, requiring greater capability building especially in emerging aviation hubs, such as Asia Pacific. To this end, in May 2025 the World Economic Forum, in partnership with GenZero, launched Green Fuel Forward – a new campaign aimed at boosting demand for SAF in Asia Pacific, complementing the work of Airports of Tomorrow and the First Movers Coalition.

Which lever and when?

Quite often, the key to scaling SAF is applying a combination of all of these levers, each of which is discussed in detail in the report. Many of these do not work in isolation, or are actually relevant to a particular technology pathway or risk. For instance, production pathways looking to convert used cooking oil into SAF may use technology already commercial and could rely less on government grants to scale compared to power-to-liquid fuels, although plants could still face some technical challenges or may be exposed to volatility resulting from international trade policy, requiring some degree of government guarantees or Scope 3 partnerships. The less developed the production pathway, the higher the number of levers that could be beneficial.

The timing and sequencing of these levers also matter. Among the factors banks look at when deciding whether and how to invest in a SAF project there are: presence of equity investments from third parties, feedstock assurance (availability/sustainability), safety/technology certification of the SAF production pathway, number and bankability of offtake agreements and counterparties, and price. It is thus important for the whole industry to collaborate to ensure that all these financing requirements can be met by working across the value chain to create the conditions for a SAF facility to be financed. Government support and clear policy often catalyse commitments from the private sector, including from airlines and businesses, and thus could be introduced first – as seen in an increasing number of regions.

As government policies develop, international collaboration is essential to create a level playing field across markets and ensure new SAF production facilities, especially those deploying more advanced feedstock conversion technologies, can scale globally. This international action and coordination is essential to meet ICAO's vision for 2030 and keep the sector on the right path to net-zero carbon emissions by 2050.

Conclusion

Scaling sustainable aviation fuels requires a combination of financing mechanisms, international cooperation, and cross-value chain partnerships. Government, airlines, fuel producers, Scope 3 buyers, and strategic investors have all a key role to play. Early success stories and case studies where these players are working together are a promising sign of the potential that cross-industry and cross-country collaboration can bring in scaling SAF further. This is essential to boost demand, production and use of SAF, enable technology development and cost reductions, and ultimately enable faster progress toward ICAO's vision and aviation decarbonization.

Combining and sequencing public-private levers can increase the likelihood of SAF project financing

Innovative financing structure for large scale SAF Projects

By Christoph Michel (GIZ PtX Hub)

Introduction

Achieving decarbonization targets in Europe alone and complying with underlying policies will require considerable expansion of industrial-sized sustainable liquid fuel production capacities. By 2035, investments of over €50 billion will be needed in novel production facilities (biofuels and e-fuels). For e-fuels, additional investments in hydrogen production, carbon capture and renewable electricity are required, bringing the cumulative amount needed until 2035 to between €200 billion and €300 billion for Europe alone[1].

Despite growing interest in green hydrogen and in particular Sustainable Aviation Fuel (SAF) worldwide, securing long-term investments across its value chain remains a significant challenge. Banks and institutional investors remain cautious due to perceived risks, uncertain returns, and regulatory gaps, particularly in developing countries. The investment landscape is evolving, with traditional financiers like banks and insurance companies no longer the sole players. Specialized fund managers, private credit firms, hedge funds, and private equity giants are emerging as key funding sources. However, these investors require well-structured financial instruments with clear risk mitigation strategies to ensure confidence in their capital commitments.

At this stage SAF projects do not meet investor's triangle (risk/return/ liquidity) expectations. Investing money into a SAF project means high risk, low liquidity and not adequate returns.

With this article I would like to stimulate a discussion about an innovative finance structure called "Project Backed Security". It consists out of a managed portfolio approach and guarantees to efficiently influence the risk and liquidity profile. This would potentially significantly increase attractiveness for investors. The smart utilization in favor of guarantees instead of grants will limit potential negative effects on Governments balance sheet.

Financing requirements through the development cycle

Developing a SAF project take several years and starts with a pre-feasibility phase. After the pre-feasibility phase has been successfully finalized, the project enters into the feasibility phase, followed by Front End Engineering Design (FEED) and finally construction phase. In each of these phases the developer needs specific financing to meet the requirement of that phase and proceed into the next phase. After the FEED phase the project is entering into the Final Investment Decision (FID). Figure 1 illustrates the different phases of a typical project cycle and indicates the different types of financing a project needs at certain points of the development cycle. In this article I will focus on an innovative financial instrument for FID. It will not cover financing needs for the other phases shown in Figure 1, in particular financing feasibility studies, working capital or finding a strategic equity partner etc.

1 Financing sustainable liquid fuel projects in Europe, EIB 2024

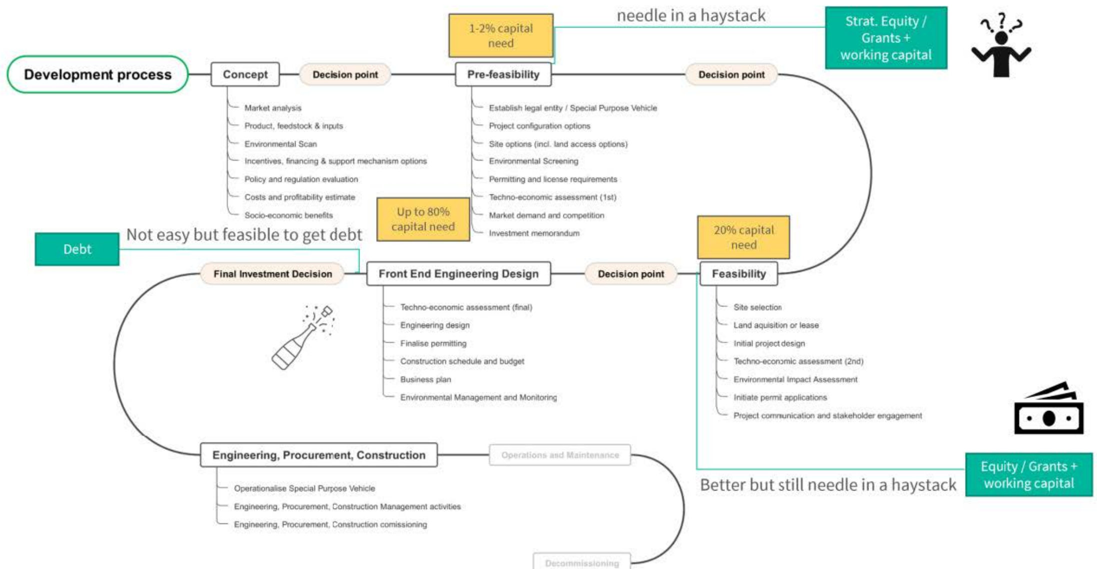


FIGURE 1: different phases of a typical project cycle.

Availability of risk capital

According to Wood Mackenzie[2] the Venture Capital inflow to climate tech has **decreased** by **14%** in 2024 compared to 2023. However **28% rise** in carbon removal technology (mainly driven by the USA) and **28% decline** in equity investment in decarbonizing high emitting industry. It appears that Investors see currently a better risk return profile in evolving industries like Artificial Intelligence (AI). However, specialists funds are on the rise as expertise in the topic becomes more relevant for investment decisions.

Generally speaking, there is sufficient capital available looking for investment however, the risk/return profile of the SAF projects are not competitive enough compared to other investment options like AI. So investors prefer to invest in other projects with a favorable risk/return profile. Overall SAF projects risk-return profiles make final investment decisions difficult even if projects are mature[3].

Changing the risk/return profile of SAF projects would increase competitiveness towards investors investment decission.

Government Guarantees to lower the overall risk profile

Treatment of guarantees for balance sheet purposes can be different in each country. In many cases guarantees are recorded on countries balance sheet as contingent liabilities, reflecting the potential obligation of the government to fulfill them if the borrower defaults. The recognition occurs when there is a significant likelihood that the guarantee will be called upon.

The accounting treatment of guarantees can affect the overall financial position of the government, influencing budgetary decisions and fiscal policies. If recognized as liabilities, they will appear on the balance sheet, impacting debt levels and fiscal ratios.

However, guarantees are a more attractive option to de-risk a SAF project than e. g. grants.

Guarantees play a crucial role in project finance by providing additional security to lenders and investors, thereby facilitating the funding of large-scale projects. Usually a guarantee is provided for a specific purpose like credit

2 Hydrogen: 5 things to look out for 2025, Wood Mackenzie December 2024
3 Financing sustainable liquid fuel projects in Europe, EIB 2024

guarantee, performance guarantee to mitigate risk or lower cost of capital.

Guarantees embedded in a waterfall structure like shown in Figure 1 would serve as a first loss piece covering all types of risks. Depending on the size of the guarantee the risk profile of all tranches (Equity, Mezzanine, Senior) can be influence in order to achieve the desired risk/return profile. The guarantee will become the centralized de-risking mechanism and ultimately works as a credit enhancement.

Pooling of lighthouse projects as a measurement of risk diversification

The World Bank's lighthouse projects focus on innovative initiatives that promote sustainable development, particularly in areas like sustainable aviation fuels (SAF). The rational behind the lighthouse selection is to focus the World Bank and global effort on a few but most promising SAF projects to ensure FID and kick off SAF production on large scale.

Translating the lighthouse idea into financing means bundling lighthouse projects into one portfolio and manage from an investor perspective the projects as a portfolio. This portfolio approach would lead in itself to a risk-diversification of SAF projects in terms of country risk, specific risks and technology risk.

Food for thoughts: Managed Project Backed Security (PBS)

Asset Backed Securities (ABS) are a well known financial instrument in the financial world. It started in 1970 in the US with a so called Ginnie Mae the first mortgage-backed security (MBS), which pooled residential mortgages and sold them to investors.

Within the financing of renewable energy so called Solar Panel ABS (Solar ABS) play a vital role in financing renewables. Solar ABS are financial instruments backed by the cash flows generated from solar energy systems — typically through leases, loans, or power purchase agreements (PPAs) with residential or commercial customers.

Similar to Solar plants a SAF plant or PtL plant generates cash flows from selling the fuel into the market via a fuel purchase agreement or also known as off-take. This expected cash flows will be the "asset" which backs the security (similar to Solar ABS) of a SAF ABS or PBS.

A typical ABS consists out of several tranches with a waterfall structure. The waterfall structure dictates how cash flows are distributed to the different groups of investors, known as **tranches**. The highest priority tranche is the senior and the lowest is the equity tranche (Figure 2).

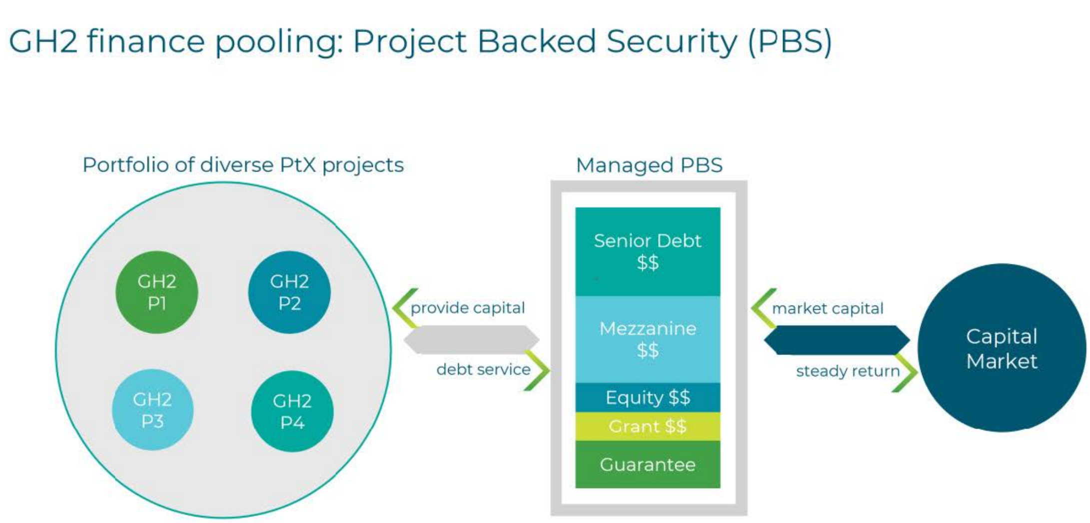


FIGURE 2: GH2 finance pooling: Project Backed Security (PBS).

The idea of the PBS is to add tranches below equity namely grants and guarantees to increase credit quality of the above tranches to a level, it becomes attractive to invest in for a broad range of investors in the capital market.

Combining the concept of pooling lighthouse projects into one managed portfolio with a managed PBS and guarantees to booster the credit quality of the tranches could become next generation of financing instruments for lighthouse SAF projects.

PBS could be a powerful tool in SAF finance. They help accelerate the adoption of clean SAF while offering investors a sustainable, long-term investment opportunity. As the world shifts toward decarbonization, PBS might playing an increasingly important role in connecting capital markets with climate solutions like SAF.

Such a PBS would also further contribute to the ICAO Finvest Hub. The identified “lighthouse” SAF projects through Finvest Hub could be a basis for building a relevant portfolio and also supporting the ramp-up of managed PBS.

The RLCF Alliance: enabling SAF development in the EU and beyond

By Alexis Chausteur (European Commission) and RLCF Alliance Steering Group (European Commission, Fincantieri, FuelsEurope, Hydrogen Europe, and Safran)

The role of SAF and ReFuelEU Aviation

The aviation sector is at a critical juncture in its decarbonization journey. As air traffic continues to grow, the industry must urgently accelerate its transition towards more sustainable energy sources to meet the global objective of net-zero carbon emissions for international civil aviation by 2050. Sustainable aviation fuels (SAF) represent the most promising and viable solution for reducing aviation emissions, as they can be seamlessly integrated into existing aircraft and infrastructure while delivering significant lifecycle emissions reductions compared to conventional fossil-based jet fuels.

Recognizing the essential role of SAF and in line with the comprehensive global framework adopted at CAAF/3, the European Union has introduced a robust regulatory framework to scale up their deployment. At the heart of this effort lies the ReFuelEU Aviation Regulation[1], adopted in 2023 as part of the EU Fit for 55 Package[2]. This landmark regulation mandates a progressive increase in SAF supply at EU airports, requiring aviation fuel suppliers to blend a minimum share of SAF into jet fuel. The obligation starts at 2% in 2025 and scales up to 70% by 2050, providing long-term regulatory certainty for investors and industry stakeholders. Additionally, the regulation establishes a dedicated sub-mandate for SAF produced from renewable hydrogen (eSAF), ensuring the development of innovative and scalable fuels.

By creating a predictable demand for SAF, ReFuelEU Aviation aims to de-risk investments in SAF production, stimulate large scale SAF production and enhance Europe's energy resilience. However, effective implementation requires the collaboration of all actors in the fuel value chain, from feedstock suppliers and refiners to airlines and financiers. This is where the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance (RLCF Alliance) plays a pivotal role.

Supporting regulatory measures and driving SAF deployment

The RLCF Alliance[3] was established by the European Commission in 2022 as a multi-stakeholder platform designed to facilitate the large-scale production and deployment of renewable and low-carbon fuels for the aviation and waterborne sectors. It brings together more than 300 members covering a diverse set of industry players, research organizations, and policymakers, working collaboratively to address barriers to market uptake and accelerate the transition toward sustainable transport.

In the past years, the Alliance Roundtables (focused on feedstock, aviation, maritime and access to finance) have

1 Regulation (EU) 2023/2405: https://eur-lex.europa.eu/eli/reg/2023/2405/oj/eng
2 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en
3 https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/renewable-and-low-carbon-fuels-value-chain-industrial-alliance_en#resources

been producing valuable deliverables supporting both sectors to ramp-up the adoption of sustainable transport fuels. The aviation roundtable has played a key role in advancing the understanding of the SAF market by conducting a comprehensive stocktaking exercise. It has modelled scenarios for SAF adoption and production capacity needs, monitored the progress of SAF projects contributing to the EU objectives, explored and evaluated emerging SAF production pathways, and provided support on qualification processes and regulatory assessments, notably in the context of the EU SAF Clearing House. In parallel, the finance-focused roundtable has played a crucial role in addressing the industry's financial challenges. It has developed a funding compass, mapping available funding opportunities for RLCF projects, designed a financial model notably for eSAF produced via the Fischer-Tropsch pathway, provided a bankability guide for SAF projects and explored risk mitigation instruments, including grants, guarantees, and contracts for difference, to support investment in SAF production.

While the RLCF Alliance is primarily focused on supporting the EU's objectives for sustainable transport fuels, it also plays a crucial role on the global stage. The RLCF Alliance brings together members from close to 30 countries, fostering international collaboration and knowledge exchange. This international dimension is further strengthened through outreach activities, such as its presentation to the ICAO Council and contribution to the 2023 ICAO Stocktaking Seminar, where the RLCF Alliance shared insights and best practices with the broader aviation industry. By engaging with global stakeholders, the RLCF Alliance helps drive the development and deployment of SAF beyond Europe, contributing to worldwide decarbonization efforts in aviation.

The RLCF alliance has made remarkable strides in fostering community development and addressing the barriers to progress in developing low-carbon and renewable fuels, all while identifying potential solutions. Having successfully navigated these foundational challenges, the alliance is now poised to embark on phase two of its strategic plan. A pivotal shift in governance, meticulously adapted to concentrate on refining and expanding the pipeline of projects not only to sustain momentum but to accelerate the transition of these projects from conceptual stages to reaching Final Investment Decisions. This approach aims to ensure impactful delivery and tangible benefits for the community, reflecting RLCF Alliance's commitment to innovation and sustainability objectives.

The RLCF Alliance pipeline of projects

A key deliverable of the RLCF Alliance is its pipeline of projects[4], a dedicated repository of initiatives that contribute to the RLCF Alliance's objectives and, more broadly, to the EU regulatory framework on sustainable transport fuels in aviation and waterborne sectors. This pipeline serves as a strategic tool to showcase, support and monitor projects that are essential for scaling up SAF and other renewable fuels in Europe. It also helps identify structural difficulties to resolve them swiftly.

The pipeline is being progressively built and includes 15 projects as of April 2025, with ten focusing on aviation, particularly on eSAF and advanced biofuel production pathways. These technologies are critical for ensuring the long-term sustainability of aviation, as they diversify the feedstock base, increase the production volume to meet market demand, and provide lower-carbon alternatives with strong environmental potential.

Beyond acting as a repository, the RLCF Alliance actively enhances the visibility of these projects through showcasing events (e.g. Paris Air Show, ILA Berlin Air Show) as well as matchmaking sessions that facilitate partnerships across the value chain, including with potential finance providers. The European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) are associated to the building of the pipeline. These initiatives help projects in securing investments, strengthening collaboration, and achieving greater market integration. To further support high-impact projects, the RLCF Alliance has established a dedicated task force to develop a set of criteria for an official RLCF Alliance label. This seal of excellence will recognize projects that best contribute to the objectives of ReFuelEU Aviation and FuelEU Maritime, offering them additional credibility and support in accessing funding and market opportunities.

4 https://rlcf-alliance-platform.converve.io/pipeline_front.html.

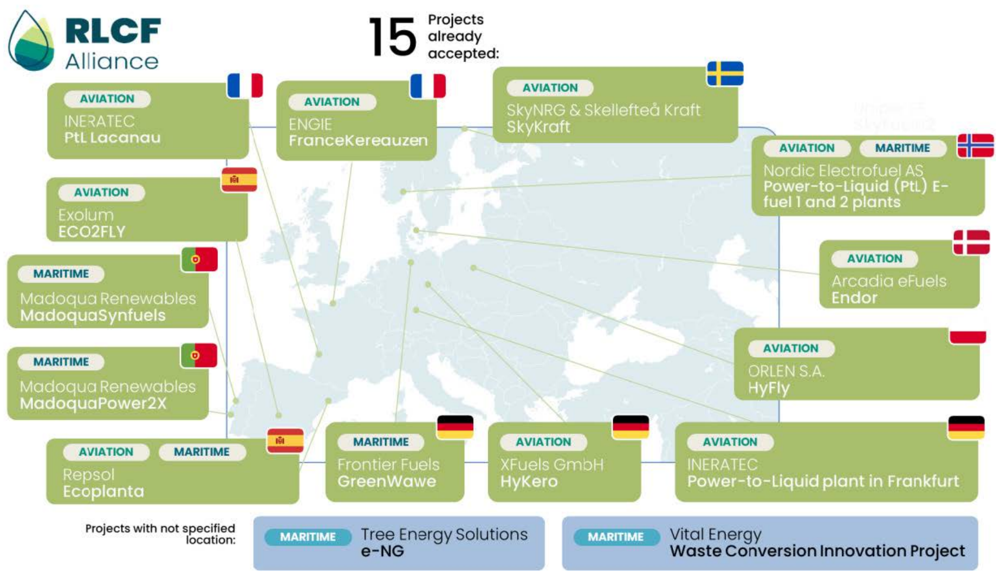


FIGURE 1: RLCF Alliance Project Pipeline.

Financing challenges

Most of the projects in the pipeline are highly advanced, having resolved key technical challenges such as securing CO_2 sources, electricity supply, and production components. Some have already completed the Front-End Engineering Design (FEED) phase and are poised to begin construction after securing a Final Investment Decision (FID). However, despite their technical readiness, these projects, particularly those focused on less commercially mature SAF production pathways, like eSAF, face significant financial hurdles. The high capital intensity of projects combined with risks associated with early-movers, whereby initial projects bear higher production costs than later entrants, continue to hinder large-scale investments and delay FID. In this context, the RLCF Alliance plays a critical role in addressing these challenges, offering a platform to facilitate investment, de-risk projects, and support policy alignment.

Way forward

The pipeline of projects, which showcases some of the best-in-class initiatives, serves as the foundation for an upcoming European Investment Bank (EIB) assessment on how to better financially support SAF projects, including with technical assistance support and potential implementation of risk mitigation instruments as needed. Moreover, the Sustainable Transport Investment Plan (STIP), recently announced by the European Commission and expected to be unveiled in the autumn, will be instrumental in tackling the financing challenges associated with sustainable transport fuels for the aviation and waterborne sectors. By providing a strategic framework to better align and use existing EU financial instruments, STIP aims to enhance investor confidence and facilitate capital flows into scaling up production of SAF and other renewable fuel projects. The RLCF Alliance's work over the last two years is intended to feed the Commission's reflection on STIP.

At the global level, initiatives such as the ICAO Finvest Hub are essential in fostering a worldwide SAF market. Recognizing its importance, the EU has committed to contributing climate finance expertise to support the establishment and operationalization of the Finvest Hub, as announced at the ICAO Global Implementation Support Symposium conference in Abu Dhabi in February 2025. This collaboration will bring the EU knowledge and expertise from the development and implementation of ReFuelEU Aviation and the RLCF Alliance to strengthen ICAO's Finvest Hub initiative in facilitating and attracting investments for SAF projects across all the regions in line with ICAO "No Country Left Behind" Strategic objective. This will help with progressing with the implementation of the ICAO Global Framework for Sustainable Aviation Fuels as adopted at CAAF/3, Lower Carbon Aviation Fuels and other Aviation Cleaner Energies and its collective global aspirational Vision to reduce CO_2 emissions in international aviation by 5 per cent by 2030, compared to zero cleaner energy use.

From Innovation to Impact: Building Tomorrow's Aerospace Sector

By Paul Adams (Aerospace Technology Institute – ATI, UK)

As ICAO and its Member States advance implementation of the collective long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050, unlocking scalable and coordinated financing has emerged as a central challenge. The ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies, adopted in November 2023 at the Third ICAO Conference on Aviation and Alternative Fuels (CAAF/3), recognises this challenge and places financing as one of its enabling building blocks. A leading example of how targeted public-private investment can accelerate this transition is found in the United Kingdom's Aerospace Technology Institute (ATI).

Catalysing Innovation Through Strategic Investments

Since its inception in 2013, the ATI has been instrumental in channelling substantial investments into cutting-edge aerospace projects in the United Kingdom. With over £3.8 billion of joint government-industry funding allocated to more than 450 R&D projects, the ATI has cultivated a robust ecosystem of innovation. This investment is not just about technological progress; it's a vital component of the UK's economic health and future prosperity. In a time of intense global competition and urgent environmental challenges, the ATI represents a strategic vision for the industry, driving collaboration and turbocharging innovation to secure economic and environmental resilience. These efforts not only advance national decarbonisation goals but also contribute directly to the global cleaner energy transition envisioned by the LTAG and ICAO Global Framework.

The UK has long been home to major aerospace industry players with wings, engines, systems and interiors all being designed and produced within its borders. Many of the ATI's projects are designed to ensure this legacy continues with the next generation of civil aircraft. Notable among these initiatives is Rolls-Royce's UltraFan demonstrator (Figure 1), the world's largest and most efficient aero engine technology demonstrator. This project exemplifies advancements in fuel efficiency and emission reductions, aligning with the UK's commitment to sustainable aviation.

FIGURE 1: Rolls-Royce's UltraFan.

Similarly, Airbus's Wing of Tomorrow programme represents a leap forward in aircraft design, focusing on next-generation carbon composite wings. This initiative aims to enhance aerodynamic performance while ensuring a system of manufacture is developed that support the substantial long term single aisle rate of production.

Innovation as an Engine of Economic Prosperity

The aerospace sector is a cornerstone of the UK economy, significantly contributing to employment, exports, and gross domestic product (GDP). At the heart of this contribution lies continuous investment in R&D, which drives innovation and keeps the UK competitive on the global stage.

Investing in R&D offers impressive returns, both for individual firms and society at large. A comprehensive study by Frontier Economics in 2023 estimated that the average private rate of return on R&D investment is about 20% per annum. This means that for every £1 a firm invests in R&D, it can expect an annual return of 20 pence from the resulting innovations.

The social returns are even more compelling. The same study found that social returns are typically twice as high as private returns, suggesting that society gains 40 pence annually for every £1 invested in R&D. This difference highlights the positive spillover effects of R&D, where benefits extend beyond the innovating firm to other sectors and the economy as a whole.

Specifically within the aerospace sector, ATI's research indicates that the social return on aerospace R&D is approximately 70% over a ten-year period, with private returns around 15%. These figures underscore the substantial and sustained economic benefits derived from investing in aerospace innovation.

Turbocharging Innovation and Global Competitiveness

R&D is the lifeblood of long term innovation, enabling the development of cutting-edge technologies that keep the UK aerospace industry at the forefront of global advancements. Through strategic investments, the ATI has been instrumental in advancing technologies ranging from advanced manufacturing techniques to zero-carbon propulsion systems.

The ATI's 'Destination Zero' strategy sets prioritisation for these investment decisions and aims to guide the sector towards the development of technologies that support its long term goals. It is built on three key roadmaps; ultra-efficient technology, zero carbon aircraft and cross-cutting enabling technologies. This strategic vision ensures that the UK remains a leader in the transition to sustainable aviation, aligning economic growth with environmental responsibility.

Empowering SMEs and Fostering Collaboration

Recognising the vital role of small and medium-sized enterprises (SMEs) in driving innovation, the ATI launched a dedicated SME Programme in 2023. This initiative offers grants of up to £1.5 million, tailored to support high-impact projects contributing to net-zero aviation goals. By streamlining the application process and encouraging collaboration between SMEs and larger firms, the programme is building strength in depth in the UK supply chain and enhancing agility within the aerospace sector.

To date, the ATI has supported 68 startups and early-stage businesses with over £18m of funding, nurturing the next generation of aerospace technologies and innovators and acting as a catalyst for private investment. This is supported by the activities of the ATI Hub which has brought together more than 600 companies and organisations across the whole supply chain to work on strategic innovation opportunities and provided a platform for innovative startups and SMEs.

Advancing Zero-Carbon Emission Flight

The ATI's FlyZero project was a pioneering initiative to convene experts from across the UK aerospace sector – from industry, academia and research organisations – to investigate zero-carbon emission commercial flight. This intensive research project sought to assess the design challenges, manufacturing demands, operational requirements and market opportunity of potential zero-carbon emission aircraft concepts. The FlyZero team concluded that green liquid hydrogen is the most viable zero-carbon emission fuel with the potential to scale to larger aircraft utilising fuel cell, gas turbine and hybrid systems

Building on the work of FlyZero was the ATI's Hydrogen Capability Network (HCN): a 2-year project that developed recommendations for bolstering the UK's capability in fundamental research areas, developing key technologies in the UK, establishing UK-based infrastructure and test facilities, and growing the UK skills base. Publishing its conclusions in May 2025, the HCN found that the UK is well-placed to lead in this emerging global market, but only if it continues to invest, collaborate, and create a coordinated long-term strategy ensure alignment between research, testing, infrastructure and skills. These findings are now being adapted into the ATI's technology strategy to ensure the importance of this area is reflected in its investment portfolio.

Addressing Non-CO_2 Emissions: A Holistic Climate Strategy

While CO_2 emissions remain a major focus in decarbonising aviation, growing scientific evidence shows that non-CO_2 effects— including nitrogen oxides (NO_X), soot particles, and the formation of contrail-induced cirrus clouds—also contribute significantly to aviation's climate impact. These non-CO_2 emissions could be responsible for more than half of aviation's total contribution to global warming, according to recent EU and IPCC studies.

To address this emerging critical area, the ATI launched the Non-CO_2 Programme in partnership with Department for Transport, Department for Business and Trade and Natural Environment Research Council (NERC). This world-leading initiative focuses on understanding, measuring, and ultimately reducing these complex climate impacts. Working with UK research institutions, OEMs, and regulatory bodies, the programme funds projects that explore fuel characteristics, aircraft technologies and knowledge, data and innovative flight operation strategies that mitigate contrail formation and high-altitude Non-CO_2 emissions.

This programme reflects a fundamental truth that achieving true climate neutrality in aviation requires more than reducing CO_2 alone. By investing in science and industry-based solutions to tackle non-CO_2 effects, the UK is taking a leadership role in developing a full-spectrum approach to sustainable aviation.

Sustained Government Support: building investor confidence

The ATI's success is built on strong and continued government support. In the 2023 Autumn Statement, the UK government pledged an additional £975 million for the ATI Programme from 2026 to 2030. This long-term commitment ensures that the UK aerospace sector can plan strategically, innovate boldly, and compete globally.

The government commitment sets a strong signal for industry and private investment, underlining the critical importance of the aerospace industry and supporting long term investment decisions making.

Charting a Sustainable Flight Path for the Future

As the aerospace industry confronts the dual challenge of decarbonisation and environmental stewardship, the ATI is playing a vital role in shaping a resilient, forward-looking UK aerospace sector. From flagship projects like Rolls-Royce UltraFan and Airbus's Wing of Tomorrow, to SME support and the pioneering work on hydrogen and the challenge of non-CO_2 emissions, the ATI ensures that the UK remains at the leading edge of advanced aerospace technology. With sustained public and private sector support, the ATI is poised to deliver not only cleaner and smarter technologies, but also long-term economic value and security by making sure the UK is a key part of the next generation of civil aircraft.

ICAO

CHAPTER TEN

Aircraft Noise

Advancing Global Standards for Aircraft Noise: Developments from CAEP/13 and Outlook to CAEP/14

By ICAO Secretariat

Overview

ICAO plays a central role in shaping the international legal framework for aircraft noise regulation. As a specialized agency of the United Nations, ICAO is instrumental in establishing global noise standards. The organization has been assessing trends in global exposure to aircraft noise, which provide a basis for sound discussion and decision-making on aircraft noise policies.

During the CAEP/13 cycle (2022–2025), significant developments have been achieved on aircraft noise mitigation, mostly through the work of the ICAO Secretariat, the Committee on Aviation Environmental Protection (CAEP), and its Working Groups—WG1 (Aircraft Noise Technical) and WG2 (Airports and Operations). This article outlines the main developments from the past triennium and highlights key areas of work planned for CAEP/14 (2025–2028). The following articles in this Chapter will further elaborate on the main outcomes of the CAEP/13 cycle highlighted in this ICAO Secretariat article.

Annex 16 Proposed Revisions and Dual Stringency Standard

One of the most important accomplishments of CAEP/13 is the development of a **dual stringency standard** that accounts for the interdependence of aircraft noise and CO_2 emissions (this work is further detailed in Chapter 3 – Climate Change Mitigation: Aircraft Technologies of this Report). After evaluating 32 scenarios in terms of cost-effectiveness and environmental benefit, CAEP/13 agreed to recommend the adoption of a new Chapter 16 to Annex 16, Volume I. This Chapter, subject to Council's approval, introduces a more stringent Landing and Take-Off (LTO) noise Standard for new subsonic aeroplane types, applicable as of 1 January 2029.

As a pivotal milestone of ICAO's environmental protection work stream, Annex 16, Volume I (Aircraft Noise) has been regularly updated through key amendments. Following its role of keeping ICAO noise certification standards up to date and effective, while ensuring that the certification procedures are as simple and inexpensive as possible, the Committee's WG1 proposed revisions to Annex 16, Volume I. These updates include both guidance material and recommended text revisions to strengthen the certification framework.

Supersonic Aircraft Noise

Regarding Supersonics, the industry is moving towards the development of a new generation of supersonic transport aircraft (SSTs). However, there are environmental concerns that need to be addressed.

In support of these developments, work was continued in ICAO to develop environmental standards for supersonic aeroplanes. On noise provisions in that regard, CAEP WG1 developed a set of reference day atmosphere and humidity standards for sonic boom, as detailed further in the article provided in Chapter 2. Work has also occurred in the context of further analyses that demonstrated two viable schemes and six noise metrics for defining boom noise certification levels. WG1 is also working to develop provisional content for acoustical measurements and data acquisition equipment specifications.

From these efforts, CAEP/13 agreed to recommend the adoption of a new **Chapter 15** of Annex 16, Volume I, which introduces a new LTO noise standard for supersonic aircraft, subject to Council's approval, also applicable from **1 January 2029**.

In addition, ICAO is closely following the research led by NASA which supports scientific data needs to establish a compatible, human response, low boom limit for the en-route SARPs. These NASA developments include a Low Boom Flight Demonstration (LBFD) aircraft which will perform community noise testing.

Operational Noise Mitigation

Based on the work of the CAEP Working Group 2 (WG2), CAEP recommended the publication of a new report titled "Good Practices on Noise Monitoring Systems"*. This report* outlines how noise monitoring systems can be used efficiently and effectively in conjunction with the ICAO Balanced Approach (BA) to support the management of noise impacts at airports.

A second report, "Environmental Interdependencies in Various Operating Scenarios" was also endorsed for publication. This report analyzes different operating scenarios to support aviation stakeholders in better understanding the trade-offs between noise and fuel burn/ CO_2 while optimizing their operational performance. The information in this report will enable Air Traffic Controllers (ATCOs) to shift from making decisions based on educated guesses to relying on informed insights, which will be useful for ATCO training.

Emerging Technology Aircraft

As the aviation sector evolves, ICAO is actively monitoring the development of **Emerging Technology Aircraft (ETA)—** including unmanned aircraft systems (UAS), remotely piloted aircraft, and urban air mobility (UAM) concepts in order to make sure prepare for timely environmental certification, as appropriate, with considerations for the noise aspects in the development of these Emerging Technology Aircraft (ETA).

To support this, ICAO developed an online tracker webpage, providing a curated collection of recent material related to aircraft noise from new technologies. Topics include low-noise eVTOL flight tests, drone noise emissions, UAS -related challenges, and experiences from ICAO Member States. The webpage also includes content from industry, academia, and regulatory bodies.

ICAO encourages Member States and stakeholders to share their experiences with ETA-related noise challenges, which may inform the development of future good practice guidance. Contributions may be submitted to officeenv@icao.int.

Research and Global Collaboration

A report entitled "Noise Technology Research for Fixed Wing Aircraft Status" on the status of ongoing research into noise reduction for subsonic aircraft has been finalized by CAEP WG1 and will soon be published on the ICAO website. Also, a White Paper on Supersonic Climate, Air Quality and Noise Impacts developed by CAEP Impacts and Science Group (ISG) is recommended to be published on the ICAO website.

The Noise dB database[1]—which hosts certified aircraft noise levels under ICAO SARPs—has been upgraded with a more user-friendly interface. It serves as a valuable resource for aircraft control authorities, airport operators, local stakeholders, and supports future revisions of certification standards.

Additionally, during the CAEP/14 cycle, WG2 will coordinate with WG1 on a supplement to guide the **consistent**

1 https://noisedb.stac.aviation-civile.gouv.fr/

application of the ICAO Balanced Approach, with a focus on transparent, practical, and harmonized implementation by States.

Next Steps

Aircraft noise will remain a **priority area** in ICAO's ongoing efforts under its Strategic Objective of **Environmental Protection**. In this context, the four pillars of the **ICAO Balanced Approach to Aircraft Noise Management** continue to serve as the foundation for coordinated global action.

Looking ahead to the CAEP/14 cycle (2025–2028), ICAO will maintain its focus on advancing both **aircraft noise standards** and **broader noise management strategies**.

As part of its work programme, **Working Group 1 (WG1)** will undertake the following activities:

- **Continue the development of new Standards and Recommended Practices (SARPs)** for en-route noise and sonic boom certification applicable to supersonic flight;
- **Continue the development of new Standards and Recommended Practices (SARPs)** for Emerging Technology Aircraft (ETA), **and** provide interim noise measurement guidelines for smaller ETA as an ICAO circular.

These efforts aim to ensure that ICAO's noise-related provisions remain scientifically sound, operationally practical, and responsive to evolving aviation technologies.

Towards future noise standards for Emerging Technology Aircraft (ETA)

By Franck Cléro (DGAC-France) and David Josephson (Joby Aviation)

Introduction

CAEP WG1 adopted the term *emerging technology aircraft* (ETA) to encompass aircraft "not covered by existing categories in current Annex 16 Volume 1 Certification Procedures". Work has begun on harmonized noise certification practices for two types of ETA, small *uncrewed aircraft systems* (UAS) commonly called drones, and larger, potentially passenger-carrying *Advanced Air Mobility* (AAM) aircraft. Unlike conventional aircraft, several different topologies have emerged, with operational and noise characteristics different from existing aeroplanes, helicopters and tilt-rotors. Novel vertical takeoff and landing aircraft that aren't helicopters or tilt-rotors have differing operational characteristics requiring new noise measurement practices due to the limitations of existing chapters of Annex 16.

As with conventional aircraft, noise certification standards are needed to assure common methods in describing and quantifying the sound generated by these aircraft. Information is needed both for airworthiness authorities to establish compliance with certification limits, and for local and regional governments to assess the noise impact of aircraft operations in their jurisdictions. The aircraft may have unique noise characteristics and may operate in close proximity to communities and away from established airports. Noise assessment measures for local consideration such as land use planning may be different from the methods used for certification.

A market in full expansion

Existing civil UAS platforms serve a variety of agricultural, industrial, public safety and security applications. Many of these operations are performed by pilots on the ground within line of sight to the aircraft but uses are beginning to emerge where the aircraft is autonomous or operated remotely, such as the BNSF railway's use for track inspection[1] or police and fire departments' use in public safety. A few authorizations have been granted for delivery of drone operations, where aircraft noise may be experienced by the public without association with an existing activity such as railways.

Larger ETA can share some characteristics with helicopters and aeroplanes, but are often electric, producing no combustion emissions, and are designed for low noise, intended to be inaudible or blend in with community soundscapes. These aircraft are mostly flown by an onboard pilot and may carry passengers. State of the art in electric propulsion today provides a range of 100-200 km on batteries, but hover time is limited to a few minutes between charges. Charging infrastructure is required at vertiports or heliports serving this type of aircraft, which in turn favors a point-to-point route structure, for example routes between city vertiports and conventional airports, rather than the more ad hoc nature of helicopter operation. Hybrid configurations using hydrogen fuel cell power generation have been demonstrated with over 800 km range.

Several different topologies have been developed, with fixed and/or tilting propellers and varying degrees of automation to enhance safety and reduce pilot workload.

1 https://www.bnsf.com/news-media/railtalk/innovation/bnsf-drone.html

The result of these design choices is often that existing noise certification practices, which require fixed power, speed and attitude settings, could be difficult to maintain within the required tolerances because the control laws of the aircraft manage the configuration of engines and control surfaces. Noise certification is performed with the aircraft in its noisiest configuration. While the measurement practices and references share much in common with helicopter noise measurements, work remains to define practices to define the noisiest condition.

Two representative electric VTOL aircraft are shown here, the Joby JAS4-1 (left) and the Eve EVE-1 (right.) The Joby uses a vectored thrust configuration with six tilting propellers, while the Eve is in lift-plus-cruise configuration with eight lift rotors and one cruise propeller.

The need for international regulation

Social acceptance is a challenge to the successful development of new services based on ETA, primarily because it can involve aircraft regularly operating away from airports, representing a new experience for people. It involves many aspects such as visual pollution, privacy, and accessibility of the new services, but the main concerns are safety, environmental issues, security and noise[2]. To handle aircraft noise specifically, ICAO has developed the Balanced Approach to Aircraft Noise Management[3] as overarching policy, based on four pillars: reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions. The balanced approach applies to ETA, as with any other kind of aircraft. In this context, CAEP has already initiated activities to develop Standards and Recommended Practices (SARPs) that will define measurement procedures and noise limits at aircraft level, for the certification process of ETA types. At a country, region or city scale, this reduction of the noise at source is supplemented by controlling local operational conditions (the three other pillars). Optimisation of the trajectories, flight frequency, time of the day, and choice of complementary noise metrics are just a few of the traditional levers to limit the overall noise exposure of the population. Only a full commitment from the international level at ICAO to local authorities will ensure a correct approach of the social acceptance of ETA.

Today, some ETA manufacturers have already applied for certification of their aircraft, such as Joby Aviation, EVE Air Mobility and Volocopter. As no international standard exists yet, certifying Civil Aviation Authorities (CAAs), such as EASA (European Union Aviation Safety Agency) and FAA (Federal Aviation Administration in the United States), have proposed guidelines based on existing procedures to fulfil the gap. ANAC (National Civil Aviation Agency in Brazil) and JCAB (Japanese Civil Aviation Bureau) have shared with WG1 similar intentions. On the way to proposing an international SARP, CAEP has reviewed existing noise measurement approaches for ETA and evaluated whether they could also be used for developing Standards for ETA, even partially. Through these activities, it was decided to refine the scope of ETA by identifying and distinguishing two general types of aircraft under consideration: smaller ETA (e.g., UAS) and larger ETA (e.g., AAM). This refinement was done to identify and organise the wide range of designs and concepts, which vary in weight, size, design

2 Study on the societal acceptance of Urban Air Mobility in Europe, EASA, May 2021
3 Details at https://www.icao.int/environmental-protection/pages/noise.aspx and ICAO Doc 9829

complexity, and operational environments, that will have to be considered. Such a range of configurations would most likely require different levels of sophistication in noise certification standards.

A first step for smaller ETA

While measurement data for larger ETA are limited, many test results on smaller ETA have been shared within the acoustic community through articles from scientific journals or conferences. However, the measurement process differs from one paper to the other, as the objectives are different. To address this lack of commonality and to develop interim noise standards for smaller ETA, some CAAs organised specific test campaigns to collect data using similar measurement guidelines and testing procedures[4,5]. These experiences have been the basis of a task initiated by WG1 to progress towards the definition of international noise measurement guidelines for smaller ETA.

In this way, WG1 agreed on procedures that test the same phases of flight as those found in several certification authorities' existing noise measurement guidelines: a reference level-flight condition, and a supplemental hover condition for aircraft capable of sustained hover. The use of conventional noise metrics was also agreed, until evidence arises for more appropriate metrics: A-weighted Sound Exposure Level, SEL(A), for level-flight and L_{Aeq}, equivalent continuous A-weighted sound pressure level for hover (over a period of 30 seconds). Despite being similar in their vast majority, these existing procedures still exhibit differences in their implementation, which were analysed in 2024. The result of this work is to be published as an ICAO circular on "Interim noise measurement guidelines for smaller emerging technology aircraft" in 2025.

This document presents the same structure as existing CAEP chapters and appendices: a first section is designed to eventually become a dedicated Chapter of Annex 16, Volume I, containing the main requirements; another section is intended to be developed into an Appendix within Volume I of Annex 16, providing details on the acceptable evaluation methods; a last section corresponds to guidance material that could ultimately become a chapter within Volume I of the ETM (Environmental Technical Manual - Doc 9501).

Future CAEP activities

The boundaries between smaller and larger ETA remain to be defined and no specific definitions or nomenclature have yet been agreed at the ICAO level. Several aspects are being considered to specify this distinction, such as maximum take-off mass, payload capacity and whether the ETA is designed for carrying people. The nature of the operation, the noise exposure and the impact on the community may also be important factors to differentiate the categories. For the time being, a broader definition of the boundaries between smaller and larger ETA has been used, with plans to refine it further in CAEP/14.

Even if it describes in detail the noise measurement procedures for smaller ETA, soon to be published as ICAO circular presents unresolved topics such as noise limits or applicability weight range, which would have required more time to be correctly addressed. Those topics will be discussed during CAEP/14 cycle to agree on a proposal for a noise standard adapted to smaller ETA.

On the larger side of the aircraft range, the discussions during the last cycle on the applicability of methods used to develop Chapter 13 to larger ETA led to recommendations for noise measurement procedures. This preliminary activity will continue during the CAEP/14 cycle to clearly define the noise measurement procedures and progress towards the definition of a dedicated noise standard.

4 EASA guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk

5 FAA Noise Certification of UAS/AAM using Rules of Particular Applicability

Noise Monitoring Systems Good Practices

By Athanasios Synodinos (ICCAIA) and Oleksandr Zaporozhets (Ukraine) [1]

Noise Monitoring Systems are an essential element of noise management at and around airport

Noise Monitoring Systems (NMS) exist since the 1960s and, in their simplest form, measure in real-time aircraft noise in the vicinity of airports. NMS feature numerous monitoring stations (portable, or fixed), strategically positioned around the airport. Figure 1 shows a typical NMS measuring station. Today`s technologies boost a wide range of NMS features, functionalities, and possibilities for integrating into other airport planning and sustainability tools. Consequently, combined with the ICAO Balanced Approach (BA), NMS tend to play an increasingly important role in airports' action plans to control noise from aircraft operations. In fact, NMS providers envisage NMS being part of integrated environmental management systems and becoming a crucial component for meeting increasing public expectations and supporting strategies for a better quality of life. Furthermore, there is a growing need for airport authorities to be transparent and provide the public with robust information (e.g. noise data) and tools (e.g. NMS public website) for impartially contributing to local land use planning decisions.

Various national and international standards are available for installing NMS around airports (for example, ISO-1996, SAE ARP4721), as well as for defining requirements for reliable measurements (ISO 20906). However, there is a notable lack of guidance on using these systems comprehensively, i.e. sharing good practices on making the most out of an NMS. Indeed, literature reviews, surveys, and case studies conducted at ICAO revealed cases where airports have either been using NMS non-comprehensively,

FIGURE 1: NMS monitoring station in Athens International Airport "Eleftherios Venizelos", Greece.

or stopped using it, due to various reasons; ranging from unreasonable public expectations (e.g. due to data/metrics misinterpretation), to misjudged planning and unexpected costs, resulting from underestimating NMS complexities.

About the ICAO initiative

In the CAEP/13 cycle, WG2 addressed the lack of NMS guidance by developing a report on NMS good practices. Aiming at providing relevant stakeholders, such as airport authorities, with reference material for using NMS to ultimately balance the airports' need to operate effectively, with the community's need to understand how noise exposure is measured and how that relates to their real-life experiences.

Although ICAO work on NMS practices at airports began about 20 years ago, the document on NMS good

1 The authors would like to acknowledge Alicja Gajewska (former ACI World) and Jean Wolfers-Lawrence (US FAA) for their significant contribution to the coordination of this work.

practices is the first official ICAO document on this topic; filling a notable and long-lived gap, i.e. the lack of guidance on comprehensively use of NMS. Aviation noise management is increasingly becoming part of a multi-disciplinary problem, and integrated systems, such as NMS, are becoming essential in shaping airports sustainability programs.

NMS and the Balanced Approach (BA) to Aircraft Noise Management

The main overarching ICAO policy on aircraft noise is the BA to Aircraft Noise Management, which consists of identifying the noise problem at an airport using objective and measurable criteria, and then analysing the various measures available to reduce noise through the exploration of four principal elements, namely reduction at source, land-use planning and management, noise abatement operational procedures and operating restrictions (see also: ICAO Resolution A41-20). Aiming at selecting noise-related measures that achieve environmental benefits in the most cost-effective manner.

Identifying a noise problem at an airport, and adopting effective mitigation measures, requires availability of adequate objective data describing the noise environment (and its changes), with respect to the surrounding housing development. NMS provide objective means, not only to promptly collect such data and therefore appraise the benefit from the different BA elements, but also to support noise models for forecasting and comparing noise exposure levels for different future scenarios. Hence contributing towards improving the ICAO BA implementation and enhancing airport ecosystem with day-to-day data.

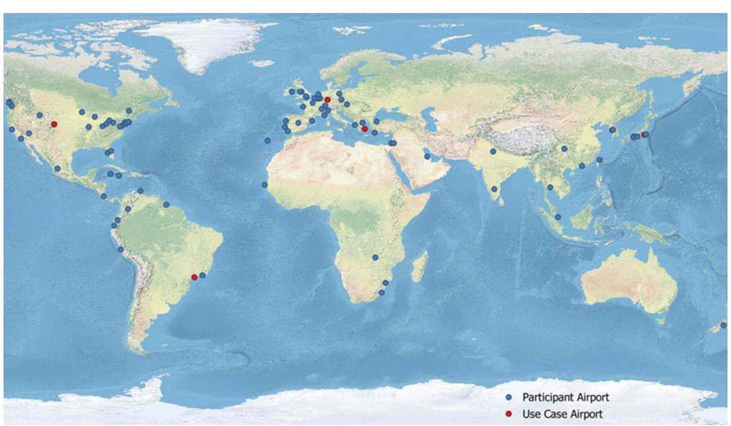


FIGURE 2: Map indicating locations of airports that responded to the survey and airports used as case studies.

What is ICAO doing on NMS?

A. Gaining understanding on current NMS practices

A necessary first step toward identifying NMS good practices required attaining a clear and holistic understanding of current practices and use cases of NMS from the point of view of different stakeholders, aiming to avoid bias due to approaching the task from specific stakeholders' perspectives. Therefore, multiple different approaches were explored and developed to acquire an understanding to deliver good practice reference material, namely, a survey to airports and interviews with NMS providers, literature review and review of use cases.

101 airports of various sizes and operational capacities and from different regions of the world participated in the survey to airports, which was web-based and consisted of open and multiple-choice questions. A more in-depth review of NMS at five 'use case' airports (namely Athens International Airport, Denver International Airport, Frankfurt International Airport, Sao Paulo Congonhas Airport, and Tokyo International Airport) was undertaken to gain additional insight into why airport implement NMS, what challenges are encountered, and identifying unique practices that contribute to successful NMS implementation. Figure 2 shows a graphical representation of the location of airports that responded to the survey.

In addition, four interviews with NMS providers were conducted; interviews were 'open', to allow NMS providers to provide unbiased responses and advice.

Data collected was analysed qualitatively and quantitatively to allow identification of trends and patterns that could lead to extraction of good practices. Figure 3 highlights the challenges of using the full capabilities of NMS. Data analysis also aimed at capturing indirect relationships, for example, on how factors such as local regulations or community engagement practices influenced not only the implementation of NMS, but also its perceived performance (e.g., its contribution in reducing complaints). Overall, the survey results provided a valuable snapshot of the current state of NMS practices at airports worldwide and a basis, not only for further research, but also for policy development, and collaboration within and beyond the aviation industry.

FIGURE 3: Reasons Cited for not using all NMS functions.

B. Main takeaways from the data collected

The main takeaways from the data collected are outlined below:

- The results of the airport survey indicate that main motivation for NMS installation at airports included:
  - meeting legal or regulatory requirements;
  - taking proactive action; and,
  - responding to community request or public pressure.

- The majority of respondents also indicated that the role of NMS in the overall aircraft noise management process is to support noise calculation and noise mapping, verify noise predictions, as well as simplify complaints management.

- The majority of respondents expressed their satisfaction with the NMS and its use as a means to communicate with regulators and the general public.

- Airports indicated challenges related to processing, verifying, and analyzing NMS data.

- Major benefits of an NMS cited by airports included improved trust, compliance support, transparency and improved stakeholder/community engagement. Effective information dissemination/disclosure was another major benefit reported by the majority of airports.

- Negative impacts of operating the NMS mainly included unreasonable expectations by the public, confusion related to data interpretation, malicious use of NMS data, (e.g., for supporting political or litigation arguments), but also the dedicated additional resources needed to operate the NMS.

- From the NMS providers perspective, NMS is regarded as a tool that goes far beyond the management of airport noise impacts. It is viewed as a comprehensive mechanism integrated with an airport's sustainability programs and as a dynamic means for supporting effective and strategic communication and engagement.

- In the future, NMS providers envisage the NMS to evolve into integrated environmental management systems (e.g., alongside air quality pollution emission tracking) and to become a crucial component for meeting increasing expectations, not only from the communities' perspectives, but also for supporting strategies for a better quality of life.

Summary of NMS Good Practices

Table 1 summarises good practices. Their applicability (and value) may vary between airports, depending on local situations, but for practical implementation, the good practices have been organized into three broad categories:

- Planning for an NMS;
- Using and Maintaining NMS; and,
- Dissemination of NMS information.

TABLE 1: NMS good practices identified by the Task Group, organized into 3 main categories

1. PLANNING FOR A NOISE MONITORING SYSTEM
• Identify the motivations for implementing. • Proactively implement an NMS. • Use NMS platforms, that are thoroughly tested. • Plan for the training needs of the personnel operating the NMS. • Comprehensively understand the NMS potential and the functionalities needed to support the airport's noise management goals. Accordingly employ full time NMS processional(s) for its efficient operation. • Consider appropriate number and location(s) for the noise monitoring stations when planning for implementation of an NMS. • Consider NMS programs that allow the NMS user to obtain radar data. • Consult with relevant stakeholders such as the ANSP, community representatives, airline and airport operators before implementing an NMS.
2. USING AND MAINTAINING A NOISE MONITORING SYSTEM
• Conduct maintenance of the NMS at least once a year, or as per the NMS providers advice. • Understand that the full breadth of benefits can only be realized after operating an NMS for several years. • Track trends and fluency of noise abatement departure procedure (NADP) use • Conduct education and information efforts.
3. DISSEMINATING NOISE MONITORING SYSTEM INFORMATION
• Determine which entities should receive NMS data based on the goals of implementing the NMS, and resources constraints. • Determine the type of information that should be displayed on a public website and whether the data should be refined before it is made publicly available. • Educate communities on noise data, metrics, thresholds and how an NMS works. • Be transparent when the NMS is not functioning correctly.

Conclusion

The potential benefits of NMS are recognised and the CAEP WG2 literature review and surveys imply that their implementation has been increasing globally, often in a more integrated manner (i.e. integrated within wider environmental platforms). Nevertheless, their use has remained incomprehensive, due to a perceived lack of guidance, unique airport needs, as well as technical complexities.

ICAO has identified and outlined NMS good practices with the aim to guide airport authorities into using their NMS more efficiently and effectively, so that they ultimately get the most benefit for their airport management and impacted communities.

ICAO believes that, in combination with the ICAO's Balanced Approach, NMS maintains a high potential in supporting airports to achieve the maximum environmental benefit in a cost-effective manner. Good practices identified thus far are not exhaustive and they should evolve along with NMS evolutions. In that context, an envisaged next step is to create means for online dissemination of the good practices, which would also allow regular reviews of the contents, based on new evidence, such as new data and use cases.

Revisiting Noise Abatement Departure Procedures (NADP) Application

Toward Data-Driven, Aircraft-Specific Departure Procedures

By Francisco Hoyas (EUROCONTROL)

Due to increasing traffic and stricter legislation regarding noise linked to air traffic movements, there is a growing interest shown by operational stakeholders in reviewing the current usage of Noise Abatement Departure Procedures (NADPs). Some NADPs may have been in place for many years and do not reflect the latest improvements in engine and airframe technologies meaning that todays aircraft generate far less noise than their counterparts when the NADPs were implemented. These reasons, together with the future expected integration of Unmanned Aerial Systems (UAS) that needs to be assessed, highlight the need to review the use of NADP 1 or 2, to support discussions with local communities around airports regarding the trade-off between noise and emissions.

The impacts of noise or fuel / emissions share a delicate equilibrium depending on which stakeholder is concerned. The interdependencies they share is often misunderstood as always being one against the other, whereas in reality there are situations where an operational response to reduce one impact may also deliver benefits for the other.

At least this is one of the conclusions of a EUROCONTROL study using a similar approach as in ICAO Circular 317[1], to study the effects on noise and emissions of different NADPs, in this case updated with more modern aircraft (3 Airbus types, 3 Boeing, 2 Embraer and 1 CRJ). The study was performed at a theoretical level using the EUROCONTROL's noise and emissions modelling tool called IMPACT. In line with ICAO_Doc_9911[2] and ECAC_Doc 29[3], the study did not focus on absolute values but rather on relative ones – e.g. noise level differences between different flight procedures.

Noise Abatement Departure Procedures

ICAO PANS-OPS established two different types of procedures in order to minimise noise impacts around airports more than 30 years ago. ICAO A was the departure procedure to avoid noise close to the airport and ICAO B to avoid noise further away from the airport. They were fixed procedures regarding the altitudes to be used for thrust reduction and acceleration, mainly decided by airports, without taking into account which type of aircraft was used and the conditions under which the departure was performed.

These procedures were reviewed and amended in 2001 by the Committee on Aviation Environmental Protection (CAEP)[4]. This review proposed a shift from two very specific and fixed procedures (A and B) to a more flexible approach where it was the aircraft user, not the aerodrome, who

1 ICAO Circular 317. Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions.
2 ICAO Doc.9911 Recommended Method for Computing Noise Contours Around Airports
3 ECAC Doc.29 Report on Standard Method of Computing Noise Contours around Civil Airports
4 For related provisions, see Annex 16, Volume I, and Annex 6, Part I and ICAO Doc 8168, Section 7

defined the specific procedure to be used, depending on current local circumstances. With the new NADP 1 and 2, there were still 2 possibilities to minimise the noise either close or further from the airport, but with these new procedures, the aircraft operator was the one responsible for defining the values (regarding altitude and speeds, within a given margin) at which each aircraft type should reduce thrust, clean the aircraft or accelerate along the horizontal departure track, once all other affecting parameters are considered.

These changes were reflected specifically in Edition 5 to Doc 8168[5], where the proposed procedures changed their names from Procedure A to NADP1 and Procedure B to NADP2. The major changes in the procedures themselves were:

- Procedure A to NADP1: initial thrust reduction altitude was 1500 feet AGL; in the new NADP1, the procedure establishes a minimum altitude of 800 feet – as opposed to a concrete altitude value - with the operator defining which concrete value it uses, based on the aircraft type.
- Procedure B to NADP2: initial acceleration to V_{ZF} (zero flap speed) changes from 1000 feet AGL to a minimum on 800 feet.

Both NADP 1 and NADP 2 reduce noise, but at different distances from the airport. Moreover, these distances vary with the type of airplane and most importantly, with the weight of the aircraft and current atmospheric conditions (essentially temperature and pressure), so that the distance at which one procedure is better than the other for noise avoidance fluctuates daily. By choosing a single procedure for all departures, airplanes are actually less noise efficient and in most conditions burning more fuel.

In Figure 1, the Procedure A (used as NADP1) is represented for all studied aircraft. As it can be seen, the profiles and altitudes at each specific distance from the airport are completely different for each aircraft type. Noise levels vary widely with aircraft size. One size doesn't fit all.

The majority of airports still impose a specific NADP or even the old ICAO A/B procedures, without taking into account the traffic mix and the noise performance of new aircraft.

Many aircraft operators also use the old procedures A or B, due to the lack of proper tools or awareness that would allow them to correctly assess which would be the best aircraft type tailored procedure to be applied for the particular conditions of each take off, like atmospheric conditions, mainly wind, aircraft type and take-off weight, among others. Of course, this needs to be done with sufficiently detailed noise and fuel performance data supplied by manufacturers.

The noise difference between NADP1 and 2 can be very small under certain conditions, compared to the amount of fuel burn saved by using NADP 2. Some of the profiles

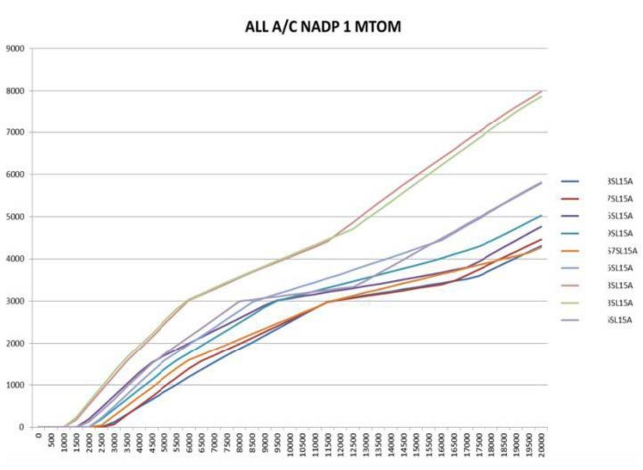


FIGURE 1: NADP1 profiles of 9 different aircraft.

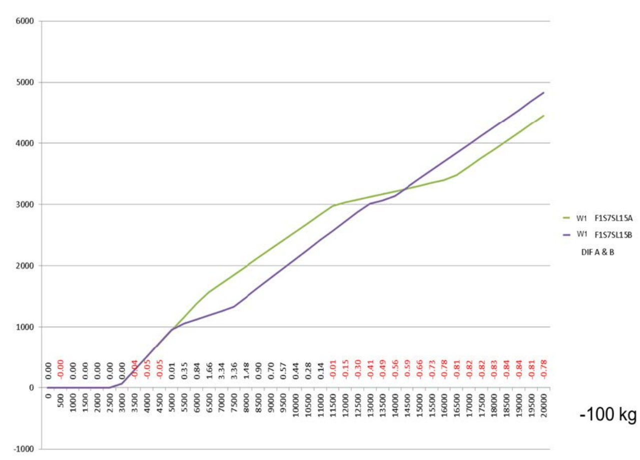


FIGURE 2: Wide Body NADP 2 versus NADP 1 with thrust reduction at after clean

5 ICAO Doc. 8168 v1. Procedures for Air Navigation Services, Flight Procedures.

studied showed a difference as low as less than 1 dB, which means that there is no real noise benefit using either of them. Whilst such small noise benefits are still welcomed, it is only useful if they occur at a distance from the airport where perceived noise is sensitive.

If the distance from the airport where noise benefits are experienced is lowly- / un- populated then the noise reduction might not be of value with fuel burn / emissions increased unnecessarily. It is very important to address the correct distance from the runway where noise is perceived as ‘very sensitive’ in order to optimise the noise abatement procedure (that is depending on aircraft type, weight and atmospheric conditions).

As with most of the other aircraft performance indicators, the main factor influencing the flight profile is the weight. When comparing the noise values of different profile procedures, the noise differences barely exceed 3dB. However, when looking at the same type, same procedure, same airport altitude and temperature, but different weights; noise levels increase on ranges that go from +5 to +11 dB when the aircraft is fully loaded. Weight makes a huge difference when looking at which procedure would be best for a specific distance from the aerodrome, which reinforces the idea that daily changes in aircraft weight, together with other daily changing atmospheric factors should be taken into account when seeking the ad-hoc most efficient procedure to apply.

Another aspect sometimes overlooked is the use of Flexible trust, which cannot only change the distances at which a specific altitude is reached, but also the noise produced by the engines while in Take-off thrust. If the intention is to be as efficient as possible in reducing the noise (not to have the aircraft at a higher altitude), take-off thrust is another important aspect that the aircraft operator can play with when choosing how flexible the take-off thrust needs to be and when to reduce it to climb thrust. The fact that the acceleration is done with less power considerably reduces the noise in the first part of the acceleration step. This contradicts some people’s belief that the sooner the aircraft climbs, less noise occurs close to the airport, as the reduction of power has a bigger impact, in certain circumstances, than the altitude gain.

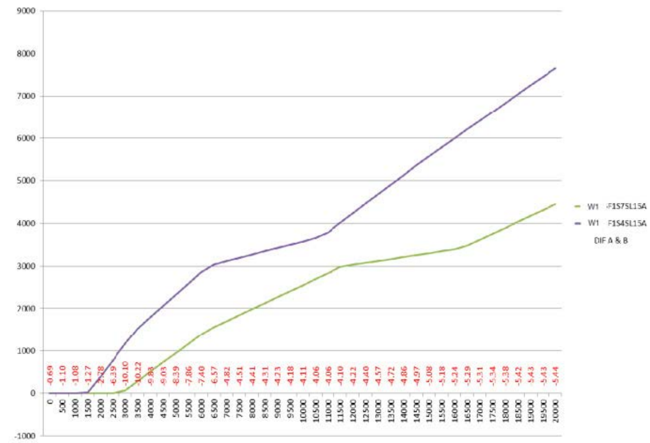


FIGURE 3: Noise difference for same Wide body, same procedure and different weight.

The application of the most appropriate NADP then depends on the inputs from airports - to identify the location of the noise-sensitive areas for each runway and Standard Instrumental Departure - and aircraft operators for the type of aircraft and its weight, not on airport operators imposing a specific procedure for all aircraft users, for all aircrafts and conditions.

The only way to achieve the best optimal noise reduction is by looking into the profiles of each aircraft type and finding those that would result in the minimum noise exposure over those sensitive points. One key way to do this is to avoid a fixed definition of the procedure to be flown and allow the application of the one best adapted to the flying conditions. At the same time noise impact is reduced where really needed, whilst this can also benefit the associated fuel consumption, with the added objective of reducing both noise and emissions, following the requirements of ICAO Doc 9829[6].

If we focus solely on emissions, on average more than 150 kilograms of CO_2 can be saved per flight by performing NADP 2 instead of NADP 1. With actual savings reflecting the aircraft type and ranging between 50-500+kg for commercial medium / heavy aircraft. These figures are calculated for the whole flight, as the chosen NADP has an impact, not only on the point where a certain intermediate altitude is reached (what could be useful for an emissions study point of view close to the airport), but also to the

6 ICAO Doc.9829. Guidance on the balance approach to aircraft noise management.

time at which cruise level is attained, impacting on the final fuel burn.

Many airports still prefer NADP 1 or even ICAO A, without correctly addressing the noise beneficial distance versus the aircraft type, traffic mix and external conditions. To enhance the efficiency of these noise abatement procedures and to understand the impacts of the changes to move away from prescriptive fixed procedures for all airplanes proposed by ICAO in 2001, they should be further reviewed.

Airport Operators should identify the location of the key noise sensitive areas in each standard instrumental departure, and allow the Aircraft Operators to choose which of the two NADP's is the most appropriate one, depending on current atmospheric conditions, times of day and type and weight of aircraft used, with the aid of proper noise modelling tools developed by manufactures (i.e. ADAS: Airbus Departure Analysis Software).

Reference Documents

Annex 6. Operation of Aircraft

EU Regulation 598/2014. Introduction of noise-related operating restrictions at Union airports within a Balanced Approach.

Aircraft Noise: A Balanced Path Toward Community and Operational Sustainability

By Jennifer Desharnais (ACI), Colette Zraibi (IATA), Jonathan Bagg (NAV CANADA)

Introduction

Aircraft noise has evolved significantly alongside advancements in aviation technology and regulatory frameworks. In the early days of commercial aviation, aircraft were relatively small and less powerful, producing moderate noise levels. However, as jet engines became the industry standard in the 1950s and 1960s, noise levels surged, leading to growing public concern, particularly around airports.

Recognizing the environmental and health impacts of aircraft noise, regulators introduced noise certification standards. The International Civil Aviation Organization (ICAO) established its first noise standards in the 1970s, with subsequent amendments tightening permissible limits. The introduction of high-bypass turbofan engines in the 1970s and 1980s significantly reduced noise compared to early turbojets, marking a major technological breakthrough.

Further advancements, including improved aerodynamics, noise-reducing engine nacelles, and quieter landing gear and flaps, have continued to drive reductions in aircraft noise. ICAO's Chapter 4 standards, introduced in 2001, imposed stricter limits, followed by Chapter 14, adopted in 2013, which requires new aircraft to be even quieter.

In parallel, noise management strategies have expanded beyond technology, incorporating operational measures like optimized flight paths, noise abatement procedures, and airport-based initiatives such as land-use planning and community engagement.

Aircraft Noise and the ICAO Balanced Approach: Finding Common Ground

In 2001, the ICAO Assembly adopted a new approach for managing aircraft noise at international airports, addressed in Annex 16 to the Convention on International Civil Aviation of 1944 (also known as the Chicago Convention) and referred to as the Balanced Approach.

The Balanced Approach is a comprehensive strategy that aims to identify all possible noise reduction measures prior to implementing operating restrictions. It consists of identifying first the noise problem at a specific airport and then analyzing various noise-related measures that achieve maximum environmental benefit most cost-effectively using objective and measurable criteria. These measures can be identified through the exploration in turn of four principal pillars: reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions.

Airports, airlines and ANSPs are deeply committed to reducing noise impacts and recognize that aircraft noise is no longer just an environmental issue; it also carries important social, political, and economic dimensions at both local and global levels. Decisions made at one airport can have far-reaching effects, influencing passenger and cargo connectivity across the network and impacting the broader aviation ecosystem, including airline operations and business models.

To ensure long-term, effective outcomes, the industry supports the principles of the ICAO Balanced Approach, which promotes a comprehensive evaluation of all available noise mitigation measures, such as quieter aircraft, operational improvements, and land-use planning, before considering operating restrictions. This ensures that the most cost-effective and locally appropriate solutions are pursued first.

Airline schedules and networks are the result of decades of strategic planning and global coordination. Sudden capacity constraints at a single airport can lead to ripple effects across this system, affecting fleet planning, crew logistics, route viability, and, ultimately, economic contributions and societal benefits such as employment.

Similarly, airports may face operational and economic disruptions if infrastructure and staffing must be scaled back due to reduced capacity. For example, night-time operating restrictions can bring respite to communities but in doing so impact time sensitive long-haul and express cargo operations and business models, with associated impacts to the flow of high value goods.

Maintaining a collaborative, and research-informed approach to noise management helps safeguard both community well-being and the broader benefits of air connectivity. The balanced approach is intended to be precisely that, recognizing that aircraft operations do impact communities, but that they also bring significant contributions to our social fabric and economies.

Perception of noise today in airport communities

The latest research indicates that aviation noise is a long-term health issue. Accumulating evidence indicates that noise can cause annoyance and sleep disturbance and could increase the risk of cardiovascular disease for people living in the vicinity of airports. Although individual aircraft have become quieter and the cumulative noise footprint surrounding airports has decreased, aircraft noise remains the most significant cause of adverse community reaction when it comes to the operation, growth and expansion of airports. Increased flight operations have counter-acted the benefits of new technology leading local communities to raise concerns about the impact of aircraft noise on their health and prompting airports and local authorities to engage in noise mitigation efforts through effective noise action plans.

In addition to increasing vulnerabilities caused by encroachment around airports, the COVID-19 pandemic has had significant effects on local communities. Drastic reduction in flight operations during this time resulted in temporary relief from aircraft noise for residents, while new societal trends such as working from home have changed exposure. The perception of aircraft noise has shifted, leading to an increased advocacy for operations restrictions in some communities in addition to growing concerns about environmental impacts. At the same time, we are at the precipice of significant innovation due to emerging technology aircraft which will drive new economic opportunities and services to the public, but which are expected to come with new sets of community concerns such as privacy, public safety, social equity, and loss of employment.

Through robust noise management strategies – such as public consultations and noise committees – airports are empowering local communities to raise concerns, contribute feedback on development plans, and play an active role in decision-making.

What is the aviation industry doing?

The aviation industry is committed to reducing aircraft noise and its impact on local communities. This effort involves the collaboration of all aviation stakeholders, including, but not limited to, aircraft and engine manufacturers, airlines, airports, and regulatory bodies.

At a global level, CAEP assists ICAO in formulating global policies and standards for noise management, including setting noise certification standards for new aircraft and updating existing standards to reflect technological advancement. Manufacturers, in turn, are developing quieter aircraft technologies.

Airlines have also been and are still fully engaged in wider efforts to mitigate aircraft noise impact on the local environment at the airports they serve. They continuously work with authorities, airports, local communities, and other stakeholders to identify tailor-made measures to address airport noise problems. They have been replacing old aircraft with newer, quieter, and more efficient models;

since 2009, almost 11,000 aircraft have been replaced at a cost of US$1.5 trillion, based on list prices.

Airports are taking a proactive approach to mitigating aircraft noise in the communities they serve through a mix of operational, technological, and collaborative measures. These include working with air traffic management services and airlines to optimize flight paths, applying noise abatement procedures like preferential runway use and continuous descent approaches, and encouraging the use of quieter aircraft. Many airports run sound insulation programs for homes and schools near flight paths. Advanced noise monitoring systems can also track and report noise levels in real time, increasing transparency and responsiveness. This helps build trust, while community engagement initiatives – like noise committees and feedback platforms – ensure residents are heard and involved in shaping local noise management strategies. Airports are also advocating for further research on noise impacts and innovative mitigation strategies, ensuring long-term solutions are grounded in evidence and community input.

Air navigation services are working with aircraft operators to structure airspace and routes in a responsible manner, conducting noise and emissions modeling to understand impacts, considering lateral placement of flight paths to avoid residentially populated areas to the extent practicable and working with airports on planning and undertaking community engagement. Through performance-based navigation, opportunities to achieve quieter continuous descent operations continue to be pursued. In some cases, nighttime specific procedures have been developed to provide respite when lower overnight traffic levels allow for greater flexibility in flight path location. Investments being made today in new Air Traffic Management platforms will increase the predictability of operations and support utilization of noise reducing procedures. Effective noise mitigation over the long term ultimately requires a whole-of-industry mindset that includes diverse stakeholder collaboration and community input, and the ongoing evaluation of emerging and novel practices.

What can we do more?

Industry to work with ICAO: new work on the Balanced Approach

To further advance efforts in aircraft noise reduction, it is essential to strengthen advocacy and enhance collaboration among all relevant stakeholders. This will be a key focus within CAEP Working Group 2 – Airport and Operations during the CAEP/14 cycle. Under a new task dedicated to the practical application of the ICAO Balanced Approach, ACI, IATA, and the Canadian Air Navigation Service Provider, NAV CANADA, will jointly lead the work, providing an opportunity for CAEP Members and Observers to actively contribute to this important topic.

Non-Acoustic Factors

Research suggests that noise exposure accounts for only about 30% of annoyance[1]. While noise levels and flight frequency contribute to annoyance, subjective elements such as trust in authorities, perceived fairness and transparency, sense of control, expectations and context, and attitudes toward aviation also play a significant role. Further increasing our understanding of the role non-acoustic factors play in how individuals perceive and react to noise aircraft noise is key to effective noise management strategies and community engagement.

Better education and collaboration with authorities

Promoting open communication and exchanging best practices can enhance stakeholders' education and collaboration with authorities. This includes working closely with organizations like the U.S. FAA, EASA, and local governments to implement effective noise reduction strategies.

Continue to improve operations and air traffic management practices

Continued efforts to leverage modern air traffic management and flight management good practices

1 https://www.icao.int/environmental-protection/Documents/ScientificUnderstanding/ICAO%20CAEP12%20White%20Paper%20on%20non-acoustic%20factors%20in%20community%20annoyance.pdf

provides an important opportunity to mitigate aircraft noise. Air navigation service providers can lead initiatives to optimize flight paths, implement Continuous Descent Operations (CDO), and enhance air traffic flow management, working with airlines to reduce the impacts of aircraft operations on the soundscape.

CAEP/13 decision on Integrated Dual Stringency

With the recent CAEP recommendation of more stringent levels for both aircraft CO_2 emissions and noise standards, we can aim to further reduce the aviation sector's environmental impact. This recommendation supports ICAO's long-term goal of net-zero carbon emissions by 2050 while addressing community noise concerns around airports.

Conclusion

The aviation industry recognizes the impact of aircraft noise on nearby communities and is working actively to shape future mitigation efforts through CAEP working groups, ICAO Standards and Recommended Practices, research, and technological advancements.

ICAO's Balanced Approach provides an essential framework that, when applied effectively, supports positive outcomes on community soundscapes while safeguarding the critical benefits that only aviation can provide in terms of global connectedness, our economies and broader society.

ICAO

CHAPTER ELEVEN

Local Air Quality

Addressing Local Air Quality: Latest Progress by ICAO

By ICAO Secretariat

One of ICAO's Environmental Goals is to limit or reduce the impact of aviation emissions on local air quality (LAQ). The existing LAQ considerations focus on aircraft engine emissions released below 3,000 feet (914 metres) and emissions from airport sources, such as airport traffic, ground service equipment, and de-icing operations, but are not limited to them.

To address Aircraft Engine Emissions, ICAO developed Annex 16, Volume II , which contains Standards and Recommended Practices (SARPs) for environmental certification of the aircraft engines. These SARPs aim to address potential adverse effects of air pollutants on LAQ, primarily pertaining to human health and welfare. Among other considerations, these provisions address: liquid fuel venting, non-volatile Particulate Matter (nvPM) impacts from mass and particles number perspectives, and the main gaseous exhaust emissions from jet engines, namely; unburned hydrocarbons (HC), oxides of nitrogen (NO_X), and carbon monoxide (CO).

Specifically, Annex 16, Volume II sets limits on the amounts of gaseous emissions and nvPM mass and number allowable in the exhaust of most civil aircraft engine types. The certification process for aircraft engine emissions is based on the Landing and Take-Off (LTO) cycle, which is considered as average and representative for the emissions emitted in the vicinity of airports. The LTO cycle contains four modes of operation, which involve a thrust setting and times-in-mode, as shown on Figure 1.

Procedurally, the engine certification process is performed on a test bed where the engine is run at each thrust setting to generate fuel flow and emissions data for each of the modes of operation. The submission of these data are mandated as part of the engine emissions certification. This certification data is stored in the publicly available ICAO Engine Emission Databank (EEDB)[1]. EEDB is the official data source for many projects and analyses performed in ICAO's Committee of Aviation Environmental Protection (CAEP) and beyond.

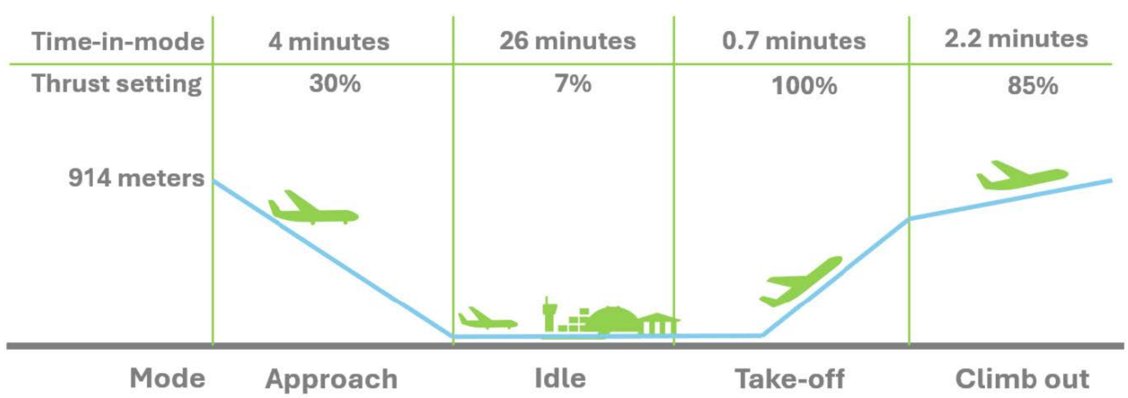


FIGURE 1: Standard engine certification LTO cycle.

1 https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

During its 13th work cycle in 2022-2025, CAEP under its Working Group 3 (WG3, Emissions Technical) successfully completed its work items on maintenance of Annex 16, Volume II and the associated guidance material reflected in the ICAO Doc 9501 – Environmental Technical Manual, Volume II. CAEP has recommended for Council's consideration the amendments to engine emissions SARPs, which include:

- the applicability language and introduction of the new terms "parent engine" and "no emissions change criteria" to increase consistency and practical clarity for the users;
- introduction of three methods to determine the maximum nvPM mass concentration and three methods to determine maximum nvPM mass and number emission indices;
- new nvPM certification point reporting requirement for 57.5 per cent of the rated thrust to the list of reference certification point (this certification point is also important for nvPM cruise emissions understanding and transitional thrust settings between 30 and 85 per cent of the rated thrust);
- alignment of Annex 16, Volume II provisions with the SAE Aerospace Recommended Practices (ARP6320B "Procedure for the Continuous Sampling and Measurement of Non-volatile Particulate Matter Emissions from Aircraft Turbine Engines" and SAE ARP6481A "Procedure for the Calculation of nvPM Sampling and Measurement System Losses and System Loss Correction Factors").

In addition to engine certification provisions, ICAO developed and is continuously updating ICAO Doc 9889 – Airport Air Quality Manual. This manual contains advice and practical information to assist ICAO Member States in implementing best practices with respect to airport-related air quality. This document also provides a process for States to determine the best approaches and analytical frameworks for assessing airport-related air quality and identifies best practices for different needs or scenarios.

CAEP/13 also provided recommendations on consequential changes to ICAO Doc 9889, such as inclusion of a new parameterised volatile particulate matter estimation methodology, guidance on the SAF impacts, expanded example calculations and additional guidance on interpolation

For the new triennium, CAEP will keep its high pace on addressing LAQ issues and progressing the related work items. For example, subject for Council approval, CAEP will develop new NO_X LTO stringency options based on the existing NO_X metrics and Overall Pressure Ration (OPR) correlating parameter while considering small engine thrust alleviation, building upon already reached progress on this topic. CAEP is planning to assess NO_X emissions mitigation technologies associated with stringency options, including costs. Additionally, CAEP plans to investigate the feasibility and added value of a potential reporting point for NO_X emission indices at 57.5 per cent of the rated thrust, with the goal to better characterize NO_X cruise emissions.

Furthermore, CAEP WG3 will continue updating ICAO Doc 9889 to reflect industry best practices, new emissions data for modern aircraft and airport emission sources, and airport operational information that affect aviation emissions, and emissions modelling methodologies, including engines not currently regulated for gaseous and nvPM emissions.

In parallel, under CAEP Modelling and Databases Group (MDG) the LAQ modelling experts are working on approaches for elaborating a "gold standard" for LAQ dispersion modelling, which involves coordination and inputs from various LAQ software tools used in CAEP.

ICAO is firmly committed to enhance its efforts in addressing LAQ and will further continue developing measures and approaches aimed at mitigating emissions impact of aviation in the vicinity of airports. And as part of this broad work stream, ICAO will continuously develop international standards, guidance material, and technical documentation as appropriate for the needs of the international community, towards sustainable future of the international aviation sector.

[1] https://www.easa.europa.eu/en/domains/environment/icao-aircraft-engine-emissions-databank

ICAO Airport Air Quality Manual Update (Doc 9889)

By Emanuel Fleuti (Zurich Airport). By Emanuel Fleuti (Zurich Airport Ltd)[1]

Background

Interest in aircraft and airport air pollutant emissions has been on the rise ever since the substantial increase in commercial turbojet traffic in the 1970s. Aircraft emissions as well as emissions from any other combustion or evaporation source produce air contaminants such as nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbon (HC), sulfur oxides (SOx) and fine particulate matter (PM), which in turn can involve broader environmental issues related to ground level ozone (O_3) and climate change, and present potential risks relating to public health and the environment. Unlike most transportation modes, aircraft travel great distances at a variety of altitudes, generating emissions that have the potential to have an impact on air quality in the local, regional and global environments.

States have historically adopted local air quality regulations to protect public health and the natural environment. Usually, air quality is regulated by a combination of national, regional and/or local regulations that establish standards on emissions sources and/or ambient (i.e. outdoor) levels of various pollutants and define the procedures for achieving compliance with these standards. However, emissions standards for aircraft engines are agreed internationally through the ICAO and subsequently adopted into domestic regulations by each ICAO Member State.

Assessing the local air quality industry-specific in a broader local context is complex and comprises several aspects (Figure 1). Airport related emissions together with other local or regional emissions sources lead to specific concentration levels in the vicinity of airports.

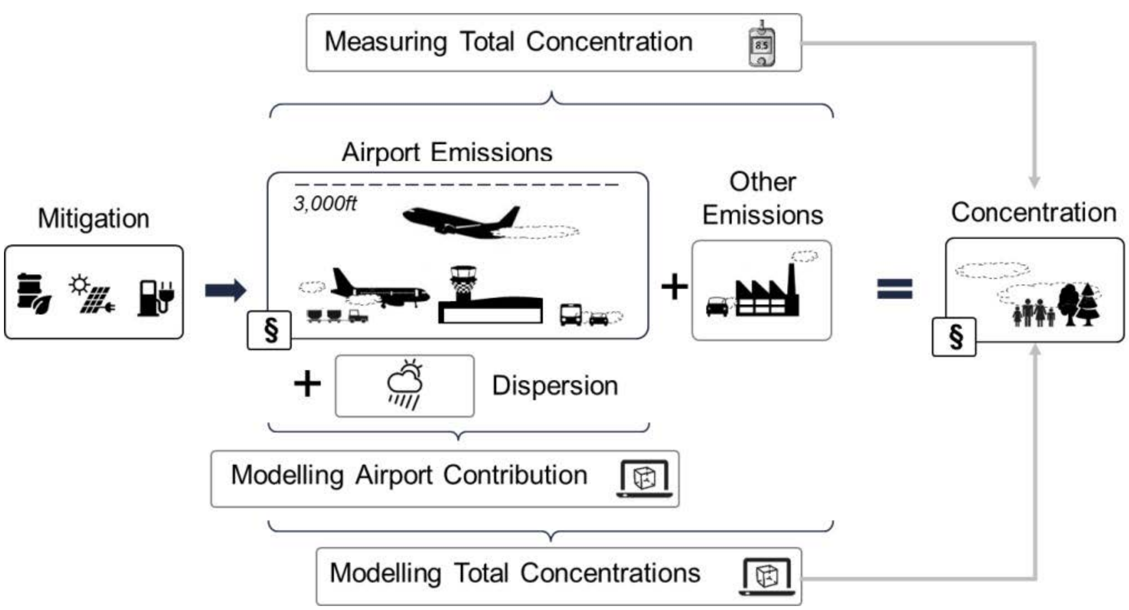


FIGURE 1: Airport air quality framework

1 Co-Lead of the Doc 9889 ad-hoc group of Working Group 3 Emissions Characterization Task Group of the ICAO Committee on Aviation Environmental Protection (CAEP)

They can be measured, but only as an ambient total. In order to determine the contribution of the airport system, concentration modelling is required – sometimes not only for airport sources, but also for the whole region with multiple sources. The assessment of the situation gives room for designing mitigation measures that will directly influence the emissions of the specifically addressed sources.

While many States, authorities, or industry practitioners have developed their methods and approaches to assess air quality, the need for state-of-the-art, internationally harmonized and recommended guidance for the global aviation industry remains unchallenged.

Airport Air Quality Manual (ICAO Doc 9889)

The International Civil Aviation Organization (ICAO) had started to develop guidance on airport air quality as early as 2006 with a first edition of the Airport Air Quality Manual (ICAO Doc 9889) being published in 2011. This guidance material was developed to assist ICAO Member States and their aviation industries in applying best practices in relation to airport-related local air quality. Doc 9889 focuses on the core of the assessment - the emission inventory. Guidance is provided on a number of key subjects including, but not limited to: emission inventory construction, emissions parameters and species, airport-related sources, local and regional sources, forecasting, and quality assurance procedures. An emissions inventory can be conducted at various levels of complexity, depending on the required fidelity of the results as well as the availability of the supporting knowledge, data, and other resources. The guidance provided in Chapter 3 is intended to be a framework for conducting studies at various levels of complexity and the guidance is given for three different levels of complexity (e.g. simple, advanced, and sophisticated).

A pre-requisite for concentration modelling is the spatial and temporal resolution of the emissions (Chapter 4). The spatial and temporal allocation of emissions provides information on locations and times with high emissions and the relevance of different emission groups. As the pollutant concentration is (neglecting other parameters) proportional to the emission, such an allocation provides a first estimate of pollutant hot spots and source apportionment with respect to pollutant concentration. It is only a first estimate because transport effects due to exhaust dynamics, wind flow, atmospheric diffusion, deposition and physical or chemical conversion processes are not considered.

Such additional effects are considered in the discussion on atmospheric dispersion models (Chapter 5), whereby the input of emission inventories alongside meteorological information is processed. The result of these processes is a time-dependent, three-dimensional concentration distribution of the pollutant and/or a specific emission source, where the concentration is the quantity of the pollutant per unit volume. Atmospheric dispersion models are an important complement to pollutant measurements. They provide comprehensive three-dimensional concentration distributions, insight into relevant transport mechanisms and a clear source apportionment. In addition, they allow study of future or other scenarios for which measurements are not available or not possible. Measurements are often conducted in order to meet legal obligations, as part of voluntary programs or for model verification (Chapter 6). Very characteristic to measurements is that they are not source discriminating and provide no option to predict future concentrations. This constitutes the need to introduce concentration modelling at the same time.

Finally, the guidance offers insights into the development of mitigation plans – outlining that any measures taken only address emissions and benefits could be seen in decreasing concentrations – and potential interrelationships associated with methods for mitigating environmental aspects (Chapters 7 and 8).

ICAO Doc 9889 Update

The Airport Air Quality manual is a document that follows the development of the scientific and technical understanding of the expert community. As new knowledge evolves, the guidance for its proper interpretation and application has to be developed as well. To this end, almost each CAEP cycle has seen an update of the manual, thus providing the practitioners with the latest available information. In the CAEP/13 cycle, a focus has been set on the modelling of particulate matter (PM) emissions, addressing not only non-volatile particle emissions, but newly the volatile particle emissions from aircraft main engines.

As a new topic, the consideration of the use of sustainable aviation fuels (SAF) in the context of local air quality has been addressed. SAF will play an important role in the decarbonization of aviation with local air quality benefits alongside. Acknowledging that SAF in the more global context is assessed for their carbon benefits, particularly over their full lifetime, Doc 9889 just looks at direct emissions from the engines. The combustion of SAF can have significant effects on the emissions of local air quality substances like SOx and PM (mass and number) in the LTO cycle and during the cruise phase. However, these effects depend on the fuel composition, the flight phase and the combustion technology of certified subsonic engines and can vary from engine model to engine model. Whereas for SOx and nvPM, the effects are significant, no outstanding emission effects for NO_X, HC and CO have been identified to date.

Enhancement in Particle Matter Estimations

Particle Matter (PM) can generally be divided into two components: non-volatile PM (nvPM) and volatile PM (vPM). So far, ICAO Doc 9889 contained information on calculating nvPM (both mass and number) and vPM (mass), but no guidance to address vPM droplet numbers. In the CAEP/13 cycle, work was done on improving nvPM emission estimation and introducing vPM number calculations (Figure 2).

The ICAO Engine Emission Database (EEDB) contains a data sheet with information on engine nvPM mass and number emissions. However, in certain cases (such as

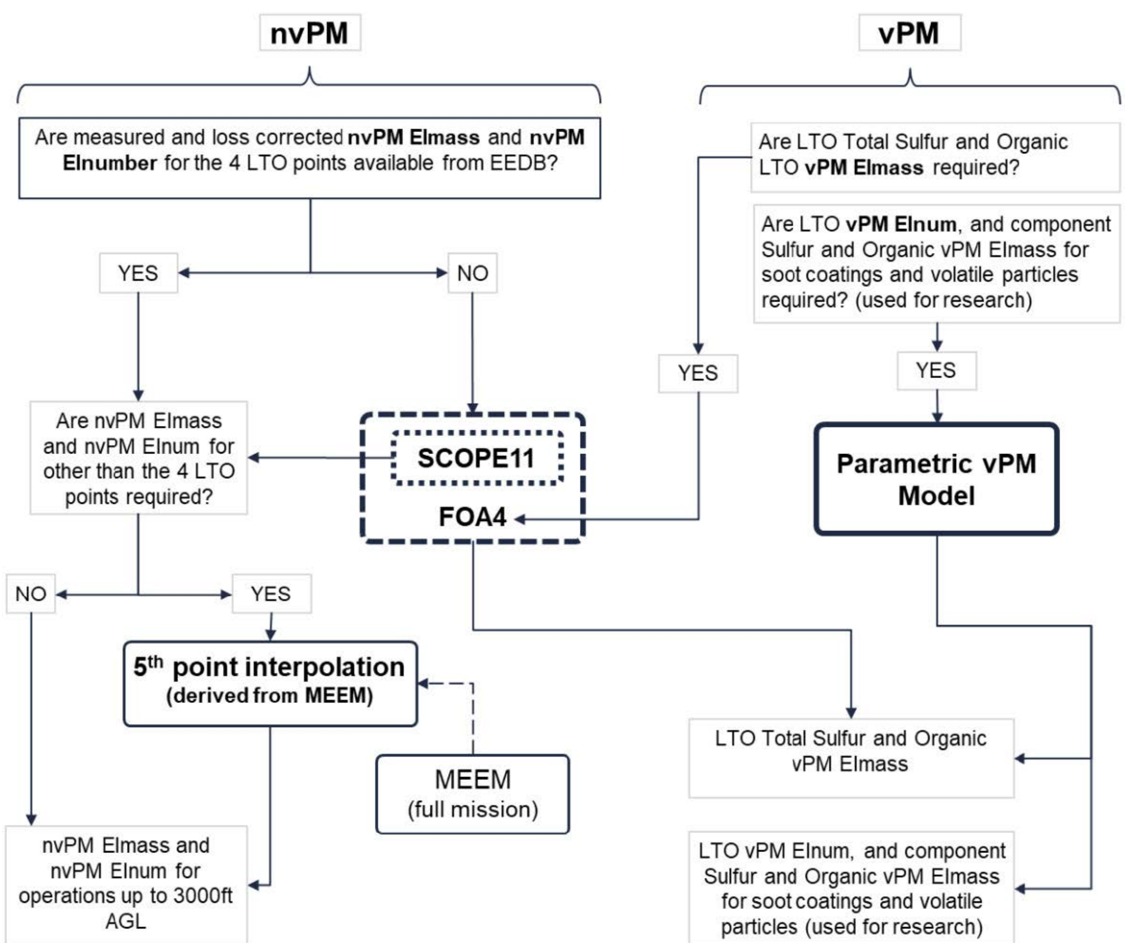


FIGURE 2: Particulate Matter Estimation Scheme

out of production engines) this information may not be available. A method to determine the nvPM (mass and number) other than with the EEDB data is using the First Order Approximation, version 4 (FOA4) using measured smoke number (SN) data. FOA4 is a method for estimating the engine exhaust particulate emissions. For non-volatile and volatile particle mass, the results for each mode of engine operation are given in the form of emission indices (EIs), as mass emitted per kilogram of fuel. For non-volatile particle number emissions, the EIs for each mode of engine operation are given as number of emitted particles per kilogram of fuel.

A new calculation methodology for estimating vPM properties in more detail has been developed by Aerodyne Research.[2] This methodology is a parameterized model based on microphysical modeling of exhaust plumes over a wide range of emissions levels. This methodology provides the vPM contributions in a more detailed breakdown than the FOA4 methodology. In addition to providing a breakdown of sulfates and condensable HC by how much of each reside in volatile droplets or as soot coatings, the methodology also allows for the estimation of vPM droplet number. That parameterized vPM methodology is a supplement to the FOA4 methodology.

There are continued efforts underway to improve vPM estimation methodologies, and those presented here provide the best available guidance at this time. The vPM guidance will be updated as needed, consistent with new developments in vPM estimation.

Summary

The latest development of Doc 9889 will provide practitioners with new guidance to address nvPM and vPM, both for mass and number. This considerably helps to not only better understand local air quality at and around airports, but also to bridge the gap between measured PM concentration which usually contain both total particle mass and numbers with modelled values.

ICAO Doc 9889 will be continually updated as civil aviation technology evolves and modelling methodologies improve.

2 Jones, S. H., & Miake-Lye, R. C. (2024). Parameterization of H_2SO_4 and organic contributions to volatile PM in aircraft plumes at ground idle. *Journal of the Air & Waste Management Association*. https://doi.org/10.1080/10962247.2024.2354820

Local Air Quality and Sustainable Aviation Fuels (SAF)

By Theo Rindlisbacher (Swiss Federal Office of Civil Aviation) and Richard C. Miake Lye (Aerodyne Research)

Introduction

Commercial aviation is making great strides in employing Sustainable Aviation Fuel (SAF) to counter the global environmental impacts of the growth of aviation traffic. The primary purpose of SAF usage is to limit aviation's contribution to the increases in global CO_2 from the burning of fossil fuels. However, numerous measurement campaigns quantifying the emissions from aircraft gas turbines have demonstrated additional emissions benefits from the use of SAF. One benefit that has become well-documented over the past decade or two is the reduction of non-volatile particle matter (nvPM) emissions on top of the CO_2 emissions reduction.

This reduction in nvPM emissions has received much attention in the context of contrail formation and potential reductions in the impact from the commercial fleet's contrail effective radiative forcing as a "non-CO_2" climate impact. nvPM, often classified as ulftra-fine particles or soot, are primary pollutants but they are also related to cloud formation. The use of SAF during aircraft cruise has the potential to contribute to optically thinner contrail cirrus with reduced warming effect. But nvPM emissions also contribute particles to the airport environment and thus contribute to Local Air Quality (LAQ) degradation and the associated negative health impacts.

For both climate and LAQ, it is important to recognize that non-CO_2 impacts are due to changes in emissions from corresponding changes in fuel composition. Research on various SAFs has allowed, and even forced, research on how fuel composition changes can affect emissions and the resulting impacts. But the changes in fuel components such as Fuel Sulfur Content (FSC) and hydrogen content (usually associated with changes in aromatic content and naphthalenic content) are not unique to SAFs. A fossil fuel refined or processed to provide the same fuel composition would have the same non-CO_2 advantages as the corresponding SAF. Of course, any fossil jet fuel with an ideal composition might have all the desired non-CO_2 benefits, but would never have the CO_2 reduction of a SAF. But non-CO_2 benefits do not necessarily need to await sufficient SAF to power the entire commercial fleet.

SAF and PM emissions

SAF, and blends of SAF with fossil kerosene, that have been tested to date, reduce the emitted mass and number of emitted nvPM, with the strongest reduction shown at engine idle conditions. Low power engine conditions are particularly relevant for ground level emissions at airports, *e.g.* when aircraft are taxiing or queuing on taxiways and main engines idling. Engine idle is a far-off-optimum running condition for gas turbines with combustion temperatures being low and combustion technology improvements are difficult to achieve in these conditions. The use of SAF and SAF blends therefore is an important measure to reduce particle emissions at airports. For higher than engine idle power, combustion technology improvements are a very strong handle to reduce particle emissions. This is, however, mostly limited to the new future engine designs. The improvements will be visible in future ICAO emission certification data. The use of SAF, however, has the advantage of having an immediate effect in the existing fleet and directly allows for particle emissions reduction in all existing and future gas turbine engines.

Additionally, SAFs are usually sulphur free, apart from contaminations. This offers the prospect of further reduction in particle emissions measured around airports. Recent studies have shown that even small FSCs, a few ppm by mass, still allow the sulfuric acid created from the combustion process to strongly affect the particle processes in the exhaust plume. However, if very pure SAF with vanishingly low FSC is used, as done at a recent test at Gulfstream with RollsRoyce, FAA, NASA, MS&T, Aerodyne, and Colorado State, new particle formation does not occur (Figure 1). This has the potential to dramatically reduce aviation particle emissions around airports, since the vast majority (90% or more) of the total PM number measured around airports is volatile PM (vPM). Whether such dramatic reductions in vPM can also have major impacts on contrail formation has yet to be determined, although recent flight campaigns (ECLIF2/NDMAX, VOLCAN, and ecoDemonstrator2023) suggest possible linkages.

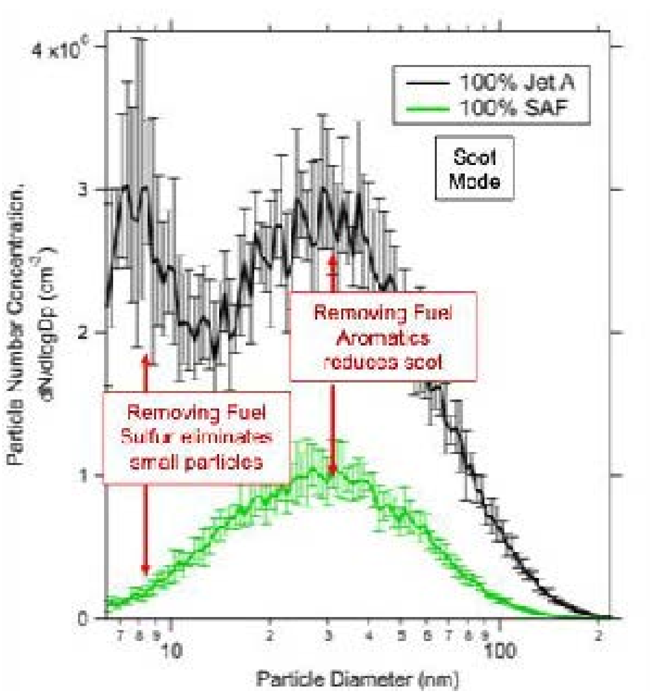


FIGURE 1: Comparison of total particle size distributions with Jet-A and very pure Synthetic Paraffinic Kerosene (SPK) SAF from the Gulfstream G700 test in October 2023.

Oil Aerosol Emissions remain as nvPM decreases due to SAF

Measurements of vPM in aircraft exhaust have shown the vPM mass to have a large contribution from engine lubrication oil[1]. Recent airport studies[2,3] have shown that the aviation contribution to PM downwind of an airport has a major component due to engine oil. As aircraft engine combustor design improves and higher H-content fuels are used, the nvPM emissions are reduced. Yet the oil contribution is affected neither by combustor design, nor by fuel composition and thus oil becomes a larger fraction of the total PM mass contribution. Recent measurements (ecoDemonstrator2022, 2023) have shown that in several modern engines, the mass from oil vPM contributions exceeds that of nvPM. Since oil is not a combustion by-product and the oil system is completely separate from the combustor in aviation gas turbine engines, current regulations do not require the measurement or certification of the emissions of oil. However, as other emissions are decreasing, the oil emissions are becoming an increasingly major contribution to the total PM emissions from aircraft.

SAF and Gaseous Pollutants

In terms of gaseous pollutants, apart from the reduction of sulphur oxides, the use of SAF tested to date has no significant effect on Nitrogen oxides (NO_X), Carbon monoxide (CO) and on the sum of hydrocarbon emissions as measured in emission certification. But what about the composition of hydrocarbon emissions?

Hydrocarbon (HC) emissions are a complex mixture of substances as a result of incomplete combustion. Some may make their way from the fuel directly into the exhaust, others are conversions from fuel HCs into emitted HCs with different chemical structure. They can be non-toxic, more toxic or less toxic than the fuel hydrocarbons. The corelease of nanoparticles together with carcinogenic

1 Timko, M. T.; Onasch, T. B.; Northway, M. J.; Jayne, J. T.; Canagaratna, M. R.; Herndon, S. C.; Wood, E. C.; Miake-Lye, R. C.; Knighton, W. B. Gas turbine engine emissions-Part II: Chemical properties of particulate matter. *J. Eng. Gas Turbine Power.* 2010, *132*, 061505/1-15.

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3 Ungeheuer, F., van Pinxteren, D., and Vogel, A. L.: Identification and source attribution of organic compounds in ultrafine particles near Frankfurt International Airport, *Atmos. Chem. Phys*., 2021,*21*, 3763–3775, https://doi.org/10.5194/acp-21-3763-2021.

polycyclic aromatic hydrocarbons (PAHs) affects air quality at airports. For modern gas turbines, incomplete combustion happens especially at engine idle, at very low power. The ICAO emission certification has a means to determine a defined sum of emitted HCs, however, there is no speciation, meaning that the composition of these emissions is not routinely measured.

Since the HC composition of SAF is very different from fossil kerosene, the HC emissions from SAF may also be different – with a prospect of being less toxic, since the most commonly used SAF to date (HEFA-SPK = Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene) is mainly composed of paraffins. A recent investigation concentrated on the amount and types of known genotoxic compounds, measured from combustion of a fossil Jet-A1 and a Jet-A1 30% HEFA-SPK blend. Genotoxic compounds, namely polycyclic aromatic hydrocarbons (PAH) can adsorb on ultrafine soot. If the soot is inhaled, these compounds can get into the body like in a Trojan Horse. It has to be noted, that such compounds are found in very low concentrations in engine exhaust, mainly at low power, but nevertheless it is important to know, whether their concentration changes with the type of fuel.[4]

The emission test referenced in Figure 2 was performed at the engine maintenance facility SR Technics, Switzerland, using the very common CFM56-7B family engine with dedicated tests[4]. Measurements were done at five thrust points, from ground idle to 85% thrust, each test point running for one hour. Blending jet fuel with HEFA-SPK lowered PAH and particle emissions by 7−34% and 65−67% at idle and 7% thrust, respectively, indicating that the use of paraffin-rich biofuels is an effective measure to reduce the exposure to nanoparticles coated with genotoxic PAHs at an airport[4].

A further Swiss emission test campaign was conducted with a small turbofan engine (PW545A) on a Cessna Citation 560XL business jet[5]. It focused again on particulate matter, gaseous pollutants and volatile organic compounds (VOC),

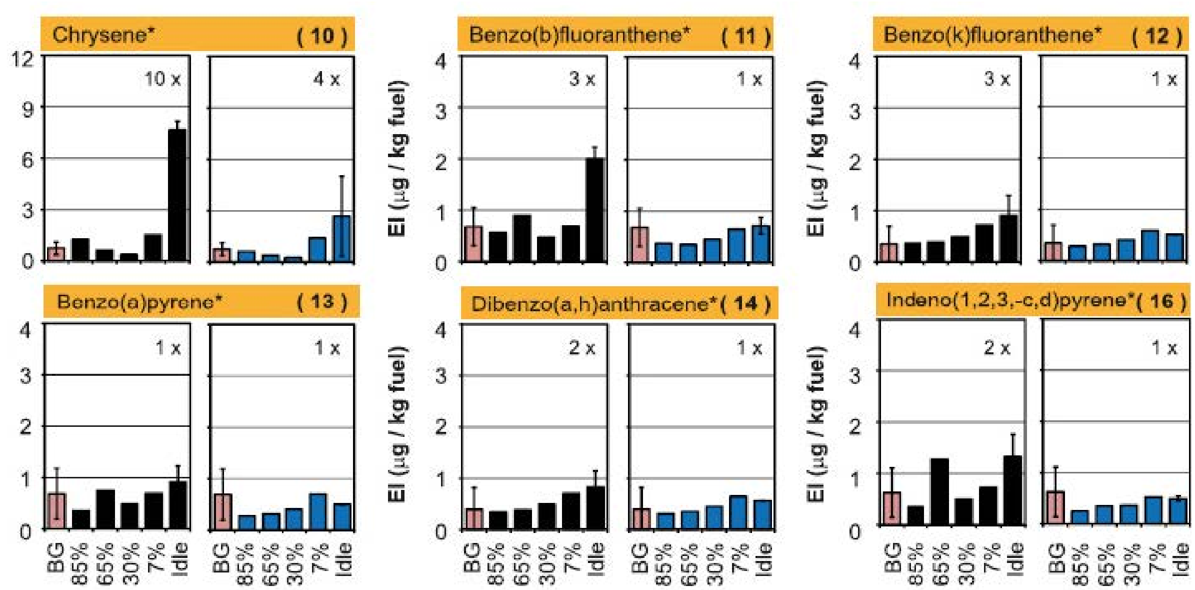

FIGURE 2: Extract of emission indices EI of priority PAH from Heeb et al.[4] The left panel of each pair is Jet-A1 and the right panel is the blend. Black bars are for the fossil kerosene, blue bars for the blend with 32% HEFA-SPK SAF. BG (pink bars) stands for background measurement. The x-axis shows the percent thrust. The numbers (e.g. 10 x) indicate how much higher the EI was measured compared to the background air (Note: the test facility is located at an airport).

4 Heeb et al, Corelease of Genotoxic Polycyclic Aromatic Hydrocarbons and Nanoparticles from a Commercial Aircraft Jet Engine – Dependence on Fuel and Thrust, Environmental Science and Technology, 2024, https://doi.org/10.1021/acs.est.3c08152

5 Durdina et al, Gaseous and Non-Volatile Particulate Emissions from a Private Jet Using Fossil Jet A-1 and a 30% HEFA-SPK Blend, Environmental Science and Technology, 2025, https://doi.org/10.1021/acsestair.5c00053

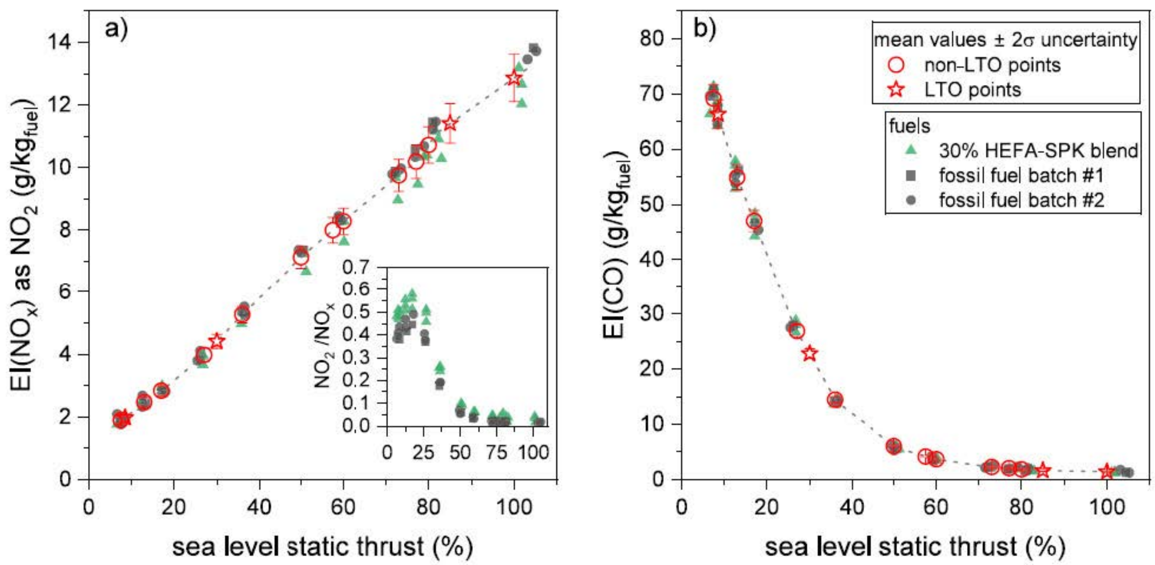

FIGURE 3: Emission Indices for NO_X and CO versus thrust for the PW545A engine, measured with pure fossil fuel batches and the 30% HEFA-SPK SAF blend. No significant differences can be observed, extract from Durdina et al.

which includes PAH. Again, HEFA-SPK SAF blend was used for comparison to the fossil base fuels. As expected, sulfur oxide emissions decreased proportionally to the fuel sulfur content, which was lower in the SAF blend.

The measurements provided SAF blend to fossil fuel signal intensity ratios for VOCs. These ratios provided a relative measure of VOC emission changes and confirmed the findings from Heeb et al.: The burning of the HEFA-SPK blend reduced formation or persistence of complex unsaturated hydrocarbons, such as aromatics and PAHs. It also confirmed no measureable significant change in emission indices for NO_X and CO.

Summary

In summary, the SAF blended fuels tested to date show a win-win-win situation for the environment. They fulfill the primary purpose of reduced life-cycle CO_2-emissions, and additionally, they reduce nvPM, reduce VOC, especially genotoxic PAH, and in general vPM particle precursor emissions like sulfur oxides. On the other hand, they do not reduce NO_X or CO, where combustion technology and fuel efficiency improvement remain as the technical measures. With cleaner combusting modern engines, contributions from lubrication oil are becoming an increasingly major contribution to the total PM emissions from aircraft. From the present state of knowledge, fuels with close to zero sulfur and high hydrogen content, such as observed with very pure SPK SAF, together with technical means to avoid lubrication oil emissions, the particle emissions and also potentially toxic gaseous emissions around airports could be strongly reduced.

Standards and Advances in Airport Air Quality Modelling

By Ulf Janicke (Janicke Consulting)[1]

Airport emission sources

Airports are a source of pollutant emissions and affect the local air quality (LAQ) at and around the airport. The dominant emission sources are the aircraft main engines during the landing-takeoff cycle (LTO) which is comprised by the flight segments approach, taxiing, take-off, and climb-out, traditionally up to 3000 ft (914 m) above ground level. Other emission sources are auxiliary power units (APU), ground support equipment (GSE), motor traffic (airside and landside), and other sources at the airport such as fuel-burning power devices.

The basis for aircraft emissions calculations is the ICAO Engines Emission Databank (ICAO EEDB) [1]. The databank is hosted by the European Union Aviation Safety Agency (EASA) on behalf of ICAO. It contains fuel flows and emission indices (EI, emission per kg fuel burned) of existing aircraft jet engines with a static thrust greater than 26.7 kN, measured at the four LTO thrust settings (7%, 30%, 85%, 100%) according to the procedures in Annex 16 "*Environmental Protection*", Volume II "*Aircraft Engine Emissions*" to the Convention on International Civil Aviation. Together with defined operation times at the four thrust settings, aircraft emissions over the LTO can be calculated.

Dispersion calculations

For aircraft, the release height of emissions has a major influence on the resulting near-ground pollutant concentration: 1 kg of a pollutant emitted during taxiing yields a much higher pollutant concentration as compared to 1 kg emitted during approach or climb at a height of some 100 m. This is in strong contrast to aircraft noise, which is transported through the ambient air at the speed of sound, while pollutants are vertically dispersed with the ambient air by turbulent diffusion.

Therefore, LTO emission is not a fully suitable concept for assessing local air quality. A dispersion calculation is required that models the atmospheric transport of the released emission and determines the pollutant concentration, usually at ground level, for suitable time periods of hours, days, or a year. Beside emissions and their localizations, a dispersion calculation requires information on meteorological key parameters (e.g. wind speed, wind direction, atmospheric stability), additional transport effects like deposition or chemical conversions, and the dynamic properties of the emitted exhaust. The latter is particularly relevant for aircraft, because the exhaust from main engines exhibits a high excess temperature and momentum significantly influencing near-field dispersion. Figure 1 shows an example result of an airport dispersion calculation.

The ICAO Document 9889 ("*Airport Air Quality Manual*") [2] provides useful information on emission and dispersion calculations for airport-related sources. In past cycles of the ICAO Committee on Aviation Environmental Protection (CAEP), several airport dispersion models have been evaluated in view of their use by CAEP. The main focus of CAEP work is nitrogen oxides (NO_x, sum of NO_2 and NO with the latter in molar mass unit of NO_2) and non-volatile particulate matter (nvPM). CO_2 emissions, which are proportional to the amount of fuel burned, are also calculated for assessing climate impacts. The following focuses on NO_x and particulate matter.

1 Ulf Janicke is lead of the Local Air Quality Task Group in the Modelling and Databases Group of the Committee on Aviation Environmental Protection.

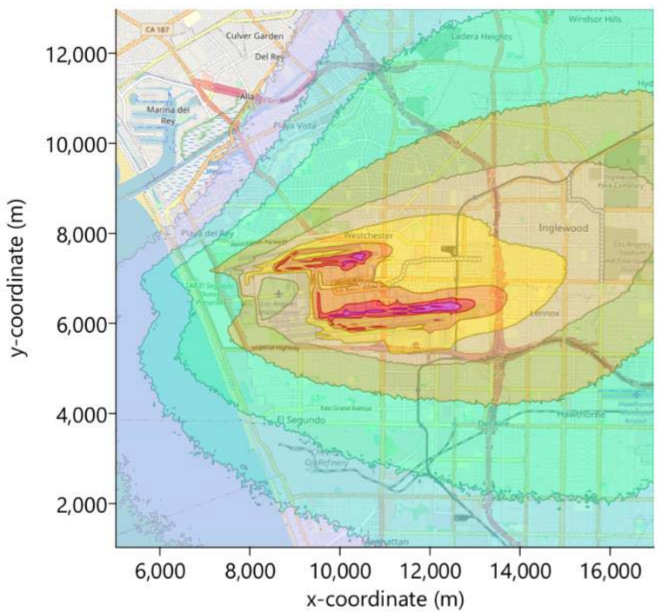

FIGURE 1: Example result of an airport dispersion calculation: NO_x monthly concentration distribution due to aircraft and GSE emissions at Los Angeles International Airport (background map: OpenStreetMap Contributors).

Nitrogen oxides

The calculation of NO_x emissions is straightforward as the ICAO EEDB contains traceably measured NO_x emission indices. Also, a dispersion calculation is straightforward as NO_x can be assumed as a chemically passive substance at time scales corresponding to typical transport times at and around airports (up to about one hour).

On the other hand, ambient air quality limit values refer to NO_2 and the calculation of NO_2 concentrations is considerably more demanding, because emitted NO can be converted into NO_2 (secondary NO_2), and vice versa. Conversion rates depend on meteorological conditions and ambient concentrations of other substances such as ozone (O_3). In addition, the NO_x emission from aircraft engines must be split into NO_2 (primary NO_2) and NO emissions, the ratio of which is dependent on type of the engine and thrust level. In the European Union, NO_2 concentrations at airports may become increasingly relevant over the next years because the ambient annual limit value will be reduced from 40 μg/m³ to 20 μg/m³ [3].

Non-volatile particulate matter

Particulate matter emitted in the core exhaust of aircraft main engines and APU consist of particles with mean diameters below 100 nm (ultrafine particles, UFP; 100 nm = 0.1 μm = 0.0001 mm) [4]. The particles have a mainly carbonaceous solid core which is regulated as nvPM. During atmospheric transport, secondary particles are created from emitted gaseous precursors (volatile particulate matter, vPM). Geometric mean diameters of non-volatile particles from aircraft engines are typically in the range of about 10 to 60 nm, whereas nucleated volatile particles start at diameters of a few nm and can grow to 10 nm or more during atmospheric transport, with volatile precursors also coating nvPM as they cool and condense.

Since 2023, new regulatory limits apply for nvPM mass and number. Accordingly, the ICAO EEDB contains with each update additional nvPM emission indices for in-production engines. For legacy engines in the ICAO EEDB, ICAO Document 9889 provides a method for estimating nvPM mass and number emission indices (First Order Approximation Version 4, FOA4). Figure 2 shows a comparison of estimated and measured emission indices and the resulting emissions over the reference LTO (fixed times-in-mode for the four thrust settings: 1560, 240, 132, and 42 s).

These tools make emissions calculations of nvPM mass and number straightforward. A dispersion calculation of nvPM number concentration can then be performed if agglomeration effects during atmospheric transport are neglected, which is a commonly applied assumption. The calculation of nvPM mass concentration is more complex because the particles can grow through condensed coatings of volatile substances. But, in general, it is the number concentration of particles that is of interest in the size regime of ultrafine particles.

Measurements of nvPM number concentrations require removal of the volatile particles, which is generally achieved by actively heating the measured aerosol (using a catalytic stripper or thermodenuder). In the sampling and measurement system, particle losses occur due to various physical processes (e.g. diffusion, thermophoresis, inertia etc.). In general, these losses are dominated by diffusional loss, hence the smaller the particles, the higher the particle

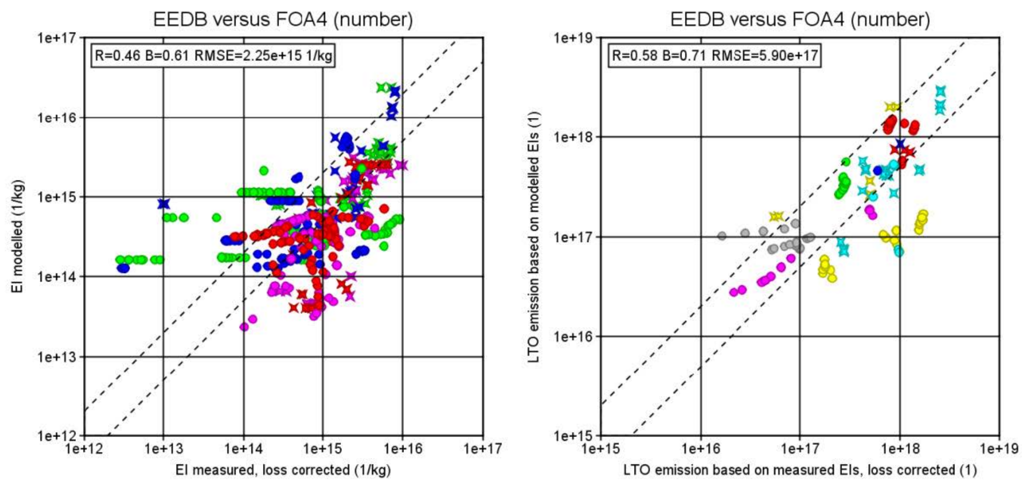

FIGURE 2: Left: Comparison of measured (ICAO EEDB 28c) and modelled (FOA4) nvPM number emission indices. Red: take-off, magenta: climb-out, blue: approach, green: taxiing, circles: turbofan, diamonds: mixed turbofan. Right: Comparison of the resulting emissions over the certification LTO (plain average over each combustor type). Red: PHASE, magenta: LEC, gray: TAPS, green: TECH, yellow: TALON, cyan: other. Dark blue symbols are the plain averages over all turbofan and mixed turbofan engines.

loss (exceeding 90% for the smallest aircraft nvPM). The ICAO EEDB provides uncorrected and loss-corrected emission indices, with more advanced loss-correction methods which use measured particle size being developed [5]. For dispersion calculations, loss-corrected emission indices should be applied.

Volatile particulate matter

Measurements have shown that a major constituent of UFP in the cooled and diluted downwind engine exhaust consists of volatile particulate matter (vPM). Modelling vPM number concentration from aircraft engines is subject to current research, with no current standard. Chemical transport models are able to cover some of the relevant processes, but often only at a low spatial resolution. Physio-chemical models have provided additional insight into relevant mechanisms [6]. In LAQ dispersion modelling, first attempts are being made to include vPM, see Figure 3 for an example. Corresponding methods will be provided in forthcoming updates of ICAO Document 9889.

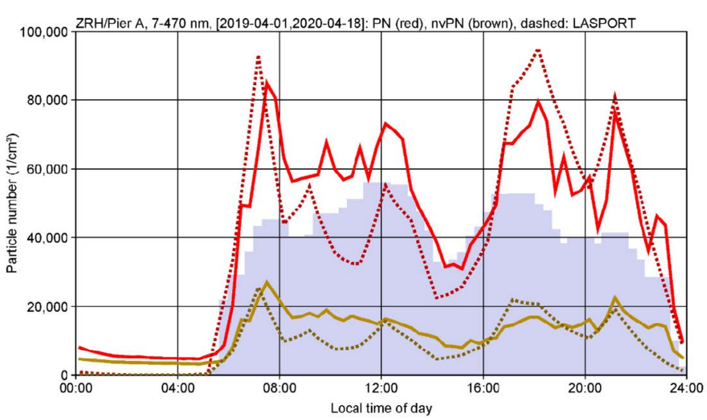

FIGURE 3: Comparison of measured (solid lines) and modelled (dashed lines) nvPM (brown) and total PM (red) number concentration at Pier A of Zurich Airport [7]. The background denotes the average aircraft movements.

Standards and harmonisation

The fact that the ICAO EEDB and ICAO Document 9889 (2nd edition) have been made freely available by ICAO significantly contributed to the global harmonisation and standardising of aircraft-related emission and dispersion calculations. This practice is expected to be maintained in the future.

Currently, the LAQ task group of the Modelling and Databases Group (MDG) in CAEP investigates the setup and application of a LAQ metric based on pollutant concentrations. Such a metric is a valuable supplement to the established LTO emissions metric and allows a better connection to impact assessments and ambient air limit values. This work may also lead to recommendations for ICAO Document 9889 and possibly to the identification and provision of so-called "gold standard" data sets, which can be used to verify and validate LAQ dispersion models in the context of aircraft and airports.

Acknowledgements: The author gratefully acknowledges the US Volpe Center and Zurich Airport AG for the provision of datasets (used for Figure 1 and Figure 3) and Andrew Crayford, Gregg Fleming, and Emanuel Fleuti for valuable comments.

Figures 1 and 3 show modelling results from the airport dispersion model LASPORT, the data shown in Figure 2 were created with the open-source tool SECTOR [8].

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[8] Janicke, U.: SECTOR: Simple Aircraft Engine Emission Calculator, www.janicke.de

Jointly regulating jet fuel aromatic and sulfur content: A near-term strategy for public health and climate benefits

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Introduction

Aircraft engines combust fuel imperfectly and incompletely, emitting combustion side products derived from fuel impurities and high-temperature reactions with air. Among these products, fine particulate matter with aerodynamic diameters of 2.5 microns and below ($PM_{2.5}$) have an outsized impact on regional air quality, public health and the climate.

Aromatic compounds, which can constitute up to 25% by volume of jet fuel, are responsible for substantial non-volatile $PM_{2.5}$ formation, a primary or direct source of particulate matter.[1] Low levels of sulphur compounds in jet fuel are responsible for sulphur dioxide (SO_2) formation, a volatile particulate matter (vPM) that is the precursor of sulphate aerosols, a potent secondary $PM_{2.5}$.[2]

Interventions focused on jointly reducing jet fuel aromatic and sulphur content present an opportunity to significantly reduce $PM_{2.5}$ emissions from both new and in-service aircraft, delivering significant public health and climate benefits in the near term. Furthermore, a swift focus on cleaning jet fuel could also facilitate the development of advanced aircraft engine combustor technologies designed to reduce NO_x emissions,[3] which continue to be a key gaseous pollutant of concern for aviation.

Regulating jet fuel aromatic content to reduce non-volatile particulate matter (nvPM) is widely recognized as a valid and complementary strategy to aircraft engine standards. However, to date, there is no regulation tapping on its outstanding potential for reducing these emissions. ICAO adopted nvPM emission standards for aircraft engine design in 2017 and 2020. These standards focus not only on particulate matter (PM) mass concentration but also PM number, emphasizing ultrafine particulate (UFP) matter. These technology-following standards were not designed to improve air quality or reduce non-CO_2 climate impacts, but rather to prevent backsliding without impacting in-service aircrafts.

Studies have demonstrated that blending synthetic alternative fuels, free of aromatics, with conventional jet fuel can significantly reduce non-volatile PM emissions, with reductions proportional to the change in aromatic content. These reductions are markedly greater at low to medium thrust conditions[4] (e.g., on the ground when idle or taxiing or during cruise and landing) than at high thrust levels. For instance, a blend comprising 32% synthetic fuel

1 ASTM International, 2021
2 Lee et al., 2020
3 Holladay et al., 2020
4 Schripp et al. 2022

and 68% conventional jet fuel has been shown to lower non-volatile PM emissions by an average of 25% in mass and 20% in number on average during landing and take-off; the same blend at low thrust conditions achieved as much as 60% decrease in PM concentrations.[5] A 50:50 blend of conventional jet fuel and synthetic fuel reduced PM number and mass emissions immediately behind a cruising aircraft by 50 to 70%.[6] The exact reduction for any given flight is difficult to pinpoint, as PM reductions are influenced by factors such as engine class and age, engine thrust settings and the aromatic content in the conventional jet fuel used in the blend.

Existing jet fuel specifications limit sulphur content to no more than 3,000 parts per million (ppm) by mass, primarily to prevent the formation of corrosive compounds that can damage turbine metal parts.[7] Regulations for road transport diesel, implemented over the last few decades in countries and regions such as the European Union, China, India, Canada, Japan or the United States mandate a maximum sulphur content of 10 or 15 ppm to lower emissions of harmful particulate matter and sulphur oxides. For reference, according to the U.S. Environmental Protection Agency, unregulated diesel in the United States contained as much as 5,000 ppm of sulphur. Many other countries have already adopted or are quickly moving towards ultra-low sulphur diesel (ULSD) regulations. These regulatory efforts offer a potential model for regulatory advancement in the aviation sector, which should also tap on synergies with ULSD production to expedite the transition to ultra-low sulphur jet fuel.

While individual Member States could unilaterally implement measures to regulate sulphur and aromatic content in jet fuel, such interventions would primarily apply to fuel uplifted within their own jurisdictions. As a result, they would presumably only cover domestic aviation and the departing leg of international flights, leaving emissions from arriving flights unaddressed. Given the need for coordinated action to achieve the greatest reductions in PM emissions across the full scope of international aviation, ICAO stands as the most appropriate body to facilitate such cooperation and ensure meaningful, global outcomes.

Public health effects

Human exposures to ambient $PM_{2.5}$ are associated with several adverse health effects. There is "causal relationship" between long- and short- term exposures to $PM_{2.5}$ and mortality and cardiovascular effects; "likely causal relationship" between long- and short- term $PM_{2.5}$ exposures and respiratory effects, nervous system effects and cancer.[8] These risks are present even at dosages in compliance with regulatory limits, meaning that compliance does not yet guarantee safety from pollution-related harms. A recent research program in Canada, Europe, and the United States reported associations between mortality and long-term exposure to low levels of ambient pollution satisfying each jurisdiction's clean air laws.[9]

Due to the confluence of transport modes and associated industrial infrastructure at major metropolitan hubs, the pollution footprint of aviation activity often overlaps with that of truck, train, and ship traffic. Even then, turbine engine aircraft contribute a potentially more acute risk to the mix: source-differentiating studies of aviation's effect on air quality consistently show elevated UFP matter in and around airports.[10] When compared to particle size distributions from other mobile sources, aircraft's fingerprint tends toward the sub-20-nanometre end of the $PM_{2.5}$ range.[11] UFP may pose greater danger than larger $PM_{2.5}$ fractions. Some literature suggests that sub-100 nanometre UFP deposits deeper in the lung during inhalation, has a high surface area-to-mass ratio, and can permeate through the alveolar membrane into the blood stream.[12]

5 Durdina et al., 2021
6 Moore et al., 2017
7 ASTM International, 2021
8 EPA, 2019
9 Health Effects Institute, 2016-2022
10 Austin et al., 2019; Hsu et al., 2013; Lammers et al., 2020; Lopes et al., 2019; E. A. Riley et al., 2016; K. Riley et al., 2021; Stacey, 2019; Westerdahl et al., 2008
11 Austin et al., 2019; E. A. Riley et al., 2016; Stacey, 2019
12 Bendtsen et al., 2021; Lammers et al., 2020

Airport workers are facing a major occupational hazard. Proximity to running jet engines is associated with heightened exposure to nano-sized particles and volatile organic compounds (VOCs), and in turn with increased risks of disease, hospital admissions and self-reported lung symptoms.[13] Communities adjacent to aircraft landing and take-off activity are also exposed to concentrated pollutant release from flightpaths directly overhead.[14]

On a global scale, aviation-attributable $PM_{2.5}$ and ozone (O_3) have been estimated to be responsible for approximately 16,000 premature mortalities each year and, of those, around a third occur within 20 km of an airport due to aviation-attributable $PM_{2.5}$.[15] This suggests that, in addition to the contributions of $PM_{2.5}$ emissions to regional air quality, impacts on public health in the vicinity of airports are an important public health concern.[16] A recent re-evaluation of that study, using greater resolution and updated epidemiological data, finds that the aviation's global air quality impacts due to aviation-attributable $PM_{2.5}$ and O_3 are greater than previously estimated, increasing the total premature mortalities attributable to 74,300 each year globally. Of those, $PM_{2.5}$ emissions account for around 21,200 premature mortalities.[17]

A study focused on China employing high-resolution emissions inventories and chemical transport modelling based on the actual trajectory of all aircraft flights estimated that aviation-attributable ambient $PM_{2.5}$ and O_3 exposures were responsible for around 67,000 deaths in China alone, with populous coastal regions in Eastern China suffering the most due to the dense aviation activity.[18] Another study based on 24-hour average $PM_{2.5}$ concentration of airport aircraft activities in China estimated that around 21,200 deaths in 2023 were due to aviation-attributable $PM_{2.5}$ emissions.[19]

Non-CO_2 climate impacts

In addition to delivering air quality improvements in and around airports and at the regional and global scale, controlling PM pollution can also reduce aviation's non-CO_2 climate impacts.[20] The non-CO_2 climate impacts of aviation constitute a significant portion of aviation's current net climate effect,[21] with persistent aircraft condensation trail (contrail) cirrus clouds being one of the primary drivers.[22] Where there are still knowledge gaps regarding contrails and contributions from various carbonaceous or non-carbonaceous PM types,[23] combustion soot particles are identified as a major constituent of contrail formation in engine exhaust. Either way, primary or secondary aerosol particles serve as condensation nuclei, becoming seed droplets for ice formation that can generate persistent contrail cirrus when flight paths intersect ice-supersaturated atmospheric conditions below a critical temperature threshold.[24]

Recent in-situ measurements of PM emissions and contrails from cruising aircraft burning paraffinic synthetic jet fuel –produced to be essentially free of sulphur compounds and containing very low or negligible amounts of aromatic compounds— have shown a significant reduction in both PM emissions[25] and on ice crystals in contrails.[26] Since aviation soot and sulphate particles are the predominant primary and secondary aerosol from aircraft,[27] this suggests that jet fuel regulation controlling both aromatic and sulphur

13 Bendtsen et al., 2021
14 Austin et al., 2021; Habre et al., 2018; Hsu et al., 2013; Hudda et al., 2014; Hudda et al., 2016; Hudda et al., 2018; Hudda et al., 2020; Logan Airport Health Study, 2014; Masiol et al., 2017; Wing et al., 2020
15 Yim et al., 2015
16 EPA, 2022
17 Eastham et al., 2024
18 Zhang et al. 2023.
19 Cui et al., 2024.
20 Bier and Burkhardt, 2019; Kärcher, 2018; Märkl et al., 2024
21 Lee et al., 2020; Burkhardt et al., 2018; Kärcher, 2018
22 Lee et al., 2020
23 e.g., Singh et al., 2024
24 Bier and Burkhardt, 2019; Kärcher, 2018
25 Dischl et al., 2024
26 Märkl et al., 2024
27 Lee et al., 2020

content is also a viable pathway for mitigating radiative forcing from contrails.

Jointly regulating jet fuel aromatic and sulphur content

A regulatory constraint on jet fuel aromatic and sulphur content could be met with either cleaner conventional jet fuel and/or sustainable aviation fuels (SAF) synthesized free of aromatics. One of the key advantages of most SAF is that they are synthesized almost entirely free of aromatics and contain no sulphur, highlighting their potential as a cleaner alternative. But SAF only holds potential for reducing harmful aviation PM emissions if a tighter regulatory cap on jet fuel aromatic and sulphur content is enforced. In its absence, there is no guaranteed reduction of aromatic hydrocarbons and sulphur in fuel blends of SAF and conventional jet fuel; economic incentives and the headroom provided by the existing upper bound for aromatic and sulphur content would cancel any potential gains.

While alternative fuels pose a natural avenue for reducing aromatics and sulphur, their gradual scale-up (e.g. 5% GHG reduction goal in 2030 adopted at the ICAO CAAF/3) means their benefits in the near term will be relatively marginal. To achieve near-term benefits, efforts should focus on reducing emissions from conventional jet fuel, while simultaneously and in a coordinated manner advancing its substitution with SAF to support long-term decarbonization goals.

When it comes to reducing aromatic content of conventional jet fuel, most researchers' attention has been directed to hydrotreating straight-run jet fuel,[28] i.e., applying post-distillation upgrading to the entire kerosene-range atmospheric distillation cut. However, modern refineries also produce jet fuel blend stocks through routine upgrading and conversion processes such as hydrocracking. These high-quality blending streams typically have lower aromatic content and very low sulphur levels.[29] Indeed, targeting lower aromatic content in conventional jet fuel also removes sulphur compounds, thereby creating an opportunity to jointly regulate them.

28 Faber et al., 2022
29 Hemighaus et al., 2007

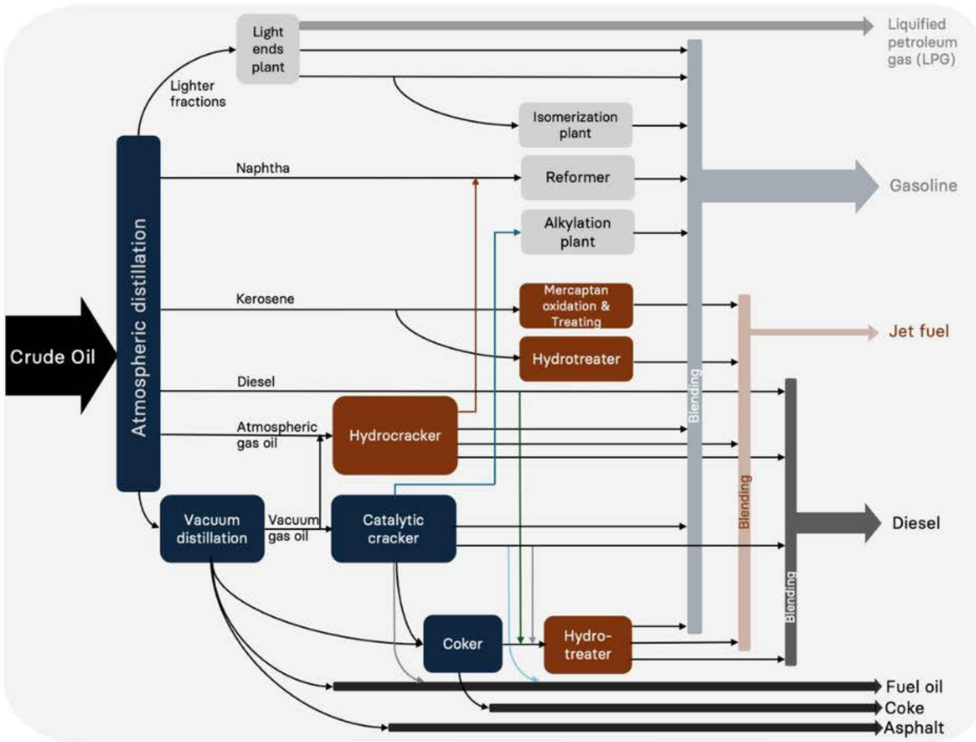

FIGURE 1: Available streams of blend stocks for jet fuel production (highlighted in brown) from all the various distillation, upgrading and conversion processes available in modern refineries. Illustrative figure adapted from Chevron Product Company's technical review on aviation fuels.[30]

Deploying cleaner conventional jet fuel at scale implies the optimization of refinery operations to ensure that blends of available streams of jet fuel from all the various distillation, upgrading and conversion processes meet lower aromatic and sulphur content specifications in the aggregate, once the blending requirements with SAF feedstocks has been considered. Operating conditions can be optimized for a target aromatics and sulphur output by adjusting parameters such as the temperature and pressure in the reactors, residency times, the hydrogen flow rate to the reactor and the catalyst type and condition.[30]

Figure 1 illustrates the different streams of blend stocks available for jet fuel production and their interaction with other petroleum products. The relative importance of the jet fuel blend stock streams is a function of crude oil characteristics, environmental constraints and market demand for petroleum products.

Implementing a staged approach to maximize near term benefits

Initial regulatory efforts to limit aromatic and sulphur content in jet fuel should be anchored in existing fuel specification frameworks, rather than pursuing structural changes to current jet fuel standards. According to ASTM International standards D1655 (for fossil jet fuel) and D7566 (for blends of synthetic and fossil jet fuel), the maximum allowable aromatic content by volume is 25%, although industry practices typically aim for 15-20%.[31] Whereas the D1655 standard has no specified minimum, the D7566 standard further requires a minimum aromatic content of 8% to prevent shrinkage of aged elastomer seals, which could cause fuel leakage.[32] Thus, setting the aromatic content at 8%, or as close to this target as practicable, would be compatible with existing airworthiness certifications and performance requirements.

30 Hemighaus et al., 2007
31 Faber et al., 2022
32 See, e.g., ASTM International, 2021

Lowering the threshold past 8% should come at a later stage as it requires further work to ensure safety. A complete phase-out of aromatics is possible though, provided that in-service aircraft have sufficient time to adapt using fresh seals; seals that have not yet been exposed to high-aromatics fuel appear to perform acceptably.[33] Otherwise, cycloalkanes could substitute for aromatics in achieving sufficient seal swell to prevent leakage while minimizing PM emissions and increasing energy content.[34]

Cost estimates leveraging existing infrastructure

The cost of reducing aromatics to just above 8% (a 50% reduction) while minimizing within it the naphthalene content, a major contributor to combustion soot and black carbon,[35] and removing sulphur compounds has been estimated to amount to an increase in jet fuel cost for air carriers of around 2%,[36] or 0.4% of their operating expenses.[37] These estimates assume that jet fuel is hydrotreated using hydrogen from steam-methane reforming in existing hydrotreating and steam reforming units, and that jet fuel producers are in a position to pass through 100% of any cost increases to air carriers. The reduction in aromatic content and the removal of naphthalene and sulphur compounds through such hydrotreating assumptions would come with a greenhouse gas (GHG) emissions penalty of around 2.5% compared to the lifecycle GHG emissions of fossil jet fuel,[38] a risk that is neutralized by greenhouse gas emissions reduction programs such as the European Union emissions trading system or the California cap and trade system.

The jet fuel cost increase of 2% captures the increment in operational costs for straight-run kerosene cuts. But there are other blend stocks for jet fuel production available in the context of modern refineries from standard upgrading and conversion processes such as hydrocracking. And these premium blending streams already have reduced aromatic and sulphur content,[39] potentially bringing down the overall cost.

Furthermore, as replacing aromatics with paraffinic molecules significantly increases hydrogen-to-carbon ratio in jet fuel and thereby its specific energy (energy content per unit of mass), the resulting gains in in-flight fuel efficiency could help offset any potential increment in fuel manufacturing operational costs and emissions. Higher specific energy can deliver greater range, high payload capacity, or decreased fuel consumption.[40]

Key takeaways

The transition to sustainable aviation necessitates a comprehensive suite of measures spanning technological, operational, and regulatory domains, including jet fuel regulation. Within this broader framework, ICAO has a unique opportunity to drive near-term benefits for both climate and air quality.

By advancing international cooperation on jet fuel regulation targeting sulphur and aromatic content, ICAO can play a pivotal role in reducing aviation's air quality and public health impacts while supporting the sector's long-term net zero climate impact imperative.

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33 Holladay et al., 2020
34 Landera et al., 2022
35 ASTM International, 2021
36 Faber et al., 2022
37 The 0.4% estimate is based on data gathered by the U.S. Department of Transportation's Bureau of Transportation Statistics and Form 41 Financial Reports, which detail operating expenses and total jet fuel costs within the airline industry.
38 Faber et al., 2022
39 Hemighaus et al., 2007
40 Holladay et al., 2020

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ICAO

CHAPTER TWELVE

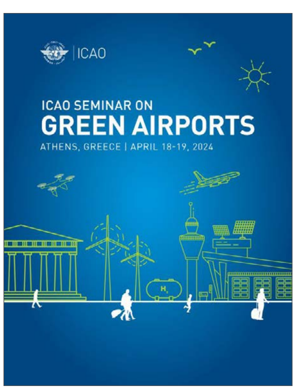
Green Airports

Green Airports: At the Frontier of Aviation's Cleaner Energy Transition

By ICAO Secretariat

Airports have long been central to connecting people, markets, and ideas across continents. Yet in an era marked by environmental urgency and the need for rapid decarbonization, their role is evolving. Today, airports stand at the frontier of a broader sustainability transition, one that redefines not only how they operate but how they contribute to the resilience and vitality of the communities they serve.

The concept of a "green airport" extends far beyond energy-efficient lighting or recycling initiatives. It speaks to a holistic transformation: an airport designed and operated with a commitment to minimize its environmental footprint, foster innovation, and engage meaningfully with its surroundings. This vision encompasses renewable energy integration, sustainable infrastructure development, biodiversity conservation, climate adaptation planning, and deep collaboration with a broad array of stakeholders.



ICAO has long recognized that achieving a net-zero aviation sector demands the full engagement of airports. As vital nodes in the air transport ecosystem, airports influence emissions directly and indirectly across a wide range of activities, and they are uniquely positioned to catalyze action, both within their boundaries and across the broader transport and energy systems they connect to. Following the adoption of the Long-Term Global Aspirational Goal (LTAG) at the 41st Session of the ICAO Assembly in 2022, and the endorsement of the ICAO Global Framework for SAF, LCAF, and other Aviation Cleaner Energies at CAAF/3 in 2023, ICAO continued to advance work on the aviation cleaner energy transition. The Green Airports Seminar, hosted in Athens in April 2024, served as an important platform to support and promote the implementation of these global initiatives.

The 2024 ICAO Green Airports Seminar discussed ambitious net-zero goals and roadmaps for airports, emerging environmental subjects such as innovations in airport management, circular economy, biodiversity, climate adaptation, as well as the transition to sustainable aviation fuels, lower carbon aviation fuels and cleaner energy sources. All Sessions within the programme of the event considered the opportunity and challenge of financing green projects and innovations, recognizing the importance of connecting and facilitating project developers' access to financial institutions' public and private funding. In addition, addressing the challenges of plastic usage in aviation is of key importance to the international community, and the 2024 ICAO Green Airports Seminar dedicated a specific Session to discuss this topic. The Seminar discussions showcased the strong support to the ongoing work of UNEP and the ongoing negotiations to develop an international legally-binding instrument on plastic pollution.

The following sections summarize the key themes and insights that emerged from the Seminar. All the presentations from panelists and the full recorded Sessions are respectively available at the event's dedicated website[1] and at ICAO.TV.[2]

1 https://www.icao.int/Meetings/greenairports2024/Pages/Programme.aspx
2 https://www.icao.tv/icao-seminar-on-green-airports

FIGURE 1: ICAO Seminar on Green Airports held at Greece, Athens, in April 2024.

- **Session 1: Setting the Scene – ICAO Work on Climate Change**

The opening session framed the critical importance of aligning airport strategies with ICAO's Long-Term Aspirational Goal (LTAG) of net-zero carbon emissions by 2050.

ICAO's recent achievements, including the outcomes of the third ICAO Conference on Aviation and Alternative Fuels (CAAF/3), have built a global policy foundation for ambitious action. Airports are expected to play a dual role: reducing their direct emissions and enabling lower-carbon air travel through supportive infrastructure and services.

The Session reaffirmed that greening airports is not peripheral to aviation's decarbonization journey — it is central to it.

- **Session 2: Key Drivers for Innovation – Sustainability**

Sustainability and innovation have become inseparable.

In this session, Athens International Airport, the Airport Regions Council, and Istanbul Airport shared examples of how the drive for greener operations is pushing technical boundaries.

From advanced energy management systems to low-impact construction techniques, airports are leveraging innovation not simply to comply with environmental standards, but to reimagine their business models and enhance resilience.

Notably, sustainability was no longer discussed as a constraint, but increasingly as a catalyst for strategic and competitive advantage.

- **Session 3: Emerging Environmental Topics**

Environmental issues confronting airports continue to diversify.

The first part of Session 3 focused on the challenge of reducing single-use plastics in aviation. Representatives from UNEP, IATA, ACI World, and IAWMA presented their strategies — including material substitutions, new design standards, and circular economy principles — aimed at curbing plastic waste without compromising safety or passenger experience.

The second part expanded the conversation to other emerging priorities: promoting circular economy models, strengthening biodiversity protections, engaging local communities more effectively, and preparing for the operational impacts of Urban Air Mobility (UAM).

Case studies from ANAC (the Brazilian Civil Aviation Authority), EUROCONTROL, Dakar Blaise Diagne Airport, and Chile's Civil Aeronautics Board brought real-world nuance to these topics, highlighting that progress often requires tailoring solutions to specific regional and cultural contexts.

- **Session 4: Taking Flight Towards Climate Resilience – Building Adaptation Strategies for Airports**

As climate risks intensify, adaptation planning is no longer optional.

Session 4 highlighted the growing need for airports to assess vulnerabilities and integrate climate resilience into every facet of their planning and operations.

ICAO's adaptation work was complemented by experiences shared by Abu Dhabi Airports, Netherlands Airport Consultants (NACO), Fraport Greece, and the World Bank.

The case studies shared by the panellists illustrated both the complexity and the urgency of taking action on adaptation measures: whether dealing with sea-level rise, extreme temperatures, or intensified storm events, airports must build resilience now to safeguard their long-term viability.

An important lesson emerged — adaptation is not a one-off project; it is a mindset that must permeate strategic thinking.

- **Session 5: Transition to Cleaner Energy Sources and Sustainable Infrastructure**

The energy transition is already reshaping airports worldwide.

Presentations from airport and regulator representatives from Indonesia, Reunion Island, Crete, and Oman showcased solar arrays, wind installations, and preliminary hydrogen initiatives now underway across airport campuses.

Energy systems are being reconfigured to prioritize renewable generation, energy efficiency, and intelligent distribution.

In doing so, airports are not only reducing their own operational emissions but increasingly positioning themselves as contributors to broader national and regional energy transitions.

- **Session 6: Era of Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and Other Aviation Cleaner Energies**

Aviation's path to net-zero emissions hinges significantly on the scale-up of Sustainable Aviation Fuels (SAF) and Lower Carbon Aviation Fuels (LCAF). Session 6 explored how airports can actively facilitate this transition.

Through the ACT-SAF Programme, ICAO is providing technical assistance and capacity-building to States. However, it became apparent thar airports themselves must invest in the necessary infrastructure — from fuel storage and blending facilities to SAF-compatible hydrant systems — to make cleaner fuels accessible.

Speakers from Neste, Repsol, Rotterdam The Hague Airport, and others emphasized that while technology pathways are advancing, robust policy support and coordinated planning remain essential.

- **Session 7: Financing Future Energy Hubs**

The financial dimension of greening airports cannot be overlooked.

Session 7 focused on mechanisms to unlock the significant investment required to deliver sustainable airport transformations.

Experts from the International Solar Alliance, World Economic Forum, European Commission, SMARTENERGY, and GEK Terna shared experiences with innovative financing models, including blended finance, risk-sharing structures, and public-private partnerships.

It became clear that designing projects with strong business cases — aligned with environmental and economic objectives — is critical to attract both public and private sector investment at the scale needed.

- **Session 8: Building Partnerships for a Sustainable Future**

  No airport can navigate the sustainability transition alone.

  Session 8 highlighted the importance of forging strong partnerships between airports, governments, airlines, energy providers, financiers, and local communities.

  Examples from Singapore, Torino, Santiago International Airport, and Airbus illustrated how strategic collaborations can enhance project feasibility, accelerate innovation, and deliver co-benefits across sectors.

  Building trust, aligning interests early, and maintaining transparent communication were all cited as essential ingredients for successful partnerships.

Towards Energy Hubs and Beyond: The Airport of Tomorrow

Throughout the Seminar, a broader vision took shape: the airport of the future will not only be a gateway for air travel but also a decentralized clean energy hub — generating, storing, and sharing renewable energy with the surrounding region. Realizing this vision will require airports to fully integrate into wider energy, transport, and digital networks.

It will demand new forms of cross-sector governance and bold leadership willing to embrace a more expansive societal role.

But the opportunities are immense. Green airports can become engines of local development, resilience, and climate action.

Next steps

Building on the momentum of recent initiatives, ICAO will continue to advance the green airport agenda, especially through the upcoming ICAO's Committee on Aviation Environmental Protection (CAEP) 14th cycle (CAEP/14), with targeted work streams led by Working Group 2 (WG2). A series of tasks will directly support airports in enhancing sustainability, resilience, and environmental performance, reflecting the broader goals established under ICAO's LTAG and the Global Framework for Cleaner Energies.

Key areas of focus will include the development of new guidance on community engagement, the promotion of climate adaptation strategies tailored for airports, and the advancement of practical tools such as the Eco-Airport Toolkit e-collection, covering biodiversity, ground operations electrification, sustainable aviation fuels, and more.

Additional efforts will address emerging environmental challenges through work on sustainable plastics management and PFAS (Perfluoroalkyl and Polyfluoroalkyl Substances) contamination at airports. Financing, operational improvements, and supporting policy coherence will also remain central, as ICAO and its partners continue to ensure that airports can play a leading role in aviation's sustainable transformation.

Through these concerted efforts, ICAO reaffirms its commitment to providing the practical guidance, tools, and frameworks that will enable airports worldwide to transition toward greener operations, delivering tangible progress on the collective path to 2050 and beyond.

Advancements in the Eco-Airport Toolkit e-Collection

By Jennifer Desharnais (ACI World)[1]

Introduction

Airports are essential global connectors, facilitating the movement of people, goods, and services while driving local economies and fostering regional development. As air travel continues to grow, airports face increasing pressure to balance operational demands with environmental sustainability. To meet this challenge, airports worldwide are embracing innovation, integrating social, environmental, and economic strategies to enhance their operations. Climate-resilient infrastructure and advanced technologies are enabling airports to drive progress in sustainability, ensuring long-term efficiency and environmental stewardship.

Eco-Airport Toolkit

Sustainability in airport operations is no longer a "nice-to-have" but has become an essential requirement. Recognizing the urgency and amplifying the benefits of innovation, ICAO established a dedicated task group to identify and share examples of airport environmental leadership at airports globally. This Eco-Airport Toolkit task group operates under Working Group 2 – Airports and Operations, within ICAO's Committee on Aviation Environmental Protection (CAEP). The Eco-Airport Toolkit e-collection, a series of concise publications accessible on ICAO's Environment website, is designed to ensure the fast dissemination of valuable insights. These papers provide practical, ready-to-use information to support the planning and implementation of airport infrastructure projects that deliver significant environmental benefits.

To date, 13 e-publications have been published on the website, each focused on a specific case study of environmental planning and at airports. This report will cover the publications developed and approved at the CAEP/12 and CAEP/13 Meetings:

CAEP/12 cycle	CAEP/13 cycle
Climate Resilient Airports	Innovation and Technology in Airport Sustainability
Water Management at Airports (including glycol management)	Environmental Impact of Unmanned Aircraft Operations at and around Airports
Air Quality Management	Addressing Single-Use Plastics: An Overview for Aviation
Sustainable Surface Access	Cleaner Energies at Airports
	Greenhouse Gas Management (GHG) and Mitigation at Airports

1. Climate Resilient Airports

As climate change intensifies, airports must adapt to extreme weather events, rising temperatures, and evolving environmental conditions to ensure safe and efficient operations. Key climate risks include flooding, storm surges, extreme heat, shifting precipitation patterns, strong winds, desertification, and biodiversity changes. To address these risks, airports can integrate resilience strategies into master planning, conduct climate risk assessment to identify vulnerabilities, and collaborate with stakeholders including airlines, municipalities, and emergency management agencies to develop coordinated adaptation measures. The publication includes other useful references, such as ICAO's Climate Change Synthesis which outlines nine primary climate impacts that can affect airports, and case studies from Canada, Mexico, France, the Netherlands, and beyond.

1 Jennifer Desharnais is Co-Lead of Working Group 2 Task Group " Eco-Airport Toolkit" of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

2. Water Management at Airports

Water is a vital resource, and effective management is essential for airport sustainability. Airports must not only use water responsibly but also manage stormwater, mitigate flooding, and ensure clean water returns to the environment. Early planning can prevent future environmental risks. Many airports implement approaches such as Integrated Water Resources Management (IWRM) or the Water Sensitive Airport framework to reduce impact and costs. Implementing Water Safety Plans (WSPs) is crucial for ensuring the safety of drinking water from the source to the aircraft. A WSP includes system assessment, operational monitoring, and management and communication procedures to consistently ensure the safety of the drinking-water supply. Key strategies include limiting pollutants, managing de-icing fluids, preventing spills, and investing in on-site treatment systems to maintain water quality. Successful examples of effective airport water management can be found worldwide, including in Malaysia, China, India, Cambodia, Canada, Brazil, Spain, Portugal. These cases highlight best practices that contribute to sustainable airport operations while safeguarding water resources.

3. Air Quality Management

Air quality is a key environmental concern for airport operators, with emissions stemming from various sources such as aircraft engines, auxiliary power units (APUs), ground support equipment (GSE), on-site power generation, fuel storage and handling, and vehicular traffic within airport premises.. While air quality is often regulated at the national or local level, airports can proactively manage emissions through comprehensive air quality management plans, and emissions inventory are a key part of it. Innovations in airport terminal heating and cooling, water management, and waste treatment also have a positive impact on reducing pollutant emissions. Explore case studies from Turkey, Australia, India, China, the Netherlands, and beyond to see successful airport air quality initiatives in action. Additionally, resources such as the ICAO Document 9889: Airport Air Quality Manual provides valuable guidance on effective air quality management, emission reduction strategies, and regulatory compliance.

4. Sustainable Surface Access

Surface access is a critical element of airport operations, but it also presents environmental challenges, including air pollution, noise, and water runoff. As such, it is a key component of airport master planning, encompassing terminal access, parking, rental car facilities, and strategies to address capacity constraints. To reduce congestion and emissions, airports are implementing innovative solutions, using advancements in digital technology and sustainable materials, and strengthening public transport connectivity, for instance. Explore successful case studies from Belgium, the United Kingdom, the United States, France, Switzerland, and Colombia, showcasing how airports are enhancing surface access sustainably and efficiently.

5. Innovation And Technology in Airport Sustainability

Airports worldwide are evolving into innovation hubs, fostering collaboration between technology experts, entrepreneurs, and research institutions. As aviation strives for net-zero emissions by 2050, airports are at the forefront of pioneering solutions, demonstrating that innovation is a cultural shift towards sustainable and forward-thinking operations. From renewable energy projects and electric or autonomous vehicles to hydrogen fueling stations and waste-to-energy initiatives, airports play a crucial role in testing, scaling, and implementing groundbreaking solutions to reduce carbon emissions and enhance operational efficiency. These innovations not only support global environmental targets but also strengthen airport resilience in the face of climate change. Beyond technology, innovation in airports drives economic growth, workforce development, and stronger stakeholder engagement. The publication highlights successful case studies from the U.S., Europe, Groupe ADP, and Canada, showcasing some of the most impactful advancements in airport innovation and technology.

6. Environmental Impact of Unmanned Aircraft Operations at and around Airports

Unmanned aircraft (UA), or drones, are rapidly expanding in use, from aerial surveys to air taxis, are expected to bring broad societal benefits. However, their integration into airspace, particularly around airports, raises sustainability concerns that need to be carefully addressed, especially considering their potential impact on local communities and ecosystems. ICAO recognizes that UAS operations will have environmental impacts, the extent of which depends on factors such as the category and size of the UAS, the type and amount of energy consumed, and the nature and location of the operation . With their rapidly evolving nature, unique operational characteristics, and often proprietary technologies, UA systems differ significantly from traditional aircraft, making it difficult to assess their full environmental impact. While current models produce lower emissions and noise, their increasing operations may present new regulatory and social acceptance challenges. To address these challenges, ICAO's Committee on Aviation Environmental Protection (CAEP) Working Group 2 (WG2) has initiated efforts to understand the environmental impact of UAS operations at and around airports. This includes conducting literature reviews and developing a "State of Play" report to assess current and potential future environmental impacts of UAS operations . Airports are encouraged to integrate UAS considerations into their environmental management systems, including conducting environmental assessments that account for UAS operations. This proactive approach will help ensure that UAS are sustainably incorporated into the aviation ecosystem. Ongoing research will be critical to guide policy and ensure their sustainable incorporation into the aviation ecosystem.

7. Addressing Single-Use Plastics: An Overview for Aviation

The aviation industry relies on a variety of single-use plastics (SUPs) due to their lightweight, cost-effectiveness, and hygiene benefits. However, their widespread use poses significant environmental and regulatory challenges.

Aviation faces several challenges related to SUP usage, recycling, and replacement. Key challenges include inconsistent regulations across regions, supply chain constraints, and limited recycling infrastructure. Airports face difficulties in waste segregation due to tight turnaround times, space constraints in catering facilities, and biosecurity regulations. Additionally, unclear marketing terminology and the absence of a standardized international definition for SUPs create confusion, making policy alignment difficult for aviation stakeholders. Meanwhile, the well-established and cost-effective nature of conventional plastics complicates the transition to sustainable alternatives. Despite these hurdles, airports and airlines are proactively implementing the best practices. The publication provides case studies on these initiatives and strategies to address SUP challenges.

8. Greenhouse Gas Management (GHG) and Mitigation at Airports

Managing greenhouse gas (GHG) emissions is now central to airport planning, with many airports recognizing the benefits of proactive climate action, improving efficiency, reputation, bond ratings, and environmental performance. As low-emission technologies continue to evolve and various funding options become available, airports have numerous opportunities to advance sustainability. A structured approach to assess current emissions, set clear objectives, and implement targeted mitigation strategies is key. Major mitigation solutions include energy efficiencies, operations and systems optimization, and investment in renewable energy and carbon capture solutions. Programs like the Airport Carbon Accreditation (ACA) offer a well-established framework for achieving emissions reductions. Furthermore, ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) assists airports in developing their emissions inventories and serves as a foundational step toward ACA accreditation.

9. Cleaner Energies

Airports are transitioning from fossil fuels to cleaner energy sources to reduce aviation's environmental impacts by 2050. This document highlights three key areas where airports are taking action: 1) reducing emissions from their operations through measures like electrifying equipment and fleets; 2) decarbonizing purchased energy using market-based instruments like Power Purchase Agreements

(PPAs), Renewable Energy Certificates (RECs) and onsite renewables; and 3) supporting the reduction of aircraft emissions, which make up the vast majority of total aviation-related emissions. During this transition, airports will face considerable challenges due to rising energy demands, and integrating clean energy goals and future needs into master planning, along with stronger cross-sector collaboration, will be key to accelerating progress toward decarbonization.

Future Developments

The Eco-Airport Toolkit e-Collection is an evolving series of concise, practical publications developed by ICAO's Committee on Aviation Environmental Protection (CAEP) Working Group 2 (WG2) to support sustainable airport development. Recognizing the increasing environmental challenges faced by airports, the toolkit showcases real-world examples of environmental leadership worldwide. To date, 13 e-publications cover a range of topics including climate resilience, water and air quality management, GHG emissions, surface access, innovation, unmanned aircraft, single-use plastics, and clean energy transitions. Each publication offers ready-to-use guidance and international case studies, supporting airports in reducing their environmental impact. The toolkit promotes early-stage planning, cross-sector collaboration, and integration of emerging technologies to enhance sustainability. Looking ahead, ICAO plans to expand the e-Collection to address biodiversity, noise, and efficient flight operations, while older resources will be updated to remain relevant. As the aviation sector works toward long-term sustainability and climate goals, the Eco-Airport Toolkit provides airports with actionable strategies and insights to help guide responsible growth.

Holistic Airport Decarbonisation from Ground to Air

By OLGA Project

hOListic & Green Airports

Introduction

Airports are pivotal nodes in the global transport network, and their environmental footprint is both significant and complex. Attaining ICAO's Long-Term Global Aspirational Goal (LTAG) for international aviation climate objectives requires systemic, integrated solutions. that span the full scope of airport operations. The **OLGA (hOListic & Green Airports)** project – co-financed by the European Union under Horizon 2020 – was launched to address this challenge head-on.

OLGA provides a comprehensive, real-world demonstration of how airports can advance decarbonization efforts across landside, terminal, airside, and energy management domains. Utilizing Paris-CDG and Milan-Malpensa, Zagreb and Cluj airports as demonstration sites, OLGA functions as a living laboratory for the development and innovative technologies and cross-sector collaboration. From hydrogen production to smart mobility platforms, digital emission monitoring, and sustainable construction, the project demonstrates that a greener airport is not just an aspiration, but an achievable path forward.

This paper summarizes OLGA's principal innovations, key outcomes, and the insights gained throughout the initiative, emphasizing how the project aligns with ICAO's long-term environmental vision and provides replicable frameworks for airports worldwide.

Innovations Across the Project

Redefining Landside Access

Multimodality and Traffic Flow Optimisation Tool

As part of the OLGA Project, Ericsson Nikola Tesla (ENT) is working on a multimodality and traffic flow optimisation tool. This innovative solution uses telecom data and machine learning to generate high-resolution insights into passenger behavior, travel patterns, and transportation demand. Data analysis ranges from 15-minute intervals to broader seasonal trends. With an impressive accuracy rate exceeding 97% when compared with traditional survey methods, the tool offers airports and airlines a powerful decision-making framework. It not only identifies unmet demand from underserved regions – presenting clear opportunities for new route development – but also enables continuous assessment of operational changes to enhance mobility and the overall passenger experience. This marks a significant step forward in aligning airport operations with real travel demand and fostering more efficient, sustainable air transport systems with the principles outlined in ICAO's *Airport Planning Manual (Doc 9184)* and the *Global Air Navigation Plan (GANP)* regarding surface access and landside operations.

Airside Decarbonisation: Sustainable Operations in Action

APU Substitution

FIGURE 1: "APU Substitution" initiative.

Air France, SAS, Groupe ADP, and SEA have collaboratively implemented the "APU Substitution" initiative at Paris Charles de Gaulle Airport, with successful replication at Milan Malpensa Airport by SAS and SEA. This forward-thinking effort is aimed at reducing the environmental footprint of aircraft ground operations by replacing the use of Auxiliary Power Units (APUs) with fixed external power and air conditioning systems (PCA and ACU) at gates. By powering aircraft on the ground through these cleaner, quieter alternatives, the initiative significantly lowers fuel consumption, CO_2 emissions, and noise pollution during turnaround operations.

Tested under real-world operational conditions – including peak traffic periods and diverse weather scenarios – the project has demonstrated tangible environmental and operational benefits. Key achievements include a reduction of 1.259 tonnes of CO_2 emissions, savings of 478 tons of fuel – with emission reductions, calculated in alignment with methodologies – and a decrease in APU operating time by over 3,000 hours, all while maintaining operational safety and efficiency. Strategic gate selection, optimised infrastructure placement, and dedicated coordination teams ensured the project's success. The initiative reflects a strong commitment to sustainability, and its proven impact has prompted further investment by Air France to expand APU substitution coverage across all long- and medium-haul operations at CDG. This model offers a scalable, impactful solution to reduce aviation's ground-level emissions and support greener airport ecosystems.

TaxiBot to Allow Engine-Off Taxiing

FIGURE 2: TaxiBot.

As part of ongoing efforts to advance sustainable aviation, the OLGA Project has supported the implementation of the TaxiBot – a semi-robotic, hybrid diesel towing vehicle designed to tow aircraft from the gate to a runway-adjacent area without the need for engine power. The task developed in collaboration with Groupe ADP, Air France, and SAS, represents a significant innovation in ground operations, aimed at reducing CO_2 and NO_X emissions, decreasing fuel consumption, minimising engine wear, and easing taxiway congestion while ensuring compliance with ICAO Annex 14 operational safety standards and Annex 16 Volume II noise requirements. By enabling engine-off taxiing, the system also contributes to lower noise levels, creating a quieter and more sustainable airport environment.

Between November 2023 and February 2024, a dedicated trial phase was carried out using one TaxiBot and four specially modified Airbus A320 aircraft. The system completed 38 missions during departure operations, showcasing its operational feasibility in real-world conditions. The final evaluation report will detail the environmental, economic, and operational impacts of the project. Early results indicate strong potential for broader deployment, reinforcing the role of innovative technologies like the TaxiBot in transforming airport ground operations and supporting global sustainability goals.

Terminal Innovations: Building Energy-Efficient Infrastructure

Improved Energy Consumption at Airport Passenger Pre-Boarding Bridge

FIGURE 3: Advanced screen-printed glazing installed.

In its ongoing pursuit of enhanced energy efficiency and passenger comfort, Groupe ADP, in partnership with Immoblade, has launched an innovative project to improve thermal performance in airport passenger pre-boarding bridges. These spaces, often constructed with extensive glazing and limited insulation, have historically posed challenges in maintaining comfortable indoor temperatures, particularly during peak summer and winter periods. The project involves replacing traditional single-glazed units with advanced screen-printed glazing aligned with the design principles outlined in ICAO Doc 9184, Airport Planning Manual, Part 1. This glazing is designed to passively regulate solar gain throughout the year – maximising heat retention in winter and minimising heat entry in summer.

Installed at Paris Charles de Gaulle Airport, the new glazing system operates with a variable solar factor, effectively reducing the cooling demand by more than 50% during summer months. Moreover, initial results indicate a 2.5-fold reduction in the number of hours where indoor temperatures exceed 26°C, contributing to a more pleasant passenger experience. Beyond comfort, this passive solution requires no additional energy to function and integrates seamlessly into existing infrastructure, making it a cost-effective, low-maintenance strategy for sustainable airport design. This initiative highlights how smart materials and design can significantly enhance operational efficiency and environmental performance in airport environments.

Solar Installation on Passenger Bridge

FIGURE 4: Solar Installation on Passenger Bridge.

In partnership with Groupe ADP, DGAC, and ITW GSE, the project combines custom-designed, anti-glare photovoltaic (PV) panels with a next-generation of Electric Ground Power Unit (eGPU) powered by Nissan car battery technology. The aim of this innovation is to harness renewable energies to generate the electricity needed by aircraft during ground operations, enabling them to remain electrically autonomous while parked on the stand.

This setup enables aircraft to receive clean, 400Hz power during turnaround operations, significantly reducing reliance on diesel-powered Ground Power Units (GPUs) and eliminating the use of onboard APUs both of which are major contributors to carbon dioxide (CO_2) emissions and noise emissions in the airside environment. The system operates as a closed-loop energy solution, prioritising solar power and switching to the conventional grid only when necessary, with no feedback into the grid itself.

Although the initial design had a larger carbon footprint, subsequent material and design optimizations can improve its environmental performance over time, especially in regions with high grid-related emissions and high solar incidence. Additional operational benefits include the PV panels serving as a solar shield, thereby reducing thermal load within the Passenger Boarding Bridge (PBB) and lowering cooling energy demand. The installation, covering a $36m^2$ roof area, the system is set for a one – year test phase starting in April 2025. Recent regulatory updates in France promoting renewable infrastructure further enhances the replicability of this initiative across European airports. This project represents a critical advancement towards cleaner, quieter, and more energy-efficient ground operations, aligning with ICAO's environmental objectives for sustainable airport development.

Clean Energy Transition: H2 and SAF

Sustainable Aviation Fuel (SAF)

SAF is derived from renewable sources such as used cooking oil (UCO) and agricultural waste, and while it emits similar levels of CO_2 during combustion, it can reduce total life-cycle emissions by up to 75% due to its sustainable production methods. SAF is fully compatible with existing aircraft and infrastructure, requiring no modifications, and can be blended directly with conventional jet fuel.

However, because SAF is injected into a shared, undifferentiated fuel distribution system, it becomes nearly impossible to physically trace which flights use SAF. To address this, OLGA, in collaboration with Air France, Attributes and Groupe ADP has developed a blockchain-based proof-of-concept tracking tool aligned with ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies. This innovative platform ensures full traceability of SAF volumes throughout the value chain, from feedstock origin and sustainability certifications (e.g. ISCC EU) to the allocation of SAF to specific flights. The tool generates digitally verified certificates, guaranteeing accurate accounting and preventing double counting of emissions reductions.

The first successful use case demonstrated the system's capabilities: 445 tons of ISCC EU-certified SAF, made from UCO feedstock and achieving 30% GHG savings, were digitally allocated to the takeoff phase of 1,470 medium-haul and 840 long-haul flights departing Paris Charles de Gaulle during the Paris 2024 Olympic & Paralympic Games. A second deployment is planned for the Milano-Cortina 2026 Winter Games, where SAF will be used to decarbonize two flights between CDG and Milan Malpensa. This initiative represents a major step toward scalable, verifiable SAF deployment, supporting both climate targets and the future of sustainable aviation.

System Intelligence: Monitoring, Measuring, and Optimising

OLGA's Dashboard for Sustainable Decision-Making

As part of OLGA's cross-cutting Work Package 6 (Cross-cutting aspects), an interactive dashboard has been developed to serve as a forward-looking decision-support tool for airport environmental teams, public authorities and other key stakeholders. This innovation addresses a significant gap in current environmental tools by integrating, within a single platform, data from air quality monitoring stations, detailed emission inventories (including road traffic, Ground Support Equipment (GSE), and aviation), and advanced atmospheric dispersion models. The platform integrates real-time data and emissions inventories to support decision-making by airport operators.

The dashboard empowers users to explore and compare scenarios involving infrastructure developments, regulatory policies, or technological innovations – such as GSE electrification, low-emission zones, enhanced public transport, or Sustainable Aviation Fuel (SAF) deployment. By linking emissions from specific sources to their effects on air quality, it facilitates source apportionment and helps quantify the actual environmental benefit of each initiative.

The tool was developed using real operational data and piloted at Paris-CDG, Cluj, Milan and Zagreb airports.

It synthesizes inputs from several OLGA work packages, acting as the systemic link between technical innovations and measurable environmental outcomes. Designed for transparency and replicability, the dashboard transforms complex data into intuitive visualizations, fostering shared understanding and informed action among diverse stakeholders. This innovation illustrates OLGA's holistic approach to airports and supports long-term environmental planning, connecting today's operational decisions with tomorrow's cleaner and healthier airport environments.

Green Airports based on the good practices implemented in Dominican Republic international airports

By Judit De Leon (IDAC) and Carolina Joaquín (Cibao International Airport)

Introduction

An environmental management system (EMS) provides a structured approach for systematically identifying and managing significant environmental aspects of aviation operations and has proven effective across a wide range of aviation stakeholders, including airports, airlines, manufacturers, and government agencies. An EMS is one of the tools available for managing environmental issues at an airport, along with sustainability plans, certifications, compliance, and other processes. In accordance with ICAO's *Eco-Airport Toolkit e-Collection* document titled *An Environmental Management System for Airports*, Dominican Aeronautical Regulation (RAD) No. 14. on aerodrome design and operations requires that aerodromes with international operations establish an Environmental Management System. This system must address the most significant aspects associated with aerodrome operations, such as: consumption of non-renewable natural resources, atmospheric emissions from stationary and mobile sources, soil and water pollution, discharge of liquid and solid waste, and generation of hazardous substances.

The Dominican Republic generates more than 7 million tons of waste per year, or approximately 650 kg per inhabitant. The primary method used for the final disposal of solid waste is open-air sanitary landfills. By 2023, 358 open-air landfills had been registered in the country. Just in October 2020, Law 225-20 was enacted, which aims of preventing waste generation, ensuring the right of every person to live in a healthy environment, protecting public health, and reducing the greenhouse gases emitted by waste.

Electricity generation in the Dominican Republic relies primarily on conventional fossil fuel sources, notably coal and natural gas. Solid waste generation has been a concern for decades. This case study highlights the efforts made by airports have made to address these two issues. In the 4th edition of the action plan on reducing CO_2 emissions from international civil aviation, Dominican Republic airports committed to transitioning towards low-carbon and renewable energy sources for electricity generation.

Environmental Management System for Airports

Cibao International Airport (AIC)

Cibao International Airport (AIC), located in Santiago de los Caballeros, Dominican Republic's second-largest city, decided to seek an alternative to reduce the volume of waste directed to landfills. To this end, the airport acquired 31 garbage disposal stations and constructed the warehouse to serve as a centralized collection center.

FIGURE 1: Center for Collection and Segregation of Solid Waste at AIC.

A reinforced concrete warehouse measuring covering 197.64 square meters, is divided into several functional zones: reception and weighing, waste segregation, recyclable materials warehouse, hazardous waste warehouse, restrooms, and dispatch area. Thus, the AIC Solid Waste Management Plan was initiated in 2020, with the goal of reducing landfill waste by recovering recyclable materials. This project aligns with Law 225-20, the General Law on Comprehensive Management and Co-processing of Waste, which stipulates that waste producers are responsible for proper separation. The plan encompassessolid waste management across the entire airport terminal, including concessionaires and other customers. The following entities, in their role as stakeholders, have promoted the development of the project as an example of solid waste management: Cibao International Airport Administration, the Ministry of Environment, and Santiago City Council.

The Airport generates an average of 420 tons of solid waste annually, of which pproximately 11% is recovered for recycling each year. This reduction not only decreases waste management costs but also reduces the number of trips required to the final disposal site, as the airport owns and operates the compactor trucks used for transportation.

FIGURE 2: IDAC visit to AIC in 2023. In the photo: Mr. Miguel Mejía sub director del IDAC y Director de Desarrollo Sustentable, Ms. Wilma Paulino, Mr. Geldy Núñez, Ms. Carolina Joaquín, Mr. Jorge Salcé, Ms. Judit De León.

This solid waste management project involved an investment of approximately $290,000.00 USD. In 2021, the annual cost of solid waste management was approximately $16,000.00 USD, and in 2023, the annual cost of waste management was $16,500.00 USD. Although total waste generation period increased by 15%, during the 2021-2023, management costs management costs remained relative stable. This economic benefit is directly associated with the recovery of recyclable waste and a 35% reduction in landfill trips.

This waste recovery has also had a positive impact on emissions reductions, specifically carbon dioxide (CO_2) emissions, preventing the release of 142 tons of CO_2. Although the primary objective of this project is not to generate economic profit, but rather to solve an environmental problem, revenue from the sale of recyclable waste has so far amounted to $11 million over three years. The Airport's commitment is to continue implementing projects that align with sustainability criterial.

Clean Energy at Airports

Cibao International Airport (AIC):

FIGURE 3: Photo of AIC, the photovoltaic park.

Electricity generation in the AIC currently results in emissions of over 600 $kgCO_{2e}$ per MWh based on National Interconnected Electric System.

In response, and as part of its sustainability and corporate responsibility policy, the shareholders of Cibao International Airport initiated a photovoltaic generation project for on-site consumption by the airport and its tenant companies. Launched in 2013, the project aimed to achieve energy independence and gradually reduce emissions, particularly those associated with grid electricity. The initiative was supported by incentives under Law No. 57-07 on Incentives for Renewable Energy and Special Regimes.

FIGURE 4: Photo of AIC, the photovoltaic park, and the TESLA battery bank.

FIGURE 5: IDAC visit to AIC. In the picture: Mr. Miguel Mejía sub director del IDAC y Director de Desarrollo Sustentable, Ms. Wilma Paulino, Mr. Geldy Núñez, Ms. Carolina Joaquín, Mr. Jorge Salcé,Ms. Judit De León.

The solar plant, located within airport grounds near the General Aviation area, integrates photovoltaic generation with energy storage. It was implemented in two phases. The first phase began in 2013 with a capacity of 1.5 MW, using 5,880 SW235 solar panels and three GT 500 inverters. The second phase began operations in 2019, adding another 1.5 MW for a total of 3.0 MW

Energy storage is achieved through a series of Tesla battery banks with a total capacity of 1,240 kWh. This capacity provides electricity for approximately two hours at night, in addition to supplying energy during peak demand throughout the day.

The photovoltaic plant required an investment of approximately $7.2 million. The payback period for the first phase was four years, while the second phase will be eight years. This project generates nearly 75% of the airport's energy consumption, leading to environmental and economic benefits. The project represents an average annual savings of $780,000.

Through these measures, complemented by certain energy efficiency initiatives, the Airport has achieved a reduction of nearly 25% in absolute greenhouse gas emissions compared to the 2016 baseline year, corresponding to approximately 1,700 tonnes of CO_2 equivalent (tCO_2e) annually. On a per-passenger basis, emissions have decreased from 1.49 $kgCO_2e$ to 1.0 $kgCO_2e$, reflecting a 33% improvement in emission intensity.

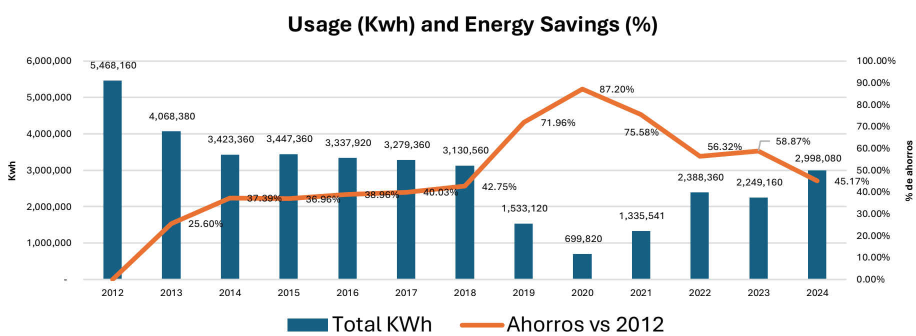


FIGURE 6: Usage (Kwh) and Energy savings (ahorros) expressed as a percentage. Source: prepared by the AIC.

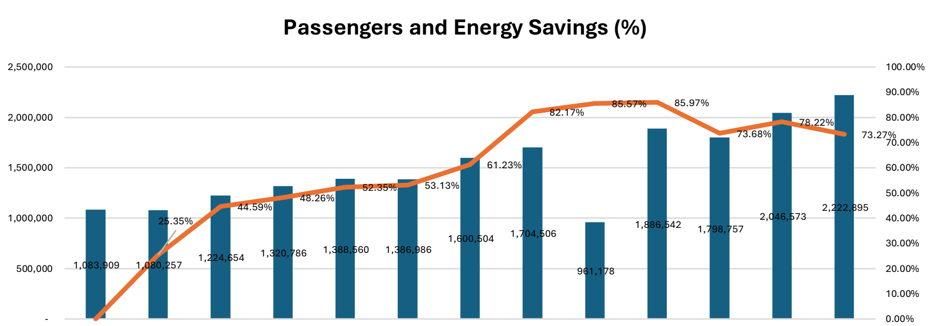


FIGURE 7: Passengers and Energy savings (ahorros) expressed as a percentage. Source: prepared by the AIC.

Advancing Decarbonization through Energy Efficiency at İGA İstanbul Airport

By Bilal Yildiz, Orhan Gül, Dr. Tunc Cavcav, and İrem Bilensoy (İGA İstanbul Airport)

Towards a Low-Carbon Future: iGA's Energy Efficiency Vision

As the aviation sector faces growing pressure from climate change and the energy transition, iGA Istanbul Airport embraces its role as a frontrunner in shaping a low-carbon future. Strategically located at the crossroads of continents and cultures, iGA is not only a transportation hub but also a platform for innovation and responsibility. Energy efficiency, for iGA, is not a narrow technical objective but a foundational principle driving broader environmental, economic, and social transformation.

To support the International Civil Aviation Organization's (ICAO) Long-Term Aspirational Goal (LTAG) of net-zero carbon emissions by 2050, iGA has adopted energy efficiency as a core strategy. This approach extends beyond operational improvements to encompass governance, technology, and behavioural change, contributing directly to the United Nations Sustainable Development Goals (SDGs), particularly SDG 7, SDG 9, and SDG 13.

iGA's decarbonization roadmap aligns with ICAO's LTAG, setting interim goals to reduce emissions by 45% by 2030 and 73% by 2040. Yet, it is not targets but the systemic integration of sustainability, into infrastructure, training, operations, and partnerships, that drives lasting impact.

Through investments in real-time analytics, electrification, sustainable architecture, and behavioural, approaches, iGA is advancing a greener, smarter, and more human-centred airport model. This article outlines our journey and aims to contribute insights to the global aviation community. Realizing sustainable aviation, we believe, requires ambition, collaboration, and persistence, principles to which iGA remains firmly committed.

Governance and the Strategic Energy Framework

iGA Istanbul Airport's decarbonization strategy is guided by an integrated sustainability governance model grounded in ISO 50001-certified energy management. A cross-functional Sustainability Committee, chaired by senior executive leadership, convenes quarterly to align strategic planning with climate objectives. All major investments are subject to lifecycle-based assessments, evaluating energy intensity, mitigation potential, and adaptive capacity.

Real-time energy data informs capital investment and procurement decisions, embedding energy efficiency into broader development strategies. This systemic approach treats sustainability not as an isolated goal but as an integral component of institutional decision- making.

iGA's progress is externally validated. The airport advanced from Level 3 "Optimisation" to Level 4 "Transformation" in the Airport Carbon Accreditation (ACA) programme between 2022 and 2023, reflecting strengthened management of Scope 1 and 2 emissions and increased influence over Scope 3 through stakeholder engagement. Additionally, 2024 CDP ratings—"B" for Climate Change and "A–" for Water Security—demonstrate enhanced performance in risk governance and disclosure.

Integrated Action: Key Measures for Energy Efficiency and Decarbonisation

To advance its energy transition, iGA has implemented a coordinated programme focused on three strategic areas: infrastructure, digital energy systems, and mobility. These integrated efforts reflect current best practices in airport energy management and these initiatives aim to deliver both environmental benefits and operational efficiencies.

- Renewable Energy Deployment: Supported by a €200 million clean energy investment plan, iGA has launched a phased solar photovoltaic (PV) programme to decarbonize its electricity consumption. The initial phase, currently underway, includes rooftop and parking-structure installations, generating over 10 MWh in 2024—covering approximately 20% of annual electricity demand. A large-scale utility solar farm in development is expected to produce 340 GWh annually, enabling full renewable electricity coverage for terminals, auxiliary buildings, and future expansions.
- Digital Optimisation via IoT: With over 3,000 IoT sensors integrated through a LoRaWAN network, iGA monitors energy use in real time across lighting, HVAC, escalators, and security systems. Predictive analytics are employed to manage peak loads and optimize equipment cycles.
- Building Energy Performance Enhancements: Campus-wide retrofits have introduced intelligent LED systems with occupancy and daylight sensors, reducing lighting energy use by 32% compared to 2019. Upgrades in glazing, insulation, and automated blinds have further reduced heating and cooling loads by 18%, enhancing thermal efficiency and indoor comfort.
- Electrification of Ground Operations: iGA currently operates over 100 electric ground vehicles and targets 50% fleet electrification by 2030. Diesel ground power units at contact stands have been replaced with electric alternatives (e-GPUs), contributing to emissions reduction on the airside.

Data-Driven Impact and Emissions Trends

Despite passenger volumes increasing by 34% between 2019 and 2023, iGA achieved a 25.6% reduction in Scope 1 and 2 emissions. This decoupling was made possible through aggressive energy efficiency efforts and renewable energy integration. Annual electricity savings reached 28 GWh, preventing over 12,000 tons of CO_2 emissions.

Carbon accounting is embedded into airport operations which maintains a real-time carbon dashboard and use CDP-aligned reporting protocols. Airport's (A-) score in CDP's Climate Change 2023 assessment underscores transparency and ambition (CDP, 2023).

Resilience, Innovation, and Culture

At iGA, energy efficiency is approached as a dynamic process of organizational learning and adaptive capacity-building, rather than a solely technical objective. Recognizing the critical role of human factors in systemic change, iGA mandates annual climate literacy training and embeds behavioural change approach into internal communications. These initiatives contribute to approximately 8% of total energy savings, highlighting the operational value of employee engagement.

Organizational resilience is further supported by structured protocols and adaptive infrastructure. The Meteorological Emergency Committee (MADKOM) enables anticipatory energy management during extreme weather, marking a shift toward proactive risk governance. Architectural features such as green roofs, automated shading, daylight harvesting, and regenerative transport systems enhance passive energy efficiency and thermal regulation.

In parallel, pilot projects aligned with Türkiye's national smart grid strategy and on-site battery storage integration are underway. These technologies enhance operational flexibility by enabling real-time energy balancing and reducing exposure to grid instability. Together, these behavioural, procedural, and technological measures constitute a holistic model of energy resilience tailored to the complex requirements of large-scale airport operations.

Scaling Sustainability: Partnerships and Ecosystem Engagement

iGA Istanbul Airport plays an active role beyond its core function as an aviation hub, contributing to the development of a broader green ecosystem. In this context, the airport collaborates with national utilities, mobility providers, and academic institutions. Partnerships with Türkiye's leading universities support early-stage ventures focused on energy storage, green hydrogen, and digital twin technologies—key enablers of next-generation airport infrastructure.

The airport shares methodologies and outcomes with peer airports in the region and contributes to international dialogue through platforms such as the ICAO Global Aviation Dialogues. Internally, the Climate Ambassador Program empowers employees to act as sustainability champions, fostering a culture of climate awareness within the organization and the wider aviation sector.

In parallel, efforts continue to explore the synergy between energy efficiency and sustainable mobility. The multimodal ground access strategy prioritizes electric public transport, autonomous shuttle pilots, and low-emission corridors for passengers and staff. These initiatives are designed to reduce Scope 3 emissions and enhance the overall sustainability of the airport journey.

Circularity and Materials Efficiency

At iGA, energy efficiency is conceived within a broader material and resource circularity framework. Terminal and infrastructure upgrades are guided by life-cycle assessment methodologies, prioritising the use of low-embodied-carbon materials and circular construction approaches. This includes increasing integration of recycled aluminium, sustainable concrete substitutes, and modular building components—each selected to minimise environmental footprint while enabling adaptability in future expansions.

In parallel, iGA has initiated waste heat recovery pilots to support auxiliary operations such as pre-conditioned air systems. These systems serve dual purposes: reducing primary energy demand while capturing thermal energy that would otherwise be lost, thereby aligning with SDG 12 (Responsible Consumption and Production).

Water circularity forms a critical dimension of this strategy. A 15,000 m^3/day advanced wastewater treatment facility, supported by reverse osmosis technologies, enabled reclaimed water to supply 27% of the airport's total demand in 2024. Looking forward, a struvite recovery programme aims to recover phosphorous and nitrogen nutrients from aircraft wastewater to meet 20% of the airport's fertiliser needs. This closed-loop approach exemplifies how energy, materials, and water systems can be interwoven into a regenerative airport operations model.

Learnings and Global Recommendations

iGA Istanbul Airport recognises collaboration and knowledge exchange as key enablers of its decarbonisation strategy. Partnerships with institutions such as TÜBİTAK MAM and İTÜ ARI Teknokent support climate risk modelling and the testing of emerging technologies, including green hydrogen and battery storage. Engagement in ICAO's Global Aviation Dialogues and regional platforms enables iGA to contribute to policy development and sectoral learning.

Internally, the Climate Ambassador Programme fosters organisational learning by empowering employees to integrate climate awareness into daily operations. This reflects a broader commitment to aligning technological innovation with cultural and governance transformation.

From this experience, iGA proposes five guiding principles for global stakeholders:

1. Integrate energy into strategic planning — Energy considerations should inform core business and financial decisions.
2. Utilise real-time, actionable data — Tools like digital twins and predictive analytics are essential for adaptive energy management.
3. Balance capital and operational efficiency — Combining infrastructure investment with efficiency gains enhances long-term value.
4. Empower people — Organisational culture plays a critical role in accelerating or hindering climate goals.
5. Collaborate across the value chain — Scope 3 decarbonisation requires coordinated action with external partners.

These principles are iterative and practice-driven. iGA remains committed to refining and sharing its approach to support global net-zero aviation efforts.

Conclusion: From Efficiency to Transformation

iGA Istanbul Airport demonstrates that energy efficiency, when embedded into governance, design, and operations, becomes a powerful lever for sectoral decarbonisation. With a 25.6% reduction in Scope 1 and 2 emissions and a 32% drop in lighting energy consumption, our progress reflects a strategic and systems-oriented approach rather than isolated interventions. These achievements underscore our alignment with ICAO's Long-Term Aspirational Goal (LTAG) and the Sustainable Development Goals, particularly in climate action and infrastructure resilience. As one of the world's leading aviation hubs, we are not only responding to the climate challenge—we are shaping the pathway forward. By combining data- driven optimisation, stakeholder engagement, and long-term vision, iGA continues to advance confidently toward a net-zero future, setting a benchmark for sustainable transformation in global airport operations.

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CHAPTER THIRTEEN

Climate Adaptation & Resilience

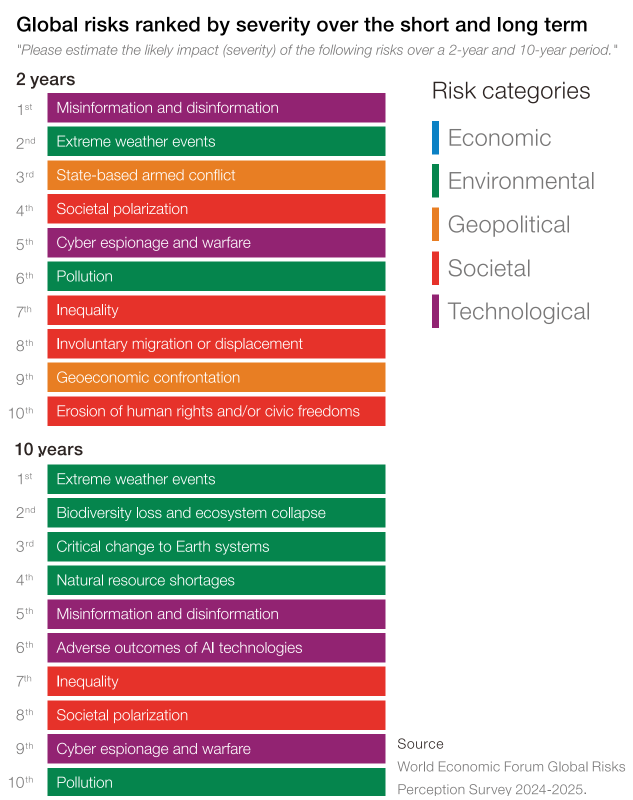
Taking Flight Towards Climate Resilience

ICAO's work towards building adaptation strategies for aviation

By ICAO Secretariat

Introduction

Climate change is reshaping the aviation sector in profound ways. Recent climate events, such as wildfires, flooding and extreme weather, have increased the concerns and urgency of addressing the impacts of climate change on aviation, and the importance for ICAO to take the lead in further assessing the climate change risks to aviation operations and infrastructure, and identifying targeted actions to assist aviation stakeholders in taking practical steps in their operations.



Source
World Economic Forum Global Risks Perception Survey 2024-2025.

Recognizing the urgency of the matter, ICAO has been actively working in supporting Member States, including Small Island Developing States, to enhance climate adaptation and resilience across global aviation infrastructure. This article explores the background, milestones, and ongoing initiatives within ICAO to support Member States, airports, aircraft operators and air navigation service providers (ANSP) across the global aviation network in facing the impacts of a changing climate.

The Growing Need for Adaptation and Resilience

According to the World Economic Forum's "Global Risks Report 2025[1]", extreme weather events are perceived as the second most crucial risk over the next two years and the most crucial risk over the next decade.

These risks are not abstract future threats and rather they are already manifesting across sectors today, with aviation being particularly vulnerable given its reliance on stable weather conditions and extensive infrastructure networks. As climate impacts intensify, airports and aviation systems around the world are experiencing increasingly severe disruptions, requiring urgent attention and adaptation efforts.

1 https://reports.weforum.org/docs/WEF_Global_Risks_Report_2025.pdf

Some examples of these effects of a changing climate already impacting aviation are:

- **Increased intensity of storms**
- **Higher average and extreme temperatures**
- **Sea level rise**
- **Shifting patterns in rain, snow, wind, and storms**
- **Desertification and sand/dust storms**
- **Frequent and persistent droughts and wildfires**

According to the Adaptation Gap Report (AGR) 2024[2] by the United Nations Environment Programme (UNEP), the quality of adaptation planning is improving, but reaching global coverage of national adaptation planning instruments will be difficult. It also states that better capacity-building and technology transfer could accelerate adaptation planning and implementation.

Some countries explicitly included and recognized the importance of airport infrastructures in their National Adaptation Plans (NAPs)[3], which aims to (1) reduce vulnerability to the impacts of climate change, by building adaptive capacity and resilience and (2) to facilitate the integration of climate change adaptation, in a coherent manner, into relevant new and existing policies, programmes and activities, in particular development planning processes and strategies, within all relevant sectors and at different levels, as appropriate.

ICAO's Efforts on Climate Adaptation and Resilience: A Timeline

ICAO continues to expand its efforts on climate adaptation with the delivery of timely and comprehensive guidance materials. Facing the growing need for adaptation and resilience of the aviation network, over the past decade, ICAO has systematically expanded its work on climate adaptation through a series of Assembly Resolutions, technical studies, and practical guidance tools. Building on the 2018 ICAO Climate Adaptation Synthesis Report, the Organization has updated this crucial document over the last three years. The 2024 edition of the Climate Adaptation Synthesis Report highlights the growing concerns of States and aviation stakeholders, underscoring that the number of States and stakeholders experiencing the impacts of climate change has tripled since 2018. This work also emphasizes the increasing challenges of climate adaptation, reinforcing the need for adaptation and resilience measures that complement ongoing mitigation efforts. Detailed information about this important piece of work will be provided in a separate article. The table below summarizes the key milestones and initiatives that illustrate ICAO's growing commitment to building resilience in the aviation sector.

2 https://www.unep.org/resources/adaptation-gap-report-2024
3 https://www.napcentral.org/about-naps

Year	Source	Description
2010	ICAO Environmental Report	Dedicated "Chapter 6 – Adaptation".[4]
2013	ICAO Environmental Report	Dedicated "Chapter 7 – Adaptation".[5]
2013	Resolution A38-18, Paragraph 33	Requested Council (..) *to monitor and disseminate relevant information on the potential impacts of climate change on international aviation operations and related infrastructure, in cooperation with other relevant international organizations and the industry.*
2015	Scoping Study	Examine effects of climate change on air navigation over the North Atlantic.
2016	ICAO Environmental Report	Dedicated "Chapter 7 - Climate Change Adaptation and Resilience".[6]
2016	Resolution A39-2, Paragraph 19	Requested Council (..) *to identify the potential impacts of climate change on international aviation operations and related infrastructure and identify adaptation measures to address the potential climate change impacts, in cooperation with other relevant international organizations and the industry.*
2017	ICAO Seminar on Green Airports	Dedicated "Session 5: Climate Adaptation and Resilience".[7]
2018	Update to Airport Planning Manual, Part 2 (ICAO Doc 9184)	Added new chapters including Chapter 9 on "Climate Change Resilience and Adaptation".
2018	Climate Adaptation Synthesis Report	Synthesize projected climate impacts and stakeholder survey results.
2018	Eco-Airport Toolkit	Provide recommendations and strategies for resilience planning.[8]
2019	ICAO Environmental Report	Dedicated "Chapter 7 Climate Change Adaptation".[9]
2019	ICAO Seminar on Green Airports in cooperation with ACI	Dedicated Session 5: Climate Adaptation and Resilience.[10]
2019	Resolution A40-18, Paragraph 26	Requested Council (..) *to identify the potential impacts of climate change on international aviation operations and related infrastructure, identify adaptation measures to address the potential climate change impacts and develop guidance on climate change risk assessment for international aviation, in cooperation with other relevant international organizations and the industry.*
2022	Climate Risk Assessment Guidance	Step-by-step guide for conducting risk assessments and planning adaptation.[11]
2022	ICAO Environmental Report	Dedicated "Chapter 9 - Climate Change Adaptation & Resilience".[12]
2022	Resolution A41-21, Paragraph 29	Requested Council (..) *to* identify adaptation measures to address the potential climate change impacts and maintain and enhance guidance on climate change risk assessment and adaptation measures for international aviation, in cooperation with other relevant international organizations and the industry.
2024	ICAO Seminar on Green Airports	Dedicated Session 4: Taking Flight Towards Climate Resilience: Building Adaptation Strategies for Airports.[13] Highlighted the urgent need for climate adaptation efforts, complementing ongoing mitigation strategies, so that airports are better prepared to manage the evolving impacts of climate change. This holistic approach to both adaptation and mitigation is vital for building resilient, sustainable airports in the face of changing climate.

4 https://www.icao.int/environmental-protection/Documents/Publications/ENV_Report_2010.pdf
5 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2013/ICAOEnvReport2013.pdf
6 https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf
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13 https://www.icao.int/Meetings/greenairports2024/Documents/ICAO2024GreenAirports_Programme_v12_presentations-final.pdf

Year	Source	Description
2025	Update of Climate Adaptation Synthesis Report	In February 2025, CAEP Working Group 2 (WG2) updated the Climate Adaptation Synthesis Report by compiling the latest information on the projected climate impacts on the aviation sector, and outlining possible adaptation and resilience measures. The updated report highlights the growing concerns of States and other stakeholders, emphasizing that the number experiencing climate change has tripled since 2018. It also underscores the need for adaptation and resilience measures to complement mitigation efforts. The Report will be soon available in ICAO's climate adaptation webpage.[14]
2025	ICAO Environmental Report	Dedicated "Chapter 13 – Climate Adaptation & Resilience".

ICAO's Cooperation with Other Organizations

ICAO collaborates actively with organizations like the United Nations Convention to Combat Desertification (UNCCD) through initiatives such as the UN Sand and Dust Storm Coalition. This coalition improves monitoring, builds expertise, and advances sustainable land management practices to mitigate desertification's impacts on aviation.

Next steps

The evidence is clear: climate change will increasingly affect aviation infrastructure, operations, and economics. ICAO's leadership in supporting adaptation and resilience across the sector is crucial to ensuring that airports and aviation systems can continue to thrive.

Through a combination of outreach activities, guidance development, stakeholder engagement, and international collaboration, ICAO will continue its efforts in supporting aviation stakeholders worldwide to "take flight" towards a more climate-resilient future.

ICAO's further efforts in providing reports and guidance are crucial in supporting States and other stakeholders understand these climate risks and develop adaptation strategies. It is also essential for ICAO to continue encouraging States to incorporate climate adaptation and resilience measures into their long-term strategies and action plans, and to implement them to avoid interruptions and significant damage to infrastructure. This will ensure the sector is ready to manage and adapt to the challenges of changing climate while maintaining operations safe and efficient.

14 https://www.icao.int/environmental-protection/Pages/adaptation.aspx

Climate Adaptation Synthesis Update

By Rachel Burgidge (EUROCONTROL)[1]

Climate change is already affecting weather and climate extremes in all global regions (IPCC, 2021). Global surface temperatures will continue to increase until at least mid-century under all emissions scenarios, which will in turn increase the frequency and intensity of effects such as heat extremes and heavy precipitation. Therefore, while the aviation sector currently operates safely and efficiently in a variety of climates, climate change will pose risks to aviation infrastructure and operations in the future as new climate realities breach the resilience capacity of legacy systems, infrastructure and operations designed for the climate of the past.

To support global aviation stakeholders with identifying the potential impacts of climate change for their organisations and then taking action to adapt and build resilience, during the CAEP/11 cycle the ICAO Committee on Aviation Environmental Protection (CAEP) Airports and Operations Working Group (WG2) produced the ICAO *2018 Climate Adaptation Synthesis Report,* a compilation of information on climate change impacts and adaptation measures for the aviation sector. The Synthesis has become a key resource for ICAO States and aviation organisations to prepare for the impacts of climate change. However, as our knowledge of climate impacts and adaptation measures is constantly evolving it is essential to ensure the content stays current. Therefore, in the CAEP/13 cycle WG2 was tasked with updating the 2018 Synthesis. Experts from more than 20 ICAO Member States and Observer Organisations actively participated in its development during the three-year cycle. This included re-running a version of the CAEP/11 Climate Adaptation Synthesis Report Stakeholder Survey, to see to what extent adaptation action has been taken and whether stakeholder concerns have evolved.

This new edition of the Synthesis, the *2024 ICAO Climate Adaptation Synthesis Report*, provides an updated compilation of existing information on the range of projected climate effects on the aviation sector, and the resulting impacts, to better understand risks to airports, Air Navigation Service Providers (ANSPs), airlines, infrastructure, and other operational factors. The information collected in the report, in combination with climate change scenario projections, will facilitate ICAO Members and Observers, and other relevant aviation stakeholders, in identifying potential effects of climate change which may impact their individual organizations, national aviation sectors and the global aviation network, together with adaptation and resiliency measures that may be beneficial. This is a synthesis of best current information for aviation stakeholders, and not a guidance document.

Updating the Synthesis

The objective of the Climate Adaptation Synthesis is to compile existing information on the range of projected climate impacts for the aviation sector so as to better understand the potential risks to planning, infrastructure, and operations. The working group considered impacts at local, regional, and global levels. It also gathered examples of related adaptation and resiliency efforts and actions that may reduce the risk associated with the impacts of climate change, some of which have already been implemented by States, local authorities, and aviation sector organisations. The science content of the report is based on the findings of the United Nations Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), and supplemented with other peer-reviewed scientific information.

1 Rachel Burbidge is Co-Lead of the climate adaptation work of Working Group 2 of the ICAO Council's Committee on Aviation Environmental Protection (CAEP).

The update of the Synthesis also involved re-running the 2017 stakeholder survey. An updated version of the survey was sent via State Letter with 259 responses received. There was at least one response from every ICAO Region. The survey asked respondents:

- whether they expect their aviation sector or organisation to be impacted by climate change;
- whether they are already experiencing any climate change impacts;
- which climate change impacts they expected to be impacted by;
- whether they were taking any measures to identify adapt to the impacts of climate change, such as a climate change risk assessment or adaptation measures; and
- how prepared do they think the global aviation sector is for the impacts of climate change and what further action might be considered.
- The key findings from the survey are presented later in this article.

Climate Adaptation Synthesis Content

The Synthesis provides a detailed overview of climate change risk and resilience for the global aviation sector. It contains information on eight physical effects of climate change:

- sea level rise
- increased intensity of storms
- changing temperatures
- changing precipitation,
- changing icing conditions
- changing wind
- desertification
- changes to biodiversity

For each of these impacts, the Synthesis describes:

1. what the physical effect is
2. the expected timescales for the effect to occur
3. the potential impacts for the aviation sector
4. potential adaptation and resilience measures to address the impact

The Synthesis also identifies business and economic impacts for the sector such as potential impacts on revenue or evolutions in air traffic demand due to climate change. Additionally, the Synthesis provides a summary of information on carrying out a climate change risk assessment and developing an adaptation plan. Finally, it provides an analysis of survey responses regarding the preparedness of the global aviation sector to deal with the impacts of climate change.

Climate change is already impacting the global aviation sector

One of the key findings of the synthesis was that 73% of survey respondents are already experiencing climate change, and just five respondents (2 percent) indicated that they do not expect to be impacted (Figure 1). This suggests that climate change impacts are a tangible risk for most of the survey respondents.

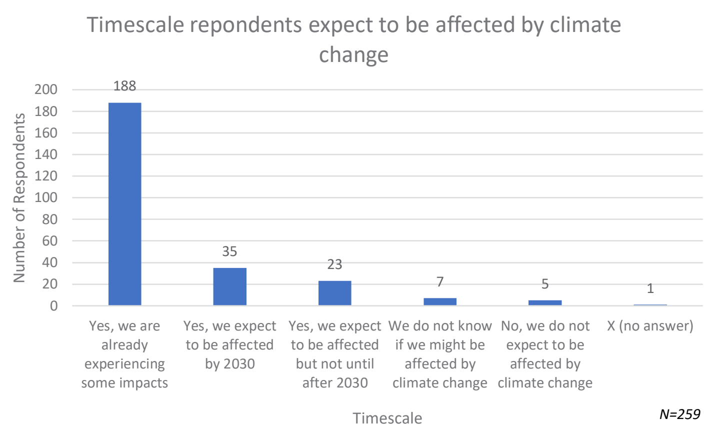

FIGURE 1: Do you expect to be impacted by climate change now or in the future?

Of the nine impact categories included in the survey, the three that survey respondents expect to be most impacted by are:

- **Higher Average and Extreme Temperatures:** 247 of 259 respondents stated they are affected today or expect to be affected in the future by Higher Average and Extreme Temperatures (95 percent). Both average global mean temperatures and extreme high-heat days are expected to increase. The impacts to aviation from higher temperatures are wide-reaching. For example, high heat days can stress cooling systems or damage the airfield surface if temperatures exceed design standards. Higher temperatures can also reduce air density, which can affect aircraft take-off requirements. Additionally, higher temperatures may cause permafrost to thaw in northern regions, destabilizing infrastructure and contributing to erosion.

- **Changing Precipitation:** 238 of 259 respondents stated they are affected today or expect to be affected in the future by Higher Average and Extreme Temperatures (92 percent). Changes in precipitation type (e.g., rain, snow, hail), as well as precipitation frequency, potentially leading to extreme rainfall or prolonged drought are projected. There is considerable variation in precipitation forecasts globally, but the IPCC AR6 WGI report states that climate change is likely to bring a change, and potential exacerbation, of these conditions to all regions. Extreme rainfall may cause flooding of airport surfaces and infrastructure, while drought may lead to reduced water availability.
- **Increased Intensity of Storms:** 209 of 259 respondents stated they are affected today or expect to be affected in the future by Higher Average and Extreme Temperatures (81 percent). The IPCC AR6 Synthesis Report illustrates how, as temperatures increase, the risk of extreme weather events, such as extreme storminess, will also increase. Increased intensity of storms may cause damage to aviation infrastructure and cause delays or cancelations to commercial air service.

Other key effects and their potential impacts include sea-level rise inundating infrastructure, changes in icing conditions leading to changes to de-icing requirements, changes to wind patterns including changes to the Jetstream which could affect flight times, and an increase in en-route turbulence. There may also be an increase in desertification and a resulting increase in sandstorms disrupting operations, an increase in wildlife hazards due to changes to biodiversity and business and economic impacts such as increased costs from delayed and cancelled flights, or changes to tourism demand.

Climate Change Adaptation and Resilience

The Synthesis also looked at what States and organisations can do to reduce the risks from climate change impacts. It found that the most common approach is to carry out a climate change risk assessment and then develop a climate adaptation plan. This process involves determining how the climate might change in the given area, and what impacts this might have on the aviation sector. The next step is identifying appropriate climate adaptation and resilience measures to reduce the consequences of the climate change impacts identified, and developing a climate adaptation plan to set out and prioritize how those measures will be implemented. For example, adaptation and resilience measures could include increasing surface drainage to counterbalance an increase in heavy precipitation, implementing defenses against sea-level rise or relocating infrastructure to higher terrain, increasing terminal cooling capacity, or re-enforcing infrastructure against stronger and more frequent storms. Of course, any decision on what measures to implement, and to what extent, are an individual state or organisation decision. Finally, given that climate may change differently or more quickly than current projections, it is important to review adaptation plans and measures at regular intervals to ensure the information is current. More detailed information can be found in the ICAO Key Steps in Aviation Sector Organisation Climate Change Risk Assessment and Adaptation Planning guidance.[2]

How prepared are we?

The final section of the Synthesis collates information from survey respondents on how prepared they consider the global aviation sector is to deal with the potential impacts of climate change. For example, 150 of the 259 (58%) respondents considered that the sector has some measures in place but that more needs to be done (Figure 2) and 59 respondents (23%) indicated that that they thought the global sector has considered adaptation but has not yet initiated any actions. These results indicate that most respondents believe the aviation sector has started to take action to adapt to climate change, but that more may need to be done.

2 https://www.icao.int/environmental-protection/Pages/Climate-Change-Climate-Risk-Assessment,-Adaptation-and-Resilience.aspx

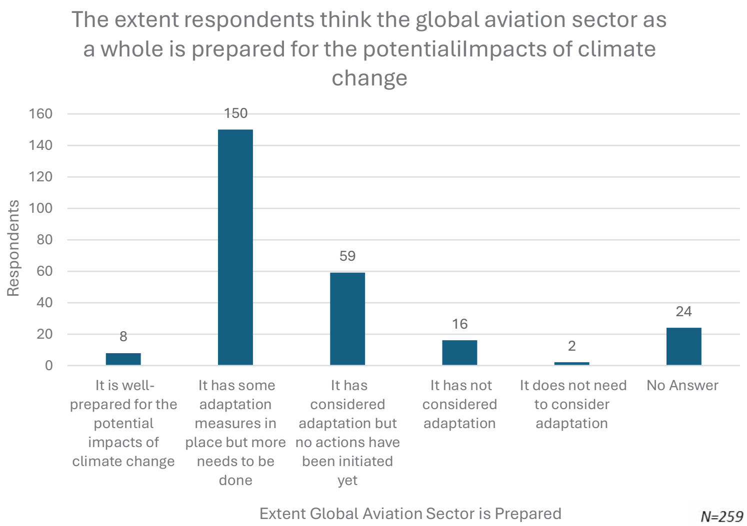

FIGURE 2: Extent to which respondents think the global aviation sector is prepared for the impacts of climate change.

Next Steps

Climate change is a growing global issue. The ICAO CAEP will continue to work on climate adaptation and resilience in the next CAEP cycle, which runs from 2025 to 2028. Of particular note, future work will focus on making information from the Synthesis available more widely, to support the global aviation sector in taking measures to adapt and build resilience to the impacts of climate change. A set of regionally-focused factsheets will also be produced to provide more detailed information at the level of ICAO regions. States and organisations will be able to use this information to support the identification of climate change effects, the potential impacts these effects may have on their aviation sectors and organisations, and to identify potential adaptation and resilience measures to implement to reduce their vulnerability to climate change impacts.

United Nations' WMO initiatives

Early Warnings for All and the Coalition on Combating Sand and Dust Storms

By Greg Brock, Stéphanie Wigniolle, Cyrille Honoré, and Sara Basart (WMO)

The World Meteorological Organization (WMO) is presently spearheading a United Nations Early Warnings for All (EW4All) initiative alongside partner agencies including United Nations Office for Disaster Risk Reduction (UNDRR), the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC).

EW4All aims to ensure universal protection from hazardous hydrometeorological, climatological and related environmental events through lifesaving multihazard early warning systems (MHEWS) by the end of 2027. MHEWS is an integrated system that allows people to know that hazardous weather or climate events are on their way, and informs how governments, communities and individuals can act to minimize impacts.

At the launch of the EW4All initiative in 2022, only half of the countries worldwide reported having adequate MHEWS in place. At the end of 2024, 108 countries reported having strengthened their early warning capabilities, which is an encouragement to further scale-up and accelerate the initiative, supporting countries engagement and leadership.

International civil aviation is currently served by a multitude of observations, forecasts, advisories and warnings that are issued on a local, national and multinational basis by national meteorological and hydrological services and other providers of aeronautical meteorological services. Building the capacity of countries through initiatives such as EW4All, especially least developed countries and small island developing States, will enable these providers to more efficiently and more effectively deliver services to aviation worldwide. This, in turn, will enable aviation to operate more safely, more efficiently, more economically and more environmentally-responsibly.

WMO is committed to continuing to work with ICAO and other industry partners in the operation and further development of aeronautical meteorological services and to assisting aviation in its pursuit to reduce its environmental footprint and to respond to the impacts of climate change through adaptation, mitigation and resilience strategies. In 2024, WMO and ICAO renewed this commitment through an update to their longstanding working arrangements.

United Nations Coalition on Combating Sand and Dust Storms

By Sara Basart (WMO)

Sand and dust storms (SDS) pose significant challenges to aviation safety, causing reduced visibility, damage to aircraft systems, and flight delays or cancellations. In response, in 2027 the United Nations General Assembly established a Coalition on Combating Sand and Dust

Storms (UNCCD)[1], bringing together countries, experts and agencies to strengthen global cooperation, improve early warning systems and reduce the impacts of SDS on critical sectors, including aviation.

Through coordinated research, data sharing and policy development, the coalition aims to protect infrastructure, public health and international transport from the growing threat of sand and dust storms. Several UN agencies contribute to the coalition's efforts, including the WMO and ICAO.

WMO plays a key role in the coalition by leading the development of global early warning systems and providing real-time atmospheric data and forecasts, though its research initiative on SDS, namely the Sand and Dust Storms Warning Advisory and Assessment System (SDS-WAS).[2]

These tools help aviation users anticipate and mitigate SDS-related hazards. ICAO meanwhile contributes to the coalition by integrating SDS risk management into international aviation standards and promoting safety guidelines for airlines and air traffic controllers.

Together, WMO and ICAO are helping to enhance global aviation resilience and support the coalition's mission to reduce the impact of sand and dust storms on air transport and public safety.

1 https://www.unccd.int/news-stories/stories/sand-and-dust-storms-coalition-launched-cop14
2 https://community.wmo.int/en/activity-areas/gaw/science-for-services/sds-was

Climate Change Adaptation Action in Europe

By Rachel Burbidge (EUROCONTROL), Andreas Busa (EASA), and Alexandre de Joybert (ACI Europe)

Key climate effects and impacts for aviation in Europe

Aviation has always been influenced by weather conditions. However, due to climate change, we are now witnessing more frequent and intense climate-related hazards, resulting in greater impact on the sector. Therefore, it is essential to prepare for these impacts to ensure the resilient functioning of the air transport sector in the years ahead.

In Europe, key climate change impacts for the sector include operational disruption and damage to infrastructure due to stronger storms, heat stress for passengers and personnel due to higher average and extreme temperatures and an increase in en-route turbulence. Find out more about effects and impacts in ICAO Secretariat and Climate Adaptation Synthesis Report articles within this Chapter.

Climate adaptation action in Europe

At European level, in 2021 the European Union adopted a 'Strategy on Adaptation to Climate Change' which addresses the need to improve the existing knowledge and management of the uncertainties associated with climate change. This will be followed by a European Climate Change Adaptation Plan, which is currently under development. In parallel, the Corporate Sustainability Reporting Directive (CSRD), which entered into force in 2023, requires companies to disclose their climate adaptation strategies, actions, targets, and risk assessments-including scenario analyses-to demonstrate how they address climate-related risks and ensure resilience.

At aviation sector level, three European organisations, ACI EUROPE, EASA and EUROCONTROL have established two cross-sector working groups which promote collaboration among stakeholders to tackle the increasing impacts of climate change and promote the adaptation action across the sector.

Established in 2022, EUROCONTROL and ACI EUROPE co-chair the European Aviation Climate Change Adaptation Working Group (EACCA-WG). The group currently has 40 member organisations including airport operators, air navigation service providers (ANSPs), aircraft operators, European aviation industry associations, and aircraft manufacturers. The objective of the Working Group is to provide aviation stakeholders with guidance, peer support and good practices on carrying out climate change risk assessments and adapting the European aviation sector to the impacts of climate change. The group has already released three valuable outputs that support action and serve as helpful resources. The first two, "Aviation Preparations for Summer Adverse Weather" and "Aviation Preparations for Winter Adverse Weather," provide tangible recommendations for European aviation organisations to prepare for the possibility of both extreme summer and winter weather events. The third deliverable is a "Briefing on Adapting Aviation to a Changing Climate" which provides information on key effects and impacts for European aviation and an overview of the key steps in climate change risk assessment and adaptation action. The group is currently developing a region-specific guidance material to support them in taking action.

Simultaneously, in 2023, EASA launched the European Network on Impact of Climate Change on Aviation (EN-ICCA) to assess weather hazard trends, their effect on aviation safety and effectiveness of mitigation measures. The EN-ICCA aims to support aviation stakeholders in better understanding and addressing the impacts of climate change on safety. It also seeks to inform the scientific community about priority research topics related to the effects of climate change on aviation and assists EASA and other relevant authorities in managing the consequences of climate change for the aviation sector. Comprising of relevant experts from national competent authorities, the aviation industry, weather and climate scientists, the work plan of the EN-ICCA includes work on future trends of severe convective storms, hail and heavy precipitation and safety concerns resulting from those trends. In addition, trends regarding airborne icing conditions are being investigated and dedicated methodologies for assessing the scientific knowledge on weather hazard trends are being developed. The latter will be a first key deliverable due to be released in 2025. The two groups work closely together, holding regular coordination meetings and sharing key findings. In 2026 the groups plan to have a joint workshop to further increase collaboration and share knowledge and experiences to drive adaptation action across the sector.

Climate change is a present reality, and its impacts are already being felt by the aviation sector around the globe. European aviation stakeholders have started to take action, but with climate-related hazards intensifying and occurring more frequently, much more action is needed to ensure the sector's resilience to future impacts. Moreover, given the interconnectedness of the aviation network, a disruption in one location can have a much wider impact. This challenge cannot be tackled by any single part of the industry alone. Therefore, it's essential that all aviation stakeholders start to take action so as to achieve the highest levels of climate resilience possible and to maintain aviation safety. As an industry we need to work together to manage and minimise the negative outcomes. Proactively taking action now will reduce future damage, costs and disruption for all stakeholders.

Understanding Airport Resilience & Adaptation: Insights from Airport Managers

By Kiran Gowda. K.S and Empati Uday Kumar (CDRI), Vivek Sindhamani and Asmeeta Das Sharma (NACO, a company of Haskoning)

1. Impact of climate risk on Airports

The Intergovernmental Panel on Climate Change (IPCC) has urged governments to prioritize adaptation to mitigate severe climate change effects. 2023 and 2024 saw major extreme rainfall events which disrupted airport surface access, diverted or delayed flights and damaged critical infrastructure, impacting aerodrome operations. The weather patterns are predicted to intensify despite the global net-zero commitments. Latest reports from IPCC have determined that the earth's global average temperature will surpass the 1.5°C target set out in the Paris Agreement regardless any action taken to cut greenhouse gas emissions (GHG). Consequently, it is expected that climate change impacts will increase in frequency and severity around the globe, affecting not just temperatures but causing unpredictable weather events, sea level rise and threats to infrastructure, transport supply chains, communities and the economy.

Airports are critical infrastructures that facilitate the movement of people and goods, making them vital to the global economy. However, they are increasingly vulnerable to extreme weather events, geological hazards and climate change. According to a World Meteorological Organization (WMO) study, climate change is already influencing the weather hazards and extreme events that impact aviation operations[1] These challenges include rising sea levels, extreme temperatures, and extreme precipitation and winds including storms, floods, cyclones, and hurricanes. Such extreme events can cause significant damage to airport infrastructure, disrupt operations, and impact financial stability.

To address these challenges, airports need to adopt climate adaptation and resilience strategies. This involves integrating infrastructure resilience practices to mitigate climate risk considerations into the design, construction, and operation & maintenance of airport infrastructure. By doing so, airports can enhance their ability to withstand and recover from climate-related disasters, ensuring continuity of operations and safety for passengers and staff.

Coalition for Disaster Resilient Infrastructure is conducting a Global Study on Disaster Resilience of Airports (GSDRA) to present the state of the aviation industry's response to climate risk. The phase 1 of the study focused on the airport's perception of resilience and capturing the current state of the industry. The phase 1 report highlights the key impacts of climate risks on airports.

a) Infrastructure Damage

Extreme weather events can cause extensive damage to airport infrastructure, including runways, terminals, and support facilities. This damage can lead to costly repairs and prolonged downtime. The key reasons for this are noted to be:

1 https://library.wmo.int/viewer/69458/download?file=AeM_Series_9_en.pdf&type=pdf&navigator=1

i. Ageing Infrastructure and Assets: Many airports operate with ageing infrastructure that was not designed to withstand current and future climate risks. This makes them particularly vulnerable to damage from extreme weather events. The GSDRA phase 1 report highlights the case of Don Mueang Airport in Bangkok. Don Mueang airport is one of the oldest international airports in the world and the oldest operating airport in Asia. In 2011, it was severely impacted by floods which led to temporary shutdown of the airport's runway. The airport was used as a temporary base for the government's relief efforts, while its runways were closed for several weeks as floodwaters inundated the area. The airport was not operational for 4 months and nearly 1.4 billion baht (52 million USD) were spent to restore it. [2] The airport implemented flood mitigation measures like berms, flood walls and sheet. Additionally, a temporary modular flood barrier system was developed to provide rapid response.

FIGURE 1: Closure due to floods- Don Muang Airport (Bangkok). Source: Thailand floods: Bangkok Don Mueang Airport pictures show extent of crisis | Daily Mail Online[3].

ii. Design and Construction Without Consideration of Climate Risks: Historically, airport design and construction seldom accounted for climate risks, leading to infrastructure that is ill-prepared to manage the impacts of climate change. This lack of preparedness can result in significant damage and operational disruptions. An example is the case of Kansai International Airport in Japan, which was inundated by Typhoon Jebi's storm surge in 2018. The airport had to close one runway for 10 days and a terminal for 17 days, highlighting the need for climate-resilient designs.

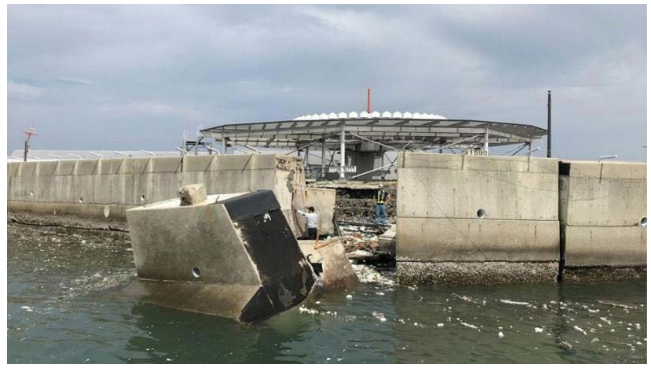

FIGURE 2: Typhoon Jebi's Impact on Kansai International Airport. Source: Improving climate resilience at Kansai International Airport[4].

b) Operational Disruptions

Operational disruptions can be caused by failure of critical infrastructure and/or unfit conditions for operations like low visibility or rain or snowstorms making the airfield unsafe for airside workers. This leads to flight delays, cancellations, and reduced capacity. These disruptions can have cascading effects on the broader transportation network and economy. Delays have a significant financial impact on airlines and airports and also significantly affects their brand image.

c) Impacts on Financial and Business Continuity

The financial impacts of climate-related disruptions can be severe, affecting revenue, increasing operational costs, and potentially leading to long-term financial instability. Additionally, post disaster recovery often comes with a heavy capex for infrastructure repair. Ensuring business continuity in the face of these challenges is critical for the sustainability of airport operations. For Kansai International Airport the estimated economic impact of Typhoon Jebi was around USD 500 million.

2 https://www.bbc.com/news/world-asia-17267833
3 https://www.dailymail.co.uk/news/article-2055644/Thailand-floods-Bangkok-Don-Mueang-Airport-pictures-extent-crisis.html
4 https://www.naco.nl/en/projects/improving-climate-resilience-at-kansai-international-airport

3. Understanding Airport Managers' Perspectives

Airport managers are increasingly aware of the risks posed by climate change. The CDRI GSDRA Phase 1 study, having participation from 111 airports from 54 countries, aimed to understand the state of the industry through the following:

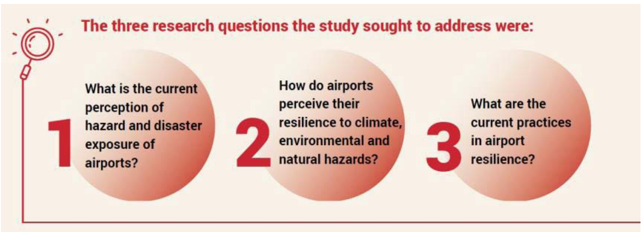

FIGURE 3: Structure of the GSDRA Phase 1 Study.

The study revealed the regional differences in approaches and maturity towards climate resilience across regions, airport sizes and ownership. For instance, airports in high income countries were seen to have conducted frequent risk and vulnerability assessments. This was driven by the access to good data, more resources, and regulatory / management motivation for action. It was also seen that larger airports (30-50 Million Annual Passengers - MAP) had the resources to purchase subscription-based datasets to inform their studies.

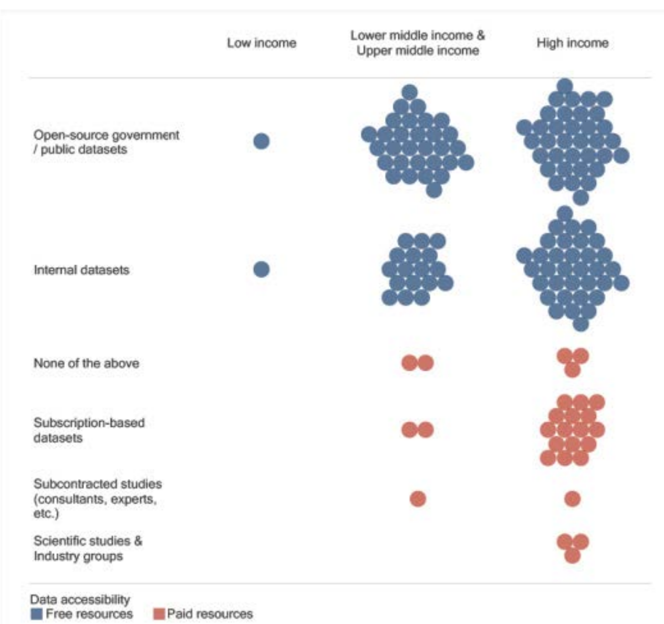

FIGURE 4: Access to data across different economies. Source: GSDRA Phase 1 Report.

Increasing importace of resilience drivers →

Resilience drivers	Africa	Asia-Pacific	Europe	Latin America	Middle East	North America	Total
Results of a Risk Assessment	4th	3rd	1st	2nd	3rd	1st	1st
Executive board / Management	2nd	1st	2nd	3rd	1st	6th	2nd
Government policies	7th	2nd	3rd	1st	1st	2nd	3rd
Human safety	1st	4th	4th	4th	4th	3rd	4th
Inclusion as part of Masterplan	3rd	5th	9th	8th		4th	5th
Insurance of assets	5th	8th	5th			5th	6th
Shareholder interests	6th	7th	7th	5th	4th	6th	7th
Investors	7th	6th	6th	7th		8th	8th
Market trends		9th	8th	6th		9th	9th

FIGURE 5: Climate risk drivers across regions. Source: GSDRA Phase 1 Report.

a) Understanding of Existing Regulations and Policies on Airport Resilience

There is a growing awareness of the importance of regulatory frameworks and policies that support airport resilience. However, the study highlighted that there are gaps in the implementation and enforcement of these regulations, which can hinder resilience efforts. Airports need to work closely with regulatory bodies to ensure that resilience measures are effectively integrated into their operations

b) Organisational challenges in integrating adaptation efforts

Integrating climate adaptation and resilience into an airport organisation and operations presents several challenges. These include limited financial resources, lack of technical expertise and training, and improper communication or coordination with the stakeholders' ecosystem. The study results highlight that airports with sufficient in-house capacity were more effective in mitigating risks. There is a need for in-house capacity building as well as streamlined stakeholder engagements for successful adaptation planning.

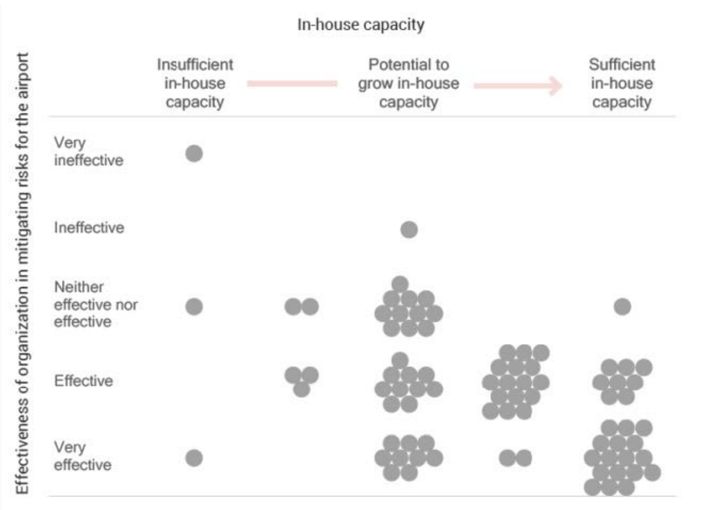

FIGURE 6: Organisations effectiveness vs in-house capacity.

c) Priorities of Airports in the Decision-Making Process

Airport managers prioritize safety, operational efficiency, and financial stability in their decision-making processes. Balancing these priorities with the need for climate resilience requires careful planning and investment. The CDRI Phase 1 study found that airports are increasingly considering resilience as a key factor in their decision-making.

d) Factors Influencing Recovery and Resumption of Operations

The ability of airports to recover and resume operations after a disaster is influenced by several factors, including the availability of emergency response plans, the resilience of critical infrastructure, and the effectiveness of coordination with external agencies. Availability of resources and effective regulatory frameworks for disaster response are also key contributors for early recovery. The CDRI Phase 1 report highlights the importance of having robust recovery plans and the need for regular drills and exercises to ensure preparedness.

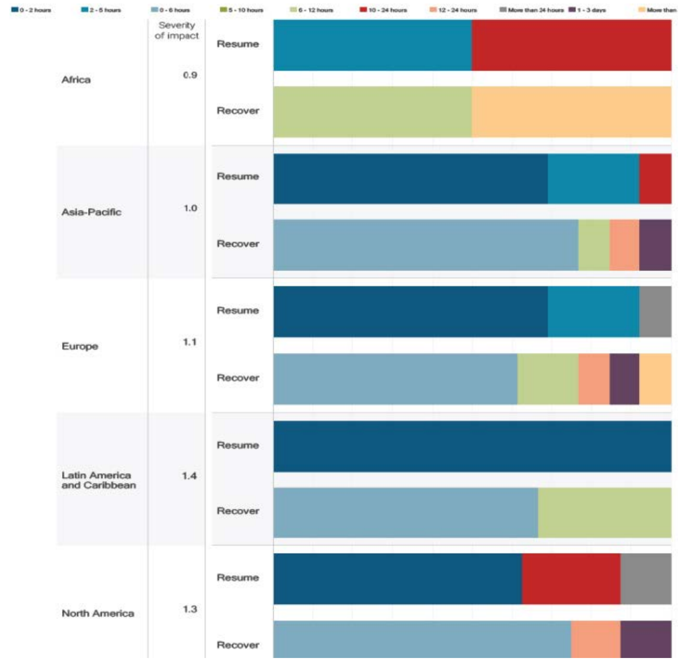

FIGURE 7: Comparison of time taken to resume from flooding.

4. Key Takeaways from GSDRA Phase 1 and Regional Insights

a) Findings from Global Airport Resilience Assessments

The GSDRA Phase 1 study provided valuable insights into the current state of airport resilience globally. Key findings include the need for improved risk assessment practices, the importance of stakeholder collaboration, and the benefits of investing in resilient infrastructure. This validates the ICAO Environmental Report 2022 emphasis on the importance of integrating climate resilience into airport planning and operations.

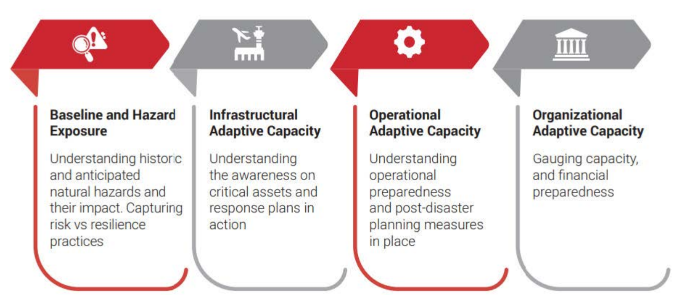

FIGURE 8: Key take-ways from CDRI Phase 1 study.

b) Regional Variations in Risk Perception and Response

The study highlighted significant regional variations in how airports perceive and respond to climate risks. Both the ICAO Environmental Report 2022 and the ACI LAC Survey which focused on understanding the challenges in the Latin American region, also discussed regional differences in climate risk perception and response, noting that airports in Asia-Pacific and Africa face unique challenges due to their geographical and socio-economic contexts

c) What Are 5 Things That Airports Can Do

FIGURE 9: Five Steps towards resilience of airports.

5. Innovative Strategies for Enhancing Airport Resilience

a) Use of Advanced Technologies

Airports are increasingly leveraging advanced technologies to enhance resilience. For example, the use of real-time data analytics and predictive modelling helps in anticipating and mitigating the impacts of extreme weather events. Technologies such as Geographic Information Systems (GIS) and remote sensing are used to monitor and manage climate risks effectively. However, access to reliable datasets remains a challenge which should be addressed by the entire aviation ecosystem collectively, specially through governing bodies.

b) Development of Climate-Resilient Designs

Innovative design approaches are being adopted to make airport infrastructure more resilient to climate change. This includes the use of materials that can withstand extreme temperatures and the construction of elevated runways and terminals to protect against sea-level rise and flooding.

c) Implementation of Green Infrastructure and nature-based design

Green infrastructure solutions, such as green roofs, permeable pavements, and rain gardens, are being implemented for improved management of stormwater and to regulate the urban heat island effect. Nature-based design is also increasingly being adopted as a core concept where the natural elements on the site are preserved and enhanced. This allows for natural drainage of the land and in turn protects the infrastructure which is not designed at vulnerable locations. These solutions not only enhance resilience but also contribute to environmental sustainability.

d) Adoption of Renewable Energy Sources

Airports are increasingly adopting renewable energy sources, such as solar and wind power, to reduce their carbon footprint and enhance energy resilience. This not only helps in mitigating climate change but also ensures a reliable energy supply during extreme weather events. Redundancy in the power system reduces dependence on the central grids and ensures business continuity in times of power outage.

e) Collaboration and Knowledge Sharing

Collaboration and knowledge sharing among airports, governments, and industry stakeholders are crucial for enhancing resilience. Initiatives such as the Global Airport Resilience Network (GARN) facilitate the exchange of best practices and innovative solutions for climate adaptation.

6. Ongoing Work of CDRI on Global Airport Resilience

CDRI Is committed to advocating for infrastructure resilience through its airport infrastructure resilience program.

a) GSDRA Phase-2

The Phase 2 builds on the findings of Phase 1 by conducting detailed assessments of 13 selected airports across 12 countries, each with varying risks and geographies. This phase will focus on exploring disaster risk management practices and financing mechanisms, with a focus on actionable recommendations and credit rating systems to ensure sustainable business continuity.

b) Technical Guidance Notes on Preparedness Measures for Airports with use cases and examples

CDRI is developing technical guidance notes to help airports implement effective preparedness measures. These notes aim to provide asset-level advisory, providing tailored, actionable guidance for specific hazards such as pluvial, fluvial, and tidal flooding. It offers targeted recommendations on structural and non-structural, engineered and operational measures that are easily integrable into Business Continuity Plans to help airport operators enhance resilience and make informed investment decisions across the disaster phases. Complementing the above measures, the team is also working to link them with real-world examples and practical solutions, facilitating implementation and encouraging cross-learning among airport operators and other critical infrastructure sectors

The notes will be validated with industry bodies like ACI through their environmental working group.

c) Simplified Guidance Notes on Risk Assessment and Procurement Frameworks for Airports

To implement the above recommendation and help airport operators with guidance on risk assessment & procurement, simplified guidance notes are being developed to assist airports in conducting risk assessments and developing procurement frameworks that prioritize infrastructure resilience and developing redundancy and business continuity.

CDRI would like to thank all the airports who participated in the GSDRA study, ACI World and the regional chapters and ICAO for their invaluable support for its airport resilience efforts.

Preparing airports for a changing climate

By Daniel Bannister, Lucy Stanbrough, Christopher Au, and Tania Roca (WTW)

As momentum in the aviation industry builds toward increased transparency and more ambitious climate targets, there is growing recognition that resilience is not just an environmental imperative, but a financial one. In an industry with high fixed costs and volatile profitability, having a keen understanding of the short- to long-term financial implications of climate risk is critical for informed decision-making and sustainable growth.

Climate-related disruptions that once seemed unlikely are now occurring with increasing frequency and severity. In truth, many of these events were always possible, but they were often not treated as plausible within traditional risk frameworks. Scientific literature and modelling have long pointed to such hazards, yet assumptions around recurrence and perceived improbability often kept them at the margins of planning. Risk is also not static, and climate change is amplifying the impact of many hazards and increasing the likelihood of disruption.

For the aviation sector, and airports in particular, this presents a growing operational challenge. From extreme heat and intense rainfall to stronger windstorms, these disruptions affect not only flight schedules but also the integrity of infrastructure, safety margins, and broader supply chains. The ripple effects extend far beyond terminals and runways to air traffic control, ground services, and global logistics networks, adding layers of complexity to resilience planning across aviation's physical and operational systems.

Understanding which climate risks are most relevant to each location, and how prepared you are to respond, is essential for strengthening airport resilience. But knowing where to invest and how to adapt requires a grounded understanding of today's risks, and a clear-eyed view of what may lie ahead.

Case study: When the desert floods

Extreme weather isn't just a challenge for storm-prone or tropical regions, it's increasingly disrupting places better known for heat and dryness. One of the most striking recent examples occurred in Dubai in 2024, where a rare and intense rainstorm overwhelmed infrastructure and disrupted operations. The UAE has minimal annual rainfall, typically around 78mm/year (for comparison, the UK's average rainfall is around 1,220mm/year), and rainstorms are rare in the region. When they do occur, they are often intense, and what's concerning is that records related to rainfall intensity that were broken in 2022 were broken again in 2024.

Dubai and the wider region lie within a hyper-arid zone, receiving very little rainfall and experiencing large year-to-year variability. Events like the April 2024 deluge are historically rare, with only short records of similar incidents available. This makes risk assessment inherently uncertain, particularly for events whose intensity and frequency are being amplified by climate change. The El Niño Southern Oscillation (ENSO), a naturally occurring climate phenomenon, has long influenced rainfall variability in the region. However, observational analyses suggest that the recent event was 10–40% more intense than it would have been during an El Niño year in a 1.2°C cooler climate.[1] In other words, human-induced warming made the event significantly more likely and more intense.

1 https://www.worldweatherattribution.org/heavy-precipitation-hitting-vulnerable-communities-in-the-uae-and-oman-becoming-an-increasing-threat-as-the-climate-warms/

A practical framework for navigating climate risk

Events like Dubai's floods serve as a warning that a narrow view of risk, based only on past data, may be insufficient in a changing climate. To better navigate these evolving challenges, applying risk management fundamentals—identifying today's vulnerabilities, quantifying their financial impact, and managing their exposure over time — can provide a practical framework.

This approach and set of challenge questions (Table 1) can support airport operators in integrating climate risk into decision-making across planning, finance, and operations:

TABLE 1: Challenging views of today's extreme risks.

Step	Action	Challenge Questions	Outcome
Identify	Identify, rank and prioritize current and future hazards to your assets	How well do you understand the physical characteristics of your assets and the local conditions that can significantly impact potential damage?	A strategic response to climate risks that protects financial performance, informs planning and disclosure.
Quantify	Assess the financial impact of physical risks and individual assets including your value chain	How are you currently assessing cost-benefit options for adaptation/ risk mitigation for physical climate and geophysical risks?	Prioritisation of investment and mitigation based on robust financial understanding.
Manage	Identify measures to avoid, reduce, transfer or retain risks from physical climate change	What are you doing to protect your organization's financial resilience to growing physical risks?	Targeted resilience-building aligned with broader strategic and operational goals.

Understanding and managing climate risk begins with a rigorous and credible assessment of today's landscape. Over the last year, flights have been grounded by searing heat[2], terminals flooded by unprecedented rainfall[3], and storms have caused damage and delays across increasingly congested skies[4]. While surprising to many, a review of historical records and climate data suggests that these events were always within the realm of possibility. This reinforces the importance of challenging assumptions and considering a wider range of scenarios when assessing risk across both near- and long-term horizons.

Case study: Airport risk index

WTW's Airport Risk Index (ARI)[5] was created as a comprehensive and data-driven framework to challenge assumptions and help operators stress-test a much broader set of severe-but-plausible risks.

Developed in partnership with the University of Cambridge Centre for Risk Studies, ARI captures the extreme disruption potential of 19 major threats across 110 airports worldwide.

WTW has been working with airports to use the insights in ARI to challenge their risk registers. The methodology is based on scenario analysis that assesses the likely scale of disruption airports may face from a range of severe but plausible threats. For each hazard, several levels of severity are modelled to reflect the range of potential operational impacts.

These scenarios help airports understand how often a disruptive event might occur and what it could mean for continuity of service, including temporary closure or loss of critical operations. This encourages a more expansive, evidence-based view of risk exposure.

2 In June 2024, a severe heatwave across the Midwest and Northeast United States led to exceeding 100ºF in many areas, causing significant flight delays and cancellations.
3 In March 2025, Valley International Airport in Harlingen, Texas, was forced to close due to severe flooding caused by a rare and intense storm. The storm brought up to 21 inches of rain, leading to significant flooding that inundated the airport's runways and facilities.
4 In June 2024, an Austrian Airlines Airbus A320 encountered a sudden hailstorm during its approach to Vienna International Airport. The aircraft sustained significant damage, including a shattered nose cone and cracked cockpit windows, due to the hailstones.
5 https://www.wtwco.com/en-gb/insights/2022/11/building-resilience-with-wtws-airport-risk-index

Bridging today's risk to tomorrow's reality

While tools like ARI provide a structured, present-day lens for understanding risk exposure, the changing climate introduces deeper layers of uncertainty. Capturing the full picture requires forward-looking tools that can account for shifting baselines and emerging climate dynamics.

Risk management best practice for airport operations begins with identifying the full range of current and future physical risk hazards. This means drawing on historical records, present-day observations, and forward-looking climate hazard datasets. These hazards include acute events such as extreme rainfall and tropical cyclones, as well as chronic risks like water scarcity and sea level rise.

Once these hazards are identified, their potential impact can be quantified. This can be done using a combination of risk engineering, catastrophe modelling, and climate data. For example, higher daily temperatures are already triggering take-off weight restrictions for aircraft. As these temperatures rise further or occur more frequently, these operational constraints are likely to intensify. Impacts to runways, terminals, and equipment may require additional capital expenditure, while disruption to value chains or ground handling may reduce capacity and productivity, placing pressure on operating margins.

Linking physical hazard information to operational and financial impact is where risk management and business strategy value becomes clearer. Assessing the possible future range of hazards, and how this affects operations and business decisions has become more relevant as the climate baseline continues to shift.

From here, management strategies can be designed. Building on existing risk appetite and tolerance, climate risks can be treated as amplifiers of existing exposures. Ultimately, the financial exposure to these risks will depend on the operational structure and business model of the airport. Some airports may prioritise risk reduction over risk transfer, whilst others may prefer to build additional contingency into operations and embed the financial impact with passengers, cargo, airlines, and the wider value chain.

To effectively assess and act on these evolving risks, airport operators need tools that integrate climate science, business exposure, and time-based foresight. This is where WTW's Climate Quantified platform plays a critical role.

Case study: Climate Quantified

This forward-looking platform supports deeper investigation into questions such as: How will extreme rainfall events shift under a 2°C or 4°C world? Which airport assets are most exposed to future sea-level rise? What does the increasing frequency of heatwaves mean for future take-off performance or cooling system demands? By combining climate models with engineering thresholds and operational data, Climate Quantified allows users to visualise and quantify climate-related losses across time horizons.

Outputs from Climate Quantified are directly aligned to decision-making — whether it's planning capital investments, evaluating long-term insurance strategies, meeting regulatory requirements, or engaging with stakeholders on climate disclosures. For an industry like aviation that must balance long-term infrastructure investments with short-term performance demands, this level of foresight is essential.

Building climate resilience, one layer at a time

As the climate continues to evolve, so too must the way airports assess and prepare for risk. A clearer understanding of present-day vulnerabilities, combined with credible insights into how those vulnerabilities may shift in the future, offers a valuable foundation for long-term planning and resilience. This dual perspective enables aviation stakeholders to consider climate risk in both operational and strategic contexts, supporting a more robust approach to adaptation over time.

The role of co-design in assessing climate risk: case of Bologna Airport

By Carmela De Vivo and Paola Mercogliano (Foundation – Euro-Mediterranean Center on Climate Change -CMCC)

Introduction

Climate change is an urgent global challenge characterized by rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events. These changes pose significant risks to critical infrastructure, particularly in the aviation sector[1,2]. As essential hubs in the global transportation network, airports are highly vulnerable to climate-related disruptions such as flooding, heatwaves and severe storms. These events can impair operations, damage infrastructure, and compromise safety, resulting in significant economic losses and widespread societal impacts. Addressing these challenges requires innovative and reliable climate risk assessment methods that foster active stakeholder engagement. Indeed, traditional risk assessments often fail to capture the full scope of system vulnerabilities, which can only be better understood through collaborative approaches. A co-design methodology ensures, instead, the development of resilient and context-specific adaptation strategies by integrating expert knowledge and localized insights, leading to solutions that are not only scientifically rigorous but also socially and economically sustainable[3]. Considering these aspects, a co-design matrix approach was developed for **Guglielmo Marconi Airport of Bologna** (hereinafter Bologna Airport) as a case study in order to quantify the climate risk. Bologna Airport, located 6 km northwest of the city center, is the seventh busiest in Italy, with more than 10 million passengers in 2024[4]. It is a key hub for national and international flights and an important economic driver for the region, supporting tourism, manufacturing, and logistics. The risk analysis involved identifying climate hazards and their evolution under different concentration scenarios using high-resolution climate data. Exposed elements were then defined, and their vulnerability was assessed through targeted questionnaires distributed to key airport stakeholders. By integrating hazard (H), exposure (E), and vulnerability (V) data, a risk matrix was created for each identified hazard (*Figure 1*). This matrix enabled a comprehensive assessment of climate risks affecting the airport system and predicting their evolution over time.

Key aspects of methodology

The first step of the risk analysis involved assessing the current and future **climate hazard** using several climate indicators based on return period (50 and 100 years return periods), identified through consultations with stakeholders. These return periods are commonly used for designing,

1 De Vivo, C.; Barbato, G.; Ellena, M.; Capozzi, V.; Budillon, G.; Mercogliano, (2023) P. Climate-Risk Assessment Framework for Airports under Extreme Precipitation Events: Application to Selected Italian Case Studies. Sustainability 2023, 15, 7300. https://doi.org/10.3390/su15097300

2 De Vivo, C., Ellena, M., Capozzi, V. et al. Risk assessment framework for Mediterranean airports: a focus on extreme temperatures and precipitations and sea level rise. Nat Hazards (2021). https://doi.org/10.1007/s11069-021-05066-0

3 Fleming, A., Bohensky, E., Dutra, L.X.C., Lin, B.B., Melbourne-Thomas, J., Moore, T., Vertigan, C., 2023. Perceptions of co-design, co-development and co-delivery (Co- 3D) as part of the co-production process–Insights for climate services. Clim. Serv. 30, 100364.

4 https://www.bologna-airport.it/benvenuto-all-aeroporto-di-bologna/?idC=62175

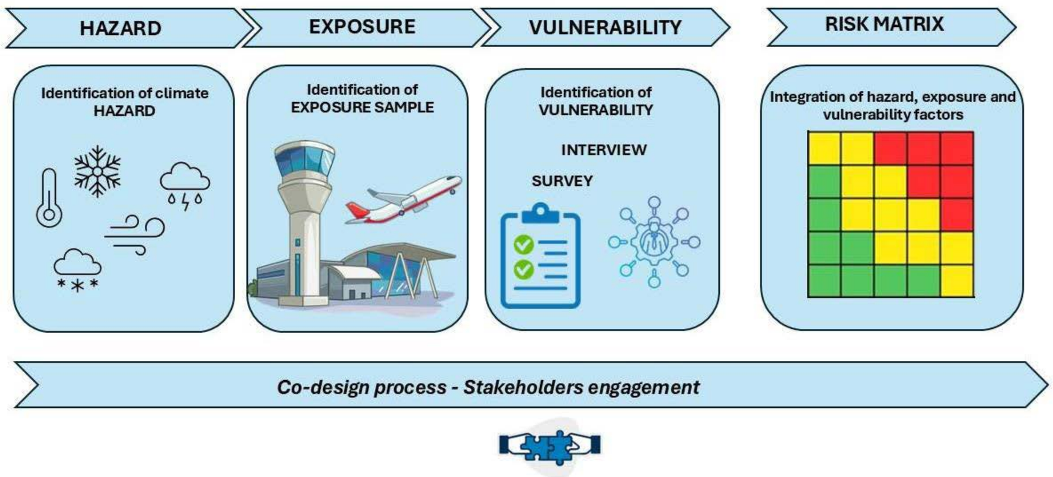

FIGURE 1: Matrix based co-design approach (adjusted from De Vivo et al. 2024).

maintaining, and adapting infrastructure to anticipated climate change impacts[5]. These climate indicators are considered representative of climate hazards that have contributed to, and may potentially cause, future losses and damages at the airport — such as an increase in extreme heat and cold events, heavy precipitation, and strong wind occurrences. The climate indicators were assessed for the reference climate period 1981-2010 using the E-OBS dataset[6], while the climate variations were evaluated by comparing the values of these indicators in the future period 2036-2065 with those of the reference period 1981-2010 using the ensemble of high-resolution climate models provided by the EURO-CORDEX[7] initiative under the three Intergovernmental Panel on Climate Change (IPCC) scenarios[8] – RCP8.5, RCP4.5 and RCP2.6. The use of indicators based on return time periods allowed to define the probability of occurrence for selected climate events and categorize them into specific classes: "Very Low" (≥100 years), "Low" (100 > TR ≥50 years), "Medium" (50 > TR ≥20 years), "High" (20 > TR ≥10 years), and "Very High" (10 > TR ≥2 years).

The second step of the risk analysis involved the **exposure assessment** through the active involvement of airport managers. This collaborative method helped to identify the most climate-vulnerable elements of the airport system, drawing on the direct experience of managers. Based on a thorough review of recent scientific literature[9] and extensive discussions with key stakeholders, the exposed elements were categorized into three main groups:

- **Airside:** includes the elements used for aircraft movement, such as runways, taxiways, control towers and aprons;
- **Landside:** refers to public access areas such as offices, terminals, airport access systems and parking areas;
- **Airport information systems** (Airport IT infrastructures): include all information systems responsible for the correct management and operation of airport services (both those relating to the airside and landside components).

5 Rianna, G., Reder, A., Sousa, M.L., Dimova, S., 2023. Harmonised procedure to update thermal loads in the Eurocodes. Case study for Italy. Climate Services 30, 100391. https://doi.org/10.1016/j.cliser.2023.100391)

6 Cornes, R., van der Schrier, G., van den Besselaar, Jones, P.D., 2018. An Ensemble Version of E-OBS Temperature and Precipitation Datasets. J. Geophys. Res. Atmos. 123. https://doi.org/10.1029/2017JD028200;

7 Jacob, D., Teichmann, C., Sobolowski, S., Katragkou, E., Anders, I., Beldaet, M., et al., 2020. Regional climate downscaling over Europe: perspectives from the EURO- CORDEX community. Regional Environmental Change 20 (51), 1–20. https://doi. org/10.1007/s10113-020-01606-9.

8 Representative Concentration Pathways (RCPs) are climate scenarios consistent with a wide range of possible changes in future anthropogenic greenhouse gas emissions, and aim to represent their atmospheric concentrations. They are subdivided into RCP2.6 (Aggressive Mitigation Scenario), RCP4.5 (Strong Mitigation Scenario), RCP6.0, and RCP8.5 (High Emission Scenario).

9 De Vivo, C., Ellena, M., Barbato, G., Pugliese, A., Marinucci, F., Barilli, T., & Mercogliano, P. (2025). A co-design matrix-based approach to evaluate the climate risks for airports: A case study of Bologna airport. *Climate Services*, *37*, 100536.

The third step was the **vulnerability assessment**, as the predisposition of the system to suffer the negative effects of climate change. Also in this phase, the main stakeholders of the two airports were actively involved, promoting an inclusive and participatory approach. Two specific questionnaires were distributed to identify the vulnerability characteristics of the exposed elements. The first questionnaire allowed to evaluate the severity of the impact of each element in relation to the climate hazards considered (e.g., assessing the potential impact of heat waves on runway performance). The second questionnaire collected information on the intrinsic characteristics of the exposed elements that influence their susceptibility to impacts of climate change (e.g. the level of maintenance of the exposed elements, the presence of materials resistant to extreme temperatures, preventive measures for addressing climate change impacts as well as the drainage capacity of the systems etc.). Once the answers to the two questionnaires had been processed, an integrated vulnerability matrix was built, which allowed to classify the exposed elements into four vulnerability categories for each climate hazard (low, medium, high, very high).

The **climate risk matrix** was developed by integrating hazard, exposure and vulnerability data. Specifically, the matrix results from the multiplication of the probability of occurrence values (hazard) and the vulnerability characteristics evaluations of the exposure samples. The resulting risk value were categorized into four risk levels: low, medium, high and very high (Table 1).

Principle results

For confidentiality reasons, only the extreme heat events results are presented, using the runway as an exposed sample. The results show that the final risk is strongly influenced by the variations of the hazards in different scenarios (RCP 2.6, RCP 4.5 and RCP8.5) and by the vulnerability characteristics identified by the questionnaires. Specifically, the "Runway" shows a "Low" risk for the RCP2.6 scenario and "High" risk level in the RCP4.5 and RCP8.5 scenarios, considering events with a return period of 50 years. Analyses highlighted that the adoption of a mitigation scenario (RCP 2.6) can lead to a substantial decrease in climate risk in the area compared to stabilization scenarios with higher concentrations (such as RCP 4.5), and compared to the scenario with high emissions and no mitigation strategy (RCP 8.5). These results helps airport stakeholders identify the areas of high climate risk that could compromise airport infrastructure. Therefore, their involvement in the planning and design of protective measures is crucial. Future adaptation strategies should prioritize the most vulnerable assets while also addressing lower-risk areas to ensure overall resilience. Specifically, to mitigate the risks due to extreme temperature events, integrating heat-resistant materials and updating design standards is essential. Innovative solutions, such as hybrid mineral fillers (HMF)[10] in asphalt and perimeter irrigation[11], can reduce surface temperatures and improve structural durability. Specifically, HMF increases emissivity, enhances rutting resistance, and improves thermal conductivity, reducing surface temperatures by up to 5.4 °C.

TABLE 1: Risk matrix to evaluate the Climate Risk levels for Airport Assets.

RISK MATRIX				
HAZARD Probability of occurrence	**VULNERABILITY OF EXPOSURE SAMPLES**			
	Low (1)	**Medium (2)**	**High (3)**	**Very high (4)**
Very low (1)	**Low (1)**	**Low (2)**	**Low (3)**	**Low (4)**
Low (2)	**Low (2)**	**Low (4)**	**Medium (6)**	**Medium (8)**
Medium (3)	**Low (3)**	**Medium (6)**	**Medium (9)**	**High (12)**
High (4)	**Low (4)**	**Medium (8)**	**High (12)**	**Very high (16)**
Very high (5)	**Medium (5)**	**High (10)**	**Very high (15)**	**Very high (20)**

10 Kong, L., Xu, L., Du, Y., Jin, J., Loprencipe, G., Moretti, L., 2022. Use of Hybrid Mineral Filler with High Emissivity in Asphalt Mixture for Cooling Road Pavements. Materials 16 (1), 175.
11 Qian, J., Miao, S., Tapper, N., Xie, J., Ingleton, G., 2020. Investigation on airport landscape cooling associated with irrigation: A case study of Adelaide airport, Australia. Sustainability 12 (19), 8123. https://doi.org/10.3390/su12198123.

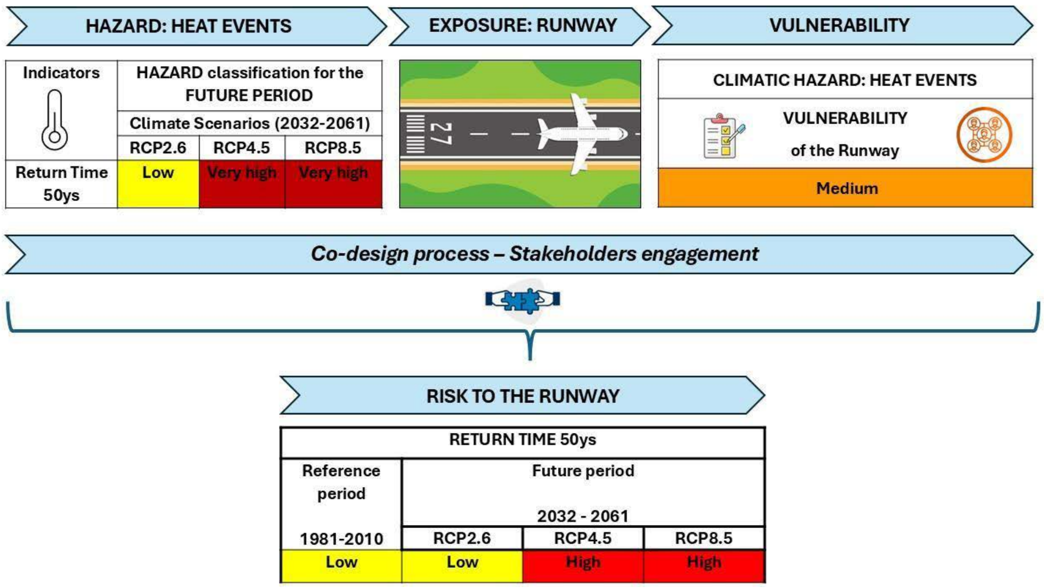

FIGURE 2: Interaction of hazard, exposure and vulnerability results to define climate risks for runways (adjusted from De Vivo et al. 2024).

Integrating climate resilience into airport infrastructure and operations will be key to addressing future challenges and ensuring the safety and efficiency of the airport system.

Conclusion

The matrix based co-design approach has emerged as a robust, scalable and highly adaptable method for evaluating climate risks to airport infrastructure. The active involvement of stakeholders during all the phases of the activity has provided critical, context-specific valuable insights. This has ensured that the risk matrices are not only scientifically sound, but also deeply rooted in the real-world conditions considering the vulnerabilities of the infrastructure. This participatory and interacting approach enhances the credibility, relevance, and practical usability of the results, supporting their seamless integration into existing decision-making and planning processes. By offering a structured yet flexible framework, this approach effectively addresses the inherent complexity of climate risk, accommodating various greenhouse gas concentration pathways and return time periods of climate events. Its versatility is particularly evaluable in responding to the variation of the climate hazards, and infrastructure vulnerabilities. A key strength of the approach lies in its capacity for dynamic updating: the matrices can be refined over time as new data becomes available, or when local factors (e.g. social/economical) change risk analysis. This enables a continuous dynamical process and fosters long-term strategic planning for adaptation. Moreover, its innovative and adaptable nature promises to enhance resilience planning for airport infrastructure, offering valuable insights for similar applications in other critical sectors facing climate challenges. Currently, the risk assessment framework is being generalized to support its application in a broader range of contexts. To this end, dedicated digital interfaces (e.g., www.dataclime.com) are being developed to streamline data collection, integration, and sharing, thus facilitating a more agile transfer of knowledge to end-users. These developments pave the way for a new generation of decision-support tools that bridge the gap between climate science and action.

This work opens up promising avenues for further research and collaboration, particularly in exploring the co-evolution of infrastructure adaptation and climate services. It invites the scientific and operational communities to co-develop next-generation frameworks that are not only technically rigorous, but also deeply embedded in stakeholder realities and decision contexts.

CHAPTER FOURTEEN

Towards a circular economy

Advancing Circular Economy Practices in Aviation

By ICAO Secretariat

Introduction

As global aviation continues to evolve, the industry faces increasing pressure to mitigate its environmental impacts. Traditionally, many sectors, including aviation, have operated within a linear economy, a system in which resources are extracted, used to produce goods, and ultimately discarded before their full value is realized. In such a model, the lifecycle of a product typically ends with its disposal. However, with growing resource scarcity and an urgent need to mitigate environmental impacts, the linear economy is proving unsustainable.

In response, the circular economy presents an alternative approach by emphasizing waste reduction, material reuse, and maximizing resource value before disposal. Although the concept of a circular economy first emerged as an economic model over 30 years ago[1], its application within the aviation industry is still evolving. By rethinking the design, operation, and retirement of aircraft, as well as waste management at the airport or by the airlines, the aviation sector can leverage a circular economy to reduce its environmental footprint, enhance efficiency and lower costs.

Understanding the Circular Economy

A circular economy is essentially a system designed to preserve the value of materials and resources for as long as possible. In contrast to the linear economy, which follows a "take, make, waste" model of production and consumption, the circular economy prioritizes resource efficiency, waste reduction, and environmental regeneration.

According to the Ellen MacArthur Foundation[2], the framework of a circular economy is built upon three key pillars: waste reduction, the circulation of products and materials, and the regeneration of natural systems.

FIGURE 1: The Circular Economy Model (source: European Parliament Research Service)

1 Rizos et al., "The Circular Economy: A Review of Definitions, Processes and Impacts."

FIGURE 2: SDGs Related to the Circular Economy Model

First, waste can be reframed not as an inevitable byproduct of production, but as a design flaw. Transitioning to a circular system requires that goods, materials, and infrastructure be designed for durability. By intentionally focusing on longevity during product design, industries can eliminate unnecessary waste at its source, thereby reducing their environmental footprint.

Second, the circular economy emphasizes keeping materials and products in circulation for as long as possible. This approach extends the lifecycle of products through practices such as repair, refurbishment, remanufacturing and recycling. The goal is to maximize the use of finite resources, reducing reliance on virgin materials and minimizing energy-intensive processes involved in production.

The third pillar of a circular economy is the regeneration of natural systems. This goes beyond merely reducing waste by focusing on restoring and renewing natural environments, rather than viewing nature solely as a resource to be extracted. Adopting a regenerative approach allows us to replicate the natural process where waste does not exist, such as in composting, which returns biological materials to the earth.

The concept of a circular economy does not only exist within a theoretical framework. Several countries have begun incorporating circularity into their national policies. For instance, the Dutch government as outlined its objectives in the 2023–2050 National Circular Economy Programme, which emphasizes reducing raw material consumption, extending the lifespan of products and parts, and minimizing waste through advanced processing methods[3]. The Netherlands aims to achieve a waste-free economy by 2050. Similarly, Chile published a long-term circular economy roadmap in 2021, which includes goals such as creating green jobs, recovering illegal dumping sites, and increasing material productivity. This comprehensive plan integrates both upstream and downstream activities to build an efficient and actionable path toward circularity[4].

Importantly, applying circular economy principles is aligned with several United Nations Sustainable Development Goals (SDGs), namely those focused on responsible consumption and production (SDG12), climate action (SDG13), and industry innovation (SDG9). By keeping materials in use longer and reducing waste, circular strategies help mitigate environmental impacts while fostering a more sustainable economy.

Circular Economy in Aviation

Aviation is a resource-intensive industry, from reliance on high-value materials in aircraft manufacturing to the significant energy demands for global airport operations. Adopting circularity in aviation presents a strategic opportunity to reduce material dependency, extend the life cycle of inputs, and recover value from end-of-life assets.

While achieving full circularity in aviation is still a long-term goal, circular economy strategies are beginning to take hold across the industry. From the design, maintenance, and retirement of aircraft, waste management onboard by airlines, to resource management, waste reduction, and infrastructure reuse at airports, circularity is reshaping the aviation ecosystem. These strategies not only aim to reduce the sector's environmental footprint but also enhance efficiency, resilience, and long-term value recovery.

The aviation industry is set for significant growth in the coming years. According to ACI and ICAO, global air passenger traffic is forecast to surpass 12 billion by 2030. In 2024, revenue passenger kilometers (RPK) reached about $8.8 trillion, representing a 101% increase since 2019[5]. Additionally, Airbus forecasts that global air traffic with more than double (2.4) over the next 20 years[6]. This rapid growth underscores the need to implement circularity in aviation, as increased demand translates to higher resource use, waste, and emissions. By integrating circular economy principles, aviation can guide its growth toward more sustainable and efficient development.

These principles can be applied to both aircraft management, operators, and airport operations, setting the foundation for more circularity in aviation.

Regarding aircraft, maintenance, reuse, and recycling is a key strategy for promoting circularity and addressing the end-of-life of the aircraft after flying. For example, retired aircraft can be disassembled, with valuable materials such as aluminum and titanium recovered for reuse.

This approach not only supports environmental goals but is also more cost-effective. Advances in aircraft disassembly now allow for nearly 80% of components to be recycled, with over 90% of an aircraft's weight reused or repurposed. Approximately 40-50% of aircraft materials are reused for maintenance, while the remaining components are reintroduced into the supply chain as raw materials[7].

Airbus and Boeing were both early pioneers in aircraft recycling. Airbus launched the Process for Advanced Management of End-of-Life Aircraft (PAMELA) project in 2005, to encourage safe and sustainable aircraft decommissioning. In 2006, Boeing founded the Aircraft Fleet Recycling Association (AFRA) to establish standards for environmentally responsible end-of-life aircraft management. Over the past decade, several other companies have continued to innovate in this area. For example, in 2013, Southwest Airlines, in partnership with various non-profits, launched the "Repurpose with Purpose" initiative, which involves removing leather seat covers from retired planes and donating them to be upcycled into new products[8].

Recycling and upcycling in aviation are not limited to aircraft alone. In June 2023, Emirates introduced a closed-loop recycling initiative[9], where damaged plastic trays, bowls, and dishes collected from their cabins are processed and remanufactured into new in-flight meal service items. This initiative further demonstrates how circular practices can be applied across different aspects of aviation operations.

Circular economy principles must also be applied on the ground, as airports play a critical role in promoting circularity within aviation and can benefit significantly from doing so.

For example, in December 2021, Aeroporti di Roma unveiled its PIONEER[10] project, co-funded by the European Union, aimed at increasing sustainability at Rome Fiumicino International Airport. The project implements a system that uses second-life batteries from the automotive sector to store excess energy generated by a 30 MW solar photovoltaic plant. The energy collected during the day is then used to meet the airport's electricity needs during high-demand evening hours. By incorporating a renewable energy storage solution, the initiative provides greater flexibility and reduces dependence on fossil fuels. Notably, PIONEER is the first project globally to use second-life batteries from multiple original equipment manufacturers at this scale. It serves as a strong example of circularity by giving electric vehicle batteries a second life after completing their initial use cycle.

Improving waste management is another important aspect of implementing circularity at airports. San Diego International Airport has taken significant steps through its Zero Waste initiative, which aims to achieve a 90% waste diversion rate and a 10% reduction in waste per passenger by 2035[11]. Key measures include composting organic waste, digitizing communications to reduce paper use, switching to reusable dishware, and implementing xeriscaping (using drought-tolerant native plants to minimize water consumption).

Plastic pollution also poses a significant challenge within waste management. In aviation and hospitality, plastics are favoured for being lightweight and hygienic, but over a third of plastic products are used once in these industries. Producing plastics relies on petroleum, and they are non-biodegradable, creating environmental issues throughout their entire life cycle. While seeking alternatives to plastic is useful, this can also introduce new complexities. Therefore, proper waste management of single use plastics (SUPs) is essential, and applying circular economy principles such as reducing use, designing for reuse, improving recycling processes and using more recycled materials, offers an environmentally responsible approach.

Airports are increasingly adopting sustainable practices to manage plastic waste. For instance, Colombia's El Dorado International Airport is advancing a Circular Economy Plan to reduce the use of virgin raw materials and increase reuse through their waste management process. Currently, 65% of its waste is revalued, with a goal of 70% by the end of 2025. By 2023, 78% of terminal waste was reused, and in 2022, the addition of 65 water refill stations helped avoid the use of over 1.7 million single-use plastic bottles that year alone.

Challenges and Support for Circular Economy in Aviation

While the integration of circularity in aviation has made significant progress in recent years, its implementation still faces notable limitations. A major component of circularity in aviation involves recycling retired aircraft, but this process encounters several challenges. For example, separating materials manually versus mechanically often involves a trade-off between quality and cost, making efficient recycling difficult. In addition, the presence of hazardous materials in aircraft further complicates safe disposal and recycling processes. Furthermore, recycling avionics, electronics, and advanced alloys like aluminum-lithium (Al-Li) and composites remain technically challenging.

Beyond material-specific issues, it is difficult to accurately assess the full scale of waste produced by the aviation industry, and some stakeholders may lack access to the advanced technologies and solutions necessary to implement circular economy practices effectively. To overcome these barriers, partnerships and support programs are essential, offering technical, financial, and political assistance, particularly to States most in need, to evaluate and implement circular economy initiatives at the local level.

In alignment with its *No Country Left Behind* initiative, ICAO has been actively raising awareness about circular economy practices in aviation. For example, ICAO organized the Seminar on Green Airports, held from 18–19 April 2024 in Athens, Greece. The Seminar included discussions on circular economy within aviation, alongside topics such as deployment and distribution of SAF, LCAF and other aviation cleaner energies at airports, financing environmental projects and mitigation measures, partnerships for a sustainable future, and adaptation measures to enhance the climate resilience of airports.

Furthermore, ICAO has provided practical guidance through the Eco-Airport Toolkit e-publication on Waste Management at Airports and the Toolkit on Single Use Plastics both of which support the implementation of circular economy practices in aviation. The Toolkit e-collection offers accessible information to aid in the development of airport infrastructure projects and environmental planning. Specifically, the waste management section outlines a three-step approach: 1) analyzing material flows; 2) identifying areas for improvement; and 3) implementing circular business models. These steps contribute to building a global platform for sharing the most effective and up-to-date technologies and applications of circular economy practices across the aviation industry. Meanwhile, the SUP publication outlines key considerations for addressing the prominent use of SUPs in aviation and provides guidance on how to reduce, manage and transition away from SUPs supported by best practice examples from the sector.

[1] Rizos et al., "The Circular Economy: A Review of Definitions, Processes and Impacts."
[2] "Circular Economy Principles." Ellen MacArthur Foundation
[3] Ministerie van Infrastructuur en Waterstaat, "Circular Dutch Economy by 2050."
[4] Ministerio del Medio Ambiente, "ROADMAP FOR a CIRCULAR CHILE BY 2040."
[5] Li, "Joint ACI World-ICAO Passenger Traffic Report, Trends, and Outlook | ACI World."
[6] "2024 Global Market Forecast," Airbus
[7] Brown, "Circularity in Flight."
[8] "Repurpose With Purpose | Southwest Airlines."
[9] Emirates, "Emirates Unveils New Closed Loop Recycling Initiative to Reduce Plastic," April 3, 2024
[10] "Pioneer Project - AEROPORTI DI ROMA - Aeroporti Di Roma."
[11] "Zero Waste Case Study: San Diego International Airport (Detailed) | US EPA," US EPA, April 14, 2025

Transitioning towards a circular economy

By International Aerospace Environmental Group (IAEG)

Overview and Importance of Circular Economy

A circular economy is an economic system that aims to minimise waste and maximise the use of resources, which contrasts with the «take-make-waste» production model of the traditional linear economy. In a circular economy, emphasis is placed on maintaining the circulation of products, materials, and resources and their highest value in the economy for as long as possible, and minimising waste and pollution through design, maintenance, repair, reuse, refurbishment, remanufacturing, and recycling.

These core principles can be very impactful for the aviation sector, which deals with durable goods made of high value materials and is subject to strict safety regulations. Transitioning towards a circular economy is crucial for addressing global sustainability challenges, in the context of resource-intensive industries like aeronautics.

Evolution of the Regulatory Landscape

The global relevance of circular economy is reflected in the increasing number of country and region-specific regulations aimed at ensuring supply security, reducing environmental footprint and advancing towards sustainability commitments. While the European Union adopts a regional approach, most regulations remain country or state specific. Many countries and regions have published general frameworks, roadmaps, and plans that are not industry specific. Key focus areas include material traceability, resource efficiency (e.g. waste reduction and recycling), extended producer responsibility, eco-design, and the introduction of key performance indicators. For instance, the European Sustainable Product Regulation (ESPR) emphasises traceability through digital product passports.

As regulations shift from waste management and recycling to extended producer responsibility and eco-design, there is an increased demand for data gathering and transparency. The international ISO 59000 series of standards on circular economy have been published, aiming to guide organisations to transition from a linear to a circular economy, thereby promoting sustainability and resource efficiency.

Future regulations may become more industry-specific, with concrete product demands such as digital product passports. However, a global and coherent framework on circular economy would mitigate the trend of over-regulation and simplify compliance for aerospace companies facing fragmented and specific regulations.

What Circular Economy Means for Aviation, Why It Matters, Current Status, and Perspectives of the Industry

Transitioning toward a more circular model will enhance the aviation industry's resilience amid supply chain challenges and resource shortages.

Unlike a linear economy, where resources are extracted, used, and disposed of, a circular economy maximises the value of existing materials, reducing reliance on newly extracted raw materials. This shift requires lifecycle thinking—from design and manufacturing to operation and end-of-life management—focusing on recycling aerospace-grade parts from decommissioned aircraft and manufacturing scrap. By using renewably sourced feedstocks, the aviation industry can globally lower its material costs while minimising the long-term need for mining and refining.

The shift toward circular economy principles also helps address supply chain challenges, particularly the sourcing of critical materials like titanium, rare earth elements. Geopolitical risks and increased competition for these limited resources make circular approaches necessary. The aviation sector can reduce dependency on scarce materials but transitioning to new materials requires retesting, recertification and quality assessments to meet safety standards and performance specifications.

Although there is not yet an industry roadmap associated with circular economy, some of its principles are well embedded in current practices of commercial aviation. Aircraft are long-lasting products, designed for more than twenty-five years and operated for more than twenty on average. Buy-to-fly ratios[1] are continuously optimised during design and manufacturing to reduce the generation of scraps[2]. The recycling of manufacturing scraps is developed for critical metals and partially for composites, and the reuse of spare parts is a key contributor to the business model and a growing market (projected to double by 2032 to reach up to USD 93.5 billion[3]). Recovery rates at the end-of-service can go beyond 90%[4] for aircraft types currently being retired, which have a high proportion of metals in their structure. However, most materials, including high-value aeronautical grade metals, are downcycled and routed to other industries.

Existing industry efforts such as the Maintenance, Repair, and Overhaul (MRO) and the spares market can be leveraged today to advance circular economy in aviation. MRO providers extend the lifecycle of aircraft and components reducing the need for new materials, while the spares market offers refurbished parts that ease sourcing difficulties. Expanding MRO services supports a circular approach by increasing resource efficiency, enhancing supply chain resilience, and ensuring critical parts stay in circulation for longer. Pursuing efforts in eco-design is also crucial, building on the lessons learned from aircraft end-of-service treatment to ease disassembly, dismantling and recycling.

Many developing areas could further drive the sector's transition, making it more resilient and profitable: digitalisation, additive manufacturing, and modelling support circular economy practices by improving product design and manufacturing, traceability, and lifecycle management. Practices like products as a service and virtualisation (digital twins) extend product value through the engineering, testing, and customer support phases.

The aviation industry would also benefit from increased investments and technological developments to support its transition. Digital mock-ups could facilitate the dismantling of aircraft, where digital passports would significantly improve material traceability. Developing materials from circular feedstocks (such as materials with increased recycled content) could reduce dependency on finite materials. Composites, which are crucial to reduce aircraft weight and reduce emissions, would benefit from advanced recycling techniques to preserve material properties for remanufacturing. Augmented reality and virtual reality would facilitate disassembly training for workers, provide more detailed visualizations of aircraft components, and even allow simulations of the disassembly process. New technologies will also be needed at scale for disassembling and sorting materials.

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1 Buy-to-fly ratio: weight ratio between the raw material (buy) used for a part and the weight of the finished part (fly)
2 Scraps: small pieces of materials (metal, composites, etc..) left over from parts manufacturing.
3 Source: Fortune Business Insights, "Aircraft Aftermarket Parts Market Size, Share & Industry Analysis,2025-2032" (2024)
4 Source: EASA, Assessment of the environmental sustainability status in the Aviation Maintenance and Production Organisation (M&P) Domain (2023)

Role of Stakeholders for a Successful Transition Toward a Circular Economy

Transitioning towards a more circular economy requires building new interactions and a new economic model for all industries, including commercial aviation. Several enabling conditions are required for a successful uptake of circular economy principles in aviation. This could start by working on a vision and indicators to monitor progress.

Experience from other industries highlights that collaboration is required between supply chain partners across the value chain, from material manufacturers to dismantlers and recyclers, but also key players from other industries such as the waste management sector, industry associations, and policy decision-makers. A global vision and indicators to monitor progress are also key success factors.

Data transparency and data exchange across players have an important role in facilitating material and equipment traceability through digital passports for components and systems, which are already in development. Challenges such as intellectual property and data sharing arise. Voluntary commitment and guidelines from industry stakeholders at a global level are required to establish a global playing field between key regions and create favourable conditions for the adoption of circularity principles.

By collaborating among stakeholders, the aviation industry can unlock the full potential of circular economy, ensuring its long-term profitability and success.

Pioneering Circularity in Airport Operations: Schiphol's Path to Zero-Waste

By Sara Solis (Royal Schiphol Group)

Introduction

At Royal Schiphol Group (Schiphol)[1] waste is no longer viewed as an inevitable by-product of air travel. Instead, it is treated as a valuable resource, meticulously monitored and managed. Schiphol has set ambitious goals to operate zero-waste airports by 2030 and achieve full circularity by 2050. These objectives are part of the Quality of Life pillar, under the circular economy chapter (Figure 1).

This is not a vision born of marketing, but one rooted in practice. Schiphol's practical approach acknowledges the substantial material resources and CO_2 emissions involved in managing high passenger volumes, and since 2016, has actively implemented circularity principles like avoidance, reuse, upcycling, and closed-loop systems across its operations. These actions signal a shift from the traditional linear approach to materials and towards a more regenerative model.

One such initiative is the 2024 food and beverage covenant, a collaborative effort with Amsterdam Airport Schiphol's concessionaires aimed at reducing environmental impact both at the front-end and back-end of operations. By promoting plant-based offerings, cutting back on single-use plastics, and reducing packaging and waste, the airport is making strides to influence consumption patterns in a practical and measurable way. While the effects are visible at Schiphol, the hope is that similar practices may inspire broader changes across the sector.

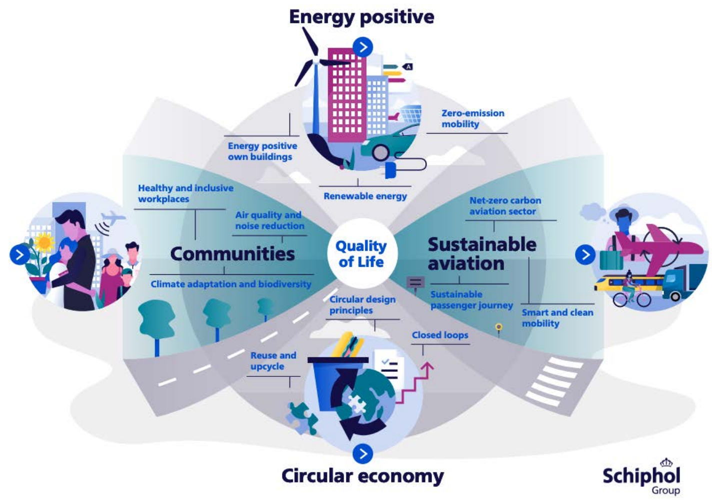


FIGURE 1: Circular Economy is one of topics in the Quality of Life pillar of Schiphol.

Schiphol's circular strategy is driven not only by environmental responsibility but also by necessity. Resource scarcity, rising material costs, and shifting public expectations are reshaping how infrastructure organisations operate. Airports, with their complex supply chains and large ecological footprints, have a unique opportunity—and responsibility—to lead by example.

Transforming Waste Management Methods

Through the EU-funded TULIPS programme, Schiphol is working to rethink how waste is generated and processed at large airports. The Circular Airports Work Package within this programme focuses on turning waste into

1 Royal Schiphol Group is the owner and operator of Amsterdam Airport Schiphol, Rotterdam The Hague Airport and Lelystad Airport, and holds a majority stake in Eindhoven Airport. For the sake of clarity, Royal Schiphol Group will hereafter be referred to as 'Schiphol'.

value, and Schiphol has joined forces with Excess Materials Exchange and Delft University of Technology to develop tools and methodologies that support this goal. The Baseline Circular Airports Method (BCAM) is one such tool[2]. By mapping material flows within airport operations, BCAM helps identify the sources, treatment pathways, and environmental impacts of waste streams. It revealed that five key streams—residual waste, plastics, swill, paper/cardboard, and cabin waste (Category 1) —dominate the Amsterdam Airport's operational profile.

Importantly, the method distinguishes between mass and impact. For instance, while residuals and plastics represent a large share by weight, cabin waste (Category 1) and plastics are far more significant in terms of CO_2 emissions. Additionally, the eco-cost, which quantifies the monetary value of the environmental impact, offers a comprehensive overview of the streams (Figure 2).

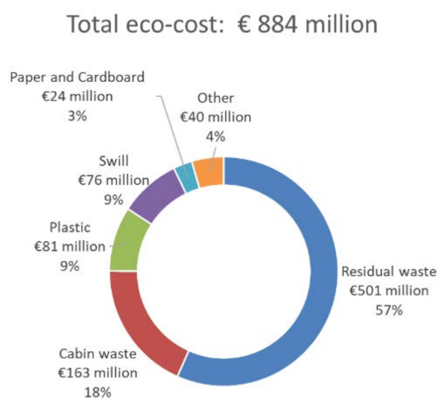


FIGURE 2: Eco-cost (LCA C3 & C4) of the operational waste at Amsterdam Airport area, 2019.

Insights like these have helped Schiphol prioritise its efforts more effectively. For instance, they have triggered actions such as redesigning waste bins to improve separation, piloting alternative treatment pathways for high-impact materials, and exploring waste-to-resource innovations.

These initiatives are part of Schiphol's shift from reactive to proactive waste management, shaped by the availability of better data. BCAM has also proved to be a valuable tool for stakeholder engagement. By translating waste flows into tangible data, Schiphol can involve partners more effectively in decision-making. This transparency has strengthened relationships with tenants, vendors, and regulators, and helped build shared ownership of sustainability goals.

Material Flow Management: Terminals, Airlines and Offices

As part of its broader transition, Schiphol launched the Material Flow Management programme in 2023 to execute its zero-waste strategy. The goal is to view waste as valuable materials, reduce consumption, and maintain or enhance their value in subsequent applications, all while minimizing environmental impact. This approach effectively puts circularity principles into practice. To support this initiative, a data-driven approach is being followed, with targets set and a monitoring system in place to guide actions.

The terminal —where around 70% of all operational waste is generated—is a priority area. (Figure 3). Schiphol has set clear performance targets for 2030, including keeping waste below 170 grams per passenger, and achieving an on-site separation rate of 65%.

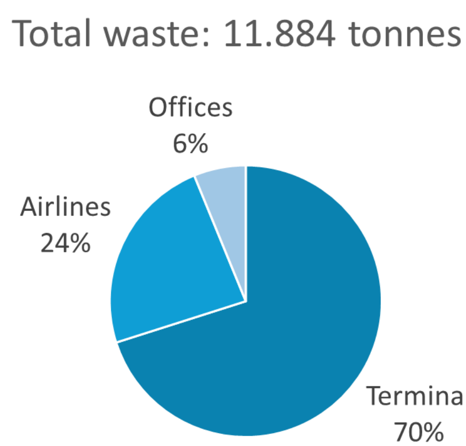


FIGURE 3: Distribution by workstream of the operational waste at Amsterdam Airport area, 2024.

2 For more information see *van der Tuin-Rademaker, A., Tschavgova, E., van Maaren, C., Solis, S., Campisano, S., & van Dam, S. (2024). Transforming waste management methods: a Dutch Airport's journey toward a circular economy through baseline measurements and strategic priority setting. Frontiers in Sustainability, 5, 1356041.*

Meeting these targets is not only about infrastructure, but also about behaviour. Enhanced bin signage, staff and vendor engagement, and pilot programmes for reusable products systems are all contributing to improvements. It's a process of learning and iteration, with results emerging gradually. These changes are already bearing fruit. In 2024, Amsterdam Airport recorded a 7.5% reduction in total waste compared to the previous year. At the same time, passenger numbers increased—demonstrating that growth and sustainability can be balanced when materials and waste systems are carefully managed.

Airline operations are also being re-examined. This workstream is responsible for 24% of the waste, as shown in Figure 3. Managing cabin waste that is classified as Category 1 remains a significant challenge due to the EU regulation 1069/2009. In response, Amsterdam Airport Schiphol is post-separating the recyclable cabin waste of several airlines. In addition, we are testing a per-flight waste tracking system to differentiate EU from non-EU flights and explore the potential for more nuanced sorting. Data from these initiatives may also inform future policy discussions. By demonstrating where and how residuals can be safely diverted from incineration or landfill, Schiphol hopes to contribute evidence-based insights that support gradual regulatory adaptation.

In addition to the terminal and the airlines, office environments are being brought into the strategy. We have begun benchmarking waste performance across Schiphol's administrative and tenant spaces. This work is supported by revised cleaning contracts, employee training, and new signage systems that reinforce circular practices.

Digital Tools for Circular Progress

A key enabler of progress has been the Amsterdam Airport Schiphol Operational Residual Stream Dashboard for zero-waste —a platform that provides transparency across the waste streams. From collection to end-of-life treatment, data is tracked and analysed to inform decisions and interventions. Each collection point in the Amsterdam Airport Schiphol area is equipped with tracking tools, enabling reporting on waste weight, type, and sources. This data is systematically collected and verified, and it is presented in a useful visualization to guide progress towards zero-waste goals. Figure 4 highlights the sections of this dashboard.

FIGURE 4: Sections of the Zero-Waste Operational Residual Stream Dashboard.

The insights extracted from this information allow operational and sustainability teams to respond to underperformance—whether it is a significant increase in a waste stream, a low separation rate, or higher CO_2-equivalent levels for end-of-life transport and treatment.

This visibility has turned insights into actions. When data revealed high quantities of a specific waste stream, Schiphol conducted targeted waste audits. We found that 45% to 55% of residual waste from passenger areas could have been recycled. Additionally, we identified recurring items in the residual waste (Figure 5).

FIGURE 5: Recurring items in the residual waste.

These insights are shared with business partners to adjust procurement practices and reduce certain streams or products. Additionally, intervention strategies, such as testing different signs or smart garbage bins in the terminal, are implemented to increase the separation rate. By providing transparent performance data, the dashboard fosters engagement and accountability.

This collaborative approach aligns everyone towards zero-waste goals, driving continuous improvement and innovation in circularity practices.

Lessons and Reflections

Schiphol's ongoing efforts offer practical reflections for other airports exploring similar goals. First, collaboration is essential. Meaningful progress requires cooperation across different stakeholder groups—from retailers to cleaning services to airline partners.

Second, data must underpin decision-making. The shift to digital monitoring has helped Schiphol evolve from intuition-based planning to performance-based management. While this system is still evolving, it's already proving valuable.

Third, policy remains a critical factor. Challenges around international catering waste (Category 1) cannot be resolved at an airport level alone. Schiphol is engaging with aviation stakeholders and EU policymakers, using data from its pilots to advocate for regulatory flexibility that supports circularity.

Fourth, innovation is best approached incrementally. Pilots in smart waste sorting, reusable systems, and per-flight data capture have allowed Schiphol to test ideas, refine processes, and scale what works.

Finally, circularity is about system thinking. It's not simply about cutting waste, but about rethinking how materials are used, recovered, and valued. The benefits are multiple—reduced emissions, lower costs, and greater resilience in the face of resource constraints.

Looking ahead, Schiphol remains committed to improving and expanding its approach. We continue to engage with peer airport operators and sustainability experts to exchange knowledge and improve practices. While much progress has been made, the path to full circularity is one of continuous refinement.

Schiphol is proud to lead the way in the circular economy by sharing its findings and learning from others. As a pioneer and innovator in sustainable practices, Schiphol is committed to driving a broader shift in how the aviation industry manages its environmental responsibilities. Embracing circularity as a shared journey, Schiphol is dedicated to making a significant and positive impact.

Sustainable Plastic Management

By Yue Huang (IATA)

CONTEXT

Plastic pollution continues to be a key environmental challenge and one of the issues of the triple planetary crisis. More than 430 million metric tons of plastic are produced each year[1] and only 10% of plastic is being recycled globally[2].

The impacts of plastic pollution can be seen along the entire plastic life cycle: from exposure to chemicals, plastic particles, and additives used in the production phase to leakage of mismanaged plastic that turns into macro and microplastics, increasing air pollution and affecting the marine environment, to the contribution to climate change from plastic production and conversion from fossil fuels.[3]

To combat plastic pollution, in March 2022, at the fifth session of the UN Environment Assembly (UNEA-5.2), a resolution was adopted to develop an international legally binding instrument that is based on a full life cycle approach, including the production, design, and disposal of plastics.[4]

The IATA report titled *Reassessing single-use plastic products in the airline sector*[5], highlights the challenges of replacing single-use plastic products due to asymmetric plastic restrictions at airport, regional, and national levels that do not consider transport emissions or aviation safety, security, and hygiene requirements.

Beyond single-use plastics, the sector also faces challenges with end-of-life management of plastic elements from cabin retrofits and composite plastics from newer aircraft types. It is important to recognize that the aircraft being manufactured today will be in service for the next 20 to 30 years. Therefore, the overall design of the components and cabin interiors need to consider options for the reuse and recycling of the material, and also be designed to improve waste management during flight operations. Another environmental concern is the aircraft tire abrasion as a source of microplastics.

Standard guidance needs to be developed to ensure that all air industry stakeholders (e.g., airlines, airports, OEMs, caterers, and ground handlers) adopt a harmonized approach to plastics management based on circular economy principles.

CONSIDERATIONS AND AREAS OF IMPROVEMENT

One of the key objectives of plastics management is to identify opportunities for environmental improvement in the production, design, use, and disposal of plastics. It is important to keep in mind that every alternative to plastics will have its own set of considerations. For example, in aviation, plastics are used because of their lightweight properties, and if replaced with heavier alternatives, this could lead to a negative impact in terms of greenhouse gas emissions.

It is important to consider the challenges and impacts to prevent unintended consequences when developing a strategic approach to tackling plastic pollution.

1 Organisation for Economic Co-operation and Development (2022). Global Plastics Outlook.
2 Chemical Pollution (2022). The huge problem of microplastics.
3 UNEP (2022). Plastic Science.
4 UN. Intergovernmental Negotiating Committee on Plastic Pollution.
5 IATA (2024). Reassessing single-use plastic products in the airline sector.

Myriads of regulatory frameworks:

Many regulators have implemented local, regional, or national restrictions without considering the characteristics of the aviation sector, resulting in a complex environment, particularly for airlines and airports.[6] Simple, harmonized regulations that include common definitions and standards for alternative products are needed.

Plastic alternatives and replacements:

Alternatives may require different processes in either the re-use phase or additional steps for disposal, which may impact logistics or the supply chain. It is important to develop guidance material to introduce practices that inform and support decision-making processes and engage with suppliers that consider operational requirements when they are creating alternative products.

Need for extra resources

The cost associated with replacing plastic products is still of great concern. This is not only associated with the product itself; it can also include additional costs such as new and adapted services, facility development, transportation, and reverse logistics.

End-of-life data and treatment

There is not enough information about waste management in the aviation sector, but innovative solutions are emerging in this area, such as automated sorting systems, new treatment methods, and data analytics.

With global air passenger demands accelerating and potentially doubling by 2040[7] , waste from airlines and airports is expected to double. On the other hand, with new aircraft being produced, the proportion of composites to be recycled is also expected to increase significantly in the medium and long term.[8]

All stakeholders in the aviation sector need to coordinate actions to promote regulatory change and encourage the development of appropriate recycling, reuse, and recovery systems.

Certification scheme for sustainable alternatives

There is a proliferation of standards and certifications that differ in definitions, methodology, and labeling systems. It is important to develop tools that are appropriate for the industry and are globally recognized.

SECTORAL APPROACH FOR AVIATION

It is important to establish a common vision and understanding, that allows for the coordination and implementation of actions among the multiple stakeholders of the aviation value chain.

It is proposed that a sectoral approach includes the following aspects:

1. **Sustainable Plastics Management in Aviation Principles**

Implementing circular economy principles into the airline sector value chain will require considerable changes to processes and procedures for stakeholders both upstream and downstream.

A well-defined set of principles will uphold a global objective even when considering particularities at national or regional levels.

These principles need to be general but ambitious, to encompass multiple actors. A good example is the Plastics Pact Network (convened by the Ellen MacArthur Foundation and WRAP), which has developed the following blueprint[9]:

6 IATA (2024). Lack of harmonized rules hampers plastic replacement.
7 IATA (2023). Global Outlook for Air Transport.
8 Scheelhaase et al. (2022). Economic and Environmental Aspects of Aircraft Recycling.

9 WRAP. The plastics pact network.

- Elimination of unnecessary and problematic plastics.
- Design for reuse and recyclability.
- Effective recycling in practice and at scale.
- Inclusion of recycled content.

2. Guidance on harmonized single-use plastic product regulations for aviation

The aim is to provide guidance for environmental authorities to develop and adopt a harmonized plastic replacement strategy for aviation, including the consideration of environmental trade-offs in current and future legislation. Environmental regulators must also consider that certain aviation products are mandated by civil aviation and public health authorities.

It is essential that the sector follows a cohesive and phased replacement plan based on standard scope, definitions, and exemptions that recognize the sector's environmental, safety, security, and hygiene characteristics.

3. Standard sectoral life cycle assessment (LCA) methodology for alternative products

A life cycle assessment (LCA) methodology is a comprehensive way of robustly measuring a product or service's environmental impacts.

A harmonized methodology for measuring the environmental impacts of plastics and their alternatives aims to increase comparability around LCAs that are applicable for the air transport sector and provide decision-making tools to objectively assess replacement to plastic items

A harmonized methodology would also help to:

- Improve the environmental impact of the air transport industry.
- Benchmark the performance of alternative systems.
- Support a harmonized regulatory approach to plastics, including single-use plastics in air transport across jurisdictions.

4. Alternative product integrity and sustainability standards

Due to the increased number of voluntary certifications available, it is necessary to review the applicable set of standards for different aviation items. Further development of a tool, either for assessment or as a repository of product information, could be useful in understanding levels of recyclability within the industry or potential uses in other industries.

5. End-of-life management practices for composite plastics

As the implementation of more circular models into the airline sector value chain gains relevance, the use of composite plastics still faces challenges regarding recycling practices.

As mentioned in a report by KPMG[10] the most challenging elements to process are alloys and carbon fiber composites. Notably, manufacturers are addressing this issue and introducing best practices for recycling composites used in airframes, interiors, and other components such as Unit Load Devices.

It is also necessary to strengthen the efforts to improve technology to facilitate composites recycling solutions.[11] Further research is needed to understand how different technologies and tools can help in the process of disassembly for reuse and recycling.

6. Goals, targets, and KPIs

Setting clear targets for design, replacement, reuse, recycling, and disposal, provides a necessary structure to measure and monitor performance.

It is important that the targets are established, taking into consideration the sector's characteristics, and used to disclose progress.

10 KPMG (2024). Circularity in Flight.
11 Wong et al. (2017). Composites recycling solutions for the aviation industry.

RECOMMENDATIONS

Collaboration across the aviation sector is vital to enabling circular economy principles while seeking a sectoral approach to facilitating the sustainable management of plastics.

Due to the numerous interconnected elements surrounding this issue, it is challenging to understand the full complexity of the topic.

Solution-focused discussions and open dialogue with key stakeholders will allow the identification of logistical changes and would reduce the burden of individual responses to the same challenges (e.g., data collection, identifying suitable replacement alternatives, and a lack of reuse and recycling infrastructure).

The entire value chain needs to coordinate to advocate for the promotion of regulatory change and simple harmonized regulations that will support the inclusion of circularity principles and encourage the development of appropriate recycling, reuse, and recovery systems.

This will lead to the adoption of best practices at every stage of a product's life cycle, promoting transparency and information sharing, identifying areas for future work.

ICAO

CHAPTER FIFTEEN

Biodiversity

Biodiversity and Nature-Based Solutions: an emerging topic for the aviation sector

By ICAO Secretariat

Introduction on Biological Diversity Crisis and Need for Urgent Action

Climate change has become an increasingly important issue in our societies, in particular since the adoption of the **Rio Declaration on Environment and Development** during the Earth Summit in 1992, which marked a key milestone in the commitment of States to tackle climate change and protect the environment. All stakeholders are now engaged in the sustainable transition of all sectors and, while the impacts of climate warming and the need to engage and implement climate mitigation and climate adaptation measures is acknowledged, scientists have called attention to an even bigger environmental crisis related to biological diversity loss.

The term biodiversity derived from "Biological diversity" refers to the "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" according the **Convention on Biological Diversity (CBD)** adopted in 1992 at the Nairobi Conference[1].

The objectives of this Convention are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding.

Since the 1960', a grave decline of biodiversity has been observed and sometimes described as a 6th mass extinction. Human activities play the major role in this unprecedented loss of biodiversity and the loss of habitats and ecosystems, land degradation and desertification, climate change and pollution and waste are jeopardizing the right to a healthy and sustainable environment and underlining the fragility of the functioning of those ecosystems.

The *WWF Living Planet Report 2024: A planet in Crisis*[2], highlighted a global environmental crisis and emphasized a "catastrophic decline of 73% in wildlife populations over the last 50 years, as measures by the Living Planet Index (LPI)", noting that the LPI is developed by the Zoological Society of London which monitor population trends accords species.

The importance of biodiversity to maintain healthy ecosystems that sustain life on Earth is highlighted by multiple organizations including through the holistic "One Health" approach that recognizes the health of ecosystems, animals, and humans as interconnected.

1 https://www.cbd.int/convention
2 https://www.arcticwwf.org/newsroom/news/wwf-living-planet-report-2024-a-planet-in-crisis/

While the **Intergovernmental Panel on Climate Change (IPCC)** provides the latest state of the science related to climate change, the **Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)**, established in 2012, is committed to strengthening the role of science in public decision-making on biodiversity and ecosystem services.

To achieve this, IPBES respond to government requests for information on biodiversity and ecosystem services, identify and prioritize key scientific information needed for policymakers, perform regular and timely, scientifically credible, independent, and peer-reviewed assessments of knowledge on biodiversity and ecosystem services on a comprehensive global, regional, and sub-regional scale, support policy formation and implementation by identifying relevant tools and methodologies and identify and create key capacity-building tools to support the use of science in policy.

The **International Union for Conservation of Nature and Natural Resources (IUCN)** is a global environmental network aiming to influence, encourage and assist societies throughout the world to conserve nature and to ensure that any use of natural resources is equitable and ecologically sustainable.

Achieving global targets, such as halting and reversing biodiversity loss by 2030 as outlined in the Global Biodiversity Framework, adopted in 2022, and limiting global temperature rise to 1.5ºC under the Paris Agreement, demands bold and immediate action. Unfortunately, current national commitments and efforts fall far short of what's necessary to meet these goals and prevent dangerous tipping points. To reach the Global Biodiversity Framework's target of safeguarding 30 per cent of the planet's lands, waters, and seas by 2030, a substantial expansion of effective protected areas is crucial. Presently, only 16 per cent of land and 8 per cent of oceans are protected, highlighting the urgency of the task ahead.

Role of Aviation to tackle Biodiversity Loss

Biodiversity and ecosystems conservation requires global, comprehensive and coordinated action, including from the aviation sector. Biodiversity has become an important consideration in ICAO's work, in areas such as aerial forest fire mitigation, species protection near airports, the prevention of wildlife trafficking, and the deployment of sustainable aviation fuels (SAFs).

Conservation of biodiversity in CORSIA framework

ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) incorporates robust sustainability criteria to ensure that the deployment of sustainable aviation fuels (SAF) supports, rather than undermines, biodiversity and conservation goals.

According to the ICAO document ***CORSIA Sustainability Criteria for CORSIA Eligible Fuels***[3], within "Conservation" theme and under the principle that the production of CORSIA, SAF should maintain biodiversity, conservation value, and ecosystem services, the following sustainability criteria for this theme must be followed:

- **Criterion 7.1**: CORSIA SAF will not be made from biomass obtained from areas that, due to their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area, unless evidence is provided that shows the activity does not interfere with the protection purposes.
- **Criterion 7.2**: Low invasive-risk feedstock will be selected for cultivation and appropriate controls will be adopted with the intention of preventing the uncontrolled spread of cultivated alien species and modified microorganisms
- **Criterion 7.3**: Operational practices will be implemented to avoid adverse effects on areas that, due their biodiversity, conservation value, or ecosystem services, are protected by the State having jurisdiction over that area.

3 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx

These criteria collectively ensure that CORSIA-eligible fuels production does not interfere with the protection purposes of areas recognized by the State for their biodiversity, conservation value, or ecosystem services.

In addition to the sustainability criteria applied to CORSIA-eligible fuels such as SAF and LCAF, biodiversity protection is also addressed through the eligibility framework for **CORSIA Eligible Emissions Units (EEUs)**.

The *ICAO document on CORSIA Eligible Emissions Units*[4] requires that offset programmes demonstrate robust environmental and social safeguards, including for biodiversity and ecosystems.

These provisions ensure that projects generating CORSIA-eligible carbon offsets do not compromise biodiversity and instead contribute to broader environmental integrity. Combined with the safeguards for sustainable fuels, this creates a holistic biodiversity-conscious approach across CORSIA's climate mitigation principles.

Biodiversity at Airports

Growing demand for transport infrastructures such as airports are putting pressure into biodiversity in a number of ways, a major sustainability challenge for airports is the balance between their construction and operation with the safeguard of natural ecosystems and biodiversity conservation under pressure by their activities.

Airports are fully engaged in this challenge and many initiatives exist showcasing the commitment of airports to protect biodiversity, when it comes to infrastructure planning, landscape management, operations, data monitoring, noise, light pollution and nature-based solutions.[5] More information is provided in other articles of this Chapter.

The Green Airports Recognition 2024 by Airports Council International (ACI) Asia-Pacific & Middle East was under the theme "Biodiversity and Nature-Based Solutions" and recognized the efforts supporting wetland restoration and creation, balancing wildlife species with airport operations, preventing wildlife trafficking, ecosystem restoration, and carbon removal through natural means[6].

ICAO's Committee on Aviation Environmental Protection (CAEP) will develop a publication on Biodiversity and Nature-Based Solutions as part of the Eco-Airport Toolkit e-collection which provide practical and ready-to-use information related to airport planning and sustainable management.

ICAO events also cover this important topic to take stock of the initiatives related to biodiversity conservation developed around the world and to create the necessary dialogue amongst the stakeholders to implement the necessary measures. The ICAO Green Airport Seminars are the opportunity to gather knowledge and best practices from airports, including measures related to biodiversity protection. For example, the 2024 Green Airports Seminar held in Athens, Greece, provided an opportunity for Dakar Blaise Diagne Airport to inform about their multiple activities planned in the airport environmental plan, including biodiversity protection, management of green spaces, water resources, water, air and soil pollution as well as management of bird disturbance. Dakar Blaise Diagne Airport highlighted three flagship actions including the development of an ethnobotanical garden, reforestation of the resettlement site and ecosystem restoration in a Matine Protected Area, bird observatory to monitor migratory species[7]. The ICAO 2024 Green Airports Seminar is detailed in Chapter 12 – Green Airports of this Report.

Such events emphasize the importance of taking into consideration biodiversity conservation in the management of infrastructure or operations and highlighted the need

4 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Emissions-Units.aspx
5 Biodiversity Conservation Initiatives at Airport's Level By Anastasios Anagnostopoulos (Athens International Airport S.A.), Nick Gabriel (Gatwick Airport), Melina Santos Vanderlinder (Aeropuertos Dominicanos - AERODOM), and Wendy Avis (Vancouver International Airport); https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art71.pdf
6 Green Airports Recognition 2024: Biodiversity and Nature-Based Solutions Press Release; https://www.airportcarbonaccreditation.org/green-airports-recognition-2024-biodiversity-and-nature-based-solutions/
7 Presentation by Yacine Kebe, Safety Environment Quality Manager Dakar Blaise Diagne Airport, 2024 ICAO Green Airports Seminar: Accessible on the ICAO public website: https://www.icao.int/Meetings/greenairports2024/Documents/Presentations/Session%203%20Part%20II/4%20-%20ACI%20Africa%20-%20Yacine%20Kebe%20final.pdf

for advocacy, coordinated approach, as well as assistance and capacity building.

Climate Adaptation and Nature-Based Solutions

Nature-based solutions (NbS) are increasingly recognized as essential tools for climate adaptation and for halting biodiversity loss. These solutions use natural processes and ecosystem services to address societal challenges such as flooding, extreme heat, and poor air quality—while at the same time enhancing biodiversity. ICAO is exploring and supporting nature-based approaches in the aviation context, particularly at the airport level, to strengthen resilience and provide co-benefits to communities and ecosystems. More information on climate adaptation and resilience is available in Chapter 13 – Climate Adaptation & Resilience of this Report.

Forest Fire Fighting

Forests cover about 30% of Earth's land surface. Behind the oceans, forests are the second largest carbon sink on the planet, not to mention the carbon stored. They are also home to 80% of the world's terrestrial biodiversity. As provided in IPCC 2021 Climate Report, widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred due to the human influence. Climate change is already affecting every inhabited region across the globe, and every year large areas of forest are affected by fires worldwide. The number of fires and their size varies from year to year, but the risk of fire is increasing globally. Fires devastate ecosystems and threaten the safety of people as they spread.

With increasing awareness of the importance of safeguarding forests, the problem of forest fires has risen over the past years to the forefront of political and public awareness. The 2020 United Nations Summit on biodiversity highlighted the crisis facing humanity from the degradation of biodiversity and the urgent need to accelerate action on biodiversity for sustainable development. It emphasized biodiversity conservation as a necessary condition for the achievements of Agenda 2030 for Sustainable Development and the fight against climate change.

Emergency responses to forest fire fighting involves both ground and air intervention forces. Although ground forces remain the principal lever of action and the coordinator of the overall response, aircraft play a crucial complementary role to control the escalation of fires. The aerial response to fires has improved over time, and contributing to this has been the continuous improvements of monitoring tools and early warning systems. However, there are always opportunities for further improvements.

The *ICAO Flying Forest Fire Fighting Dialogue (I4F)*[8] was held in 2021 aiming at exchanging the information on existing activities, technologies and arrangements and facilitating the cooperation on aviation forest fire fighting activities among States and other relevant stakeholders, by sharing knowledge, experience and resources as well as by discussing possible areas of improvements and cooperation.

It was acknowledged that the alarming trends in increasing number of wildfires across the globe are accelerating. extensive information on international firefighting practices, and on aviation solutions, expressing support to these crucial actions worldwide. The participants from the Global Fire Monitoring Center (GFMC), International Fire Aviation Working Group (IFAWG), and Joint United Nations Environment/Office for the Coordination of Humanitarian Affairs (UNEP/OCHA) Environment Unit highlighted the importance of ICAO's role.

The participants underscored the importance of identifying focal points across ICAO Member States in order to increase awareness and gain support for forest fire fighting efforts. The need for more outreach, certification work, awareness and innovations on fire fighting, forecasting, mitigation and prevention were also highlighted. Specific proposals were made on coordination towards facilitating new international aviation regulations and harmonization across States.

Advocating for a coordinated approach

ICAO continues to foster dialogue and coordination with relevant international bodies to ensure that aviation's environmental actions align with broader global

8 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ICAO ENV Report 2022 F4.pdf

sustainability agendas. A notable example of this was ICAO's participation in the United Nations Biodiversity Conference (COP15), held in December 2022 in Montreal under the theme "Ecological Civilization – Building a Shared Future for All Life on Earth". During the High-level Segment, the ICAO Secretary General delivered a keynote statement, highlighting how ICAO's work, particularly the development of sustainability criteria and eligible emissions units under CORSIA, as well as efforts to promote sustainable airport operations, contributes to the goals of the post-2022 Global Biodiversity Framework.

In parallel, ICAO took part in the UN Heads of Agencies Dialogue, convened by the UN Environment Management Group (EMG), and engaged in several bilateral meetings with high-level representatives from States and international organizations to explore avenues for enhanced cooperation. These engagements reflect ICAO's commitment to a coordinated, cross-sectoral approach to biodiversity and environmental protection.

These ICAO's cooperative activities and other key messages are also further reflected in Chapter 16 – Multistakeholder Cooperation of this Report.

Making peace with nature is a flight humankind cannot miss

By Astrid Schomaker (Convention on Biological Diversity (CBD))

In the late hours of 22 December 2022 an extraordinary event unfolded in Montreal at the city's iconic *Palais des congrès*, not far from the headquarters of ICAO. Assembled for COP 15 of the Convention on Biological Diversity (CBD), its 196 Parties adopted the Kunming-Montreal Global Biodiversity Framework (KMGBF). That moment — locally as the *Moment Montreal* — ushered in hope that the planet's biodiversity crisis can be halted and reversed through globally coordinated action under the CBD.

The thrill that the adoption of the KMGBF still evokes is amply justified: the Framework encapsulates unprecedented collective ambition. Designed as a global masterplan, it is articulated around four overarching goals: protect and restore biodiversity, prosper with nature, share benefits derived from nature fairly, and invest and collaborate to achieve all of the above. These goals are pursued through 23 action targets that must be achieved by 2030.

Remarkably, the goals and targets of the Global Biodiversity Framework are the product of a marriage of reason between diplomacy and science. It is the seminal work of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) on assessing the state of biodiversity on our planet that paved the way for the consensus around the KMGBF.

Montreal -Cali- Rome

Under the compelling theme of "Peace with nature", COP 16 of the CBD took place in Cali (from 21 October to 2 November 2024) and concluded its work in a resumed session in Rome (25 to 27 February 2025). In these two instalments, Parties completed the jigsaw they started assembling at COP 15 in Montreal. The final pieces fell into place with their agreement on the monitoring framework and the planning, monitoring, reporting and review mechanisms of the KMGBF.

At COP 16 momentous decisions were also adopted on biodiversity finance including how the implementation of the Global Biodiversity Framework is to be funded. The adopted package includes the resource mobilization strategy and a roadmap towards the establishment of a permanent financial mechanism under the Convention.

Progress did not stop there. The Parties operationalized the multilateral mechanism on the fair and equitable sharing of benefits arising from the use of genetic resources, including the "Cali Fund", which will receive contributions from companies making commercial use of data sequenced from the DNA of living organisms.

In another landmark decision, Parties established a new permanent subsidiary body with the aim of elevating the engagement and participation of indigenous peoples and local communities (IPLCs) in all the processes of the Convention. As custodians of a large percentage of the most biodiversity-rich parts of the world, IPLCs' traditional knowledge and expertise play an important role in biodiversity conservation.

From Montreal to Cali and Rome, the multilateral process under the CBD has delivered everything the Parties need to translate the global ambition of the KMGBF into commensurate national action. That endeavor has taken off in many countries.

FIGURE 1: Next Convention on Biological Diversity - COP17 will be held in Armenia.

Reduce drag, increase thrust

In any journey, reaching midpoint is the moment at which dashboards are checked, and projections are made on what lies ahead and how to reach the final destination in the most efficient way. The KMGBF, as a collective journey of planetary implications, will soon reach that point. The first global stock-take will take place at COP 17 in Yerevan in the last quarter of 2026 (Figure 1). As we approach this crucial milestone, the need for acceleration is clear.

Several Parties have by now aligned their National Biodiversity Strategies and Action Plans (NBSAPs) with the Global Biodiversity Framework. By doing so, they have set themselves up for success. NBSAPs are the principal vehicles of implementation under the Convention. The success of the KMGBF hinges on well thought-out, participatory, inclusive and adequately funded NBSAPs.

Aligning NBSAPs with the global goals and targets of the KMGBF is a crucial and highly beneficial exercise. It involves establishing what a country will do to contribute to the implementation of the Global Biodiversity Framework. These plans should reflect a whole-of-government and whole-of-society approach. By now, it is urgent that all Parties align their NBSAPs and start implementation in earnest. The scale and pace of the unfolding planetary crisis require immediate acceleration and bold course-correction.

Destination transformation

The findings of the most recent IPBES assessments are unequivocal: nothing short of transformational change cutting across all sectors of the economy can fulfill the vision that the world adopted within the KMGBF: life in harmony with nature. In activating these deep, far-reaching and essential transformations, policies must consider and leverage synergies among health, food, water and climate action. The IPBES Transformative Change and Nexus Assessments adopted in December 2024 provide policymakers with pointers to do just that.

In transforming economies, governments are in the cockpit, but the contributions of the private sector, cities and local authorities and communities are key. Many promising initiatives are coming from actors other than national governments. In the race against the clock to achieve the KMGBF targets by 2030, their actions are keeping the momentum even when governmental commitment falters.

Few sectors illustrate the challenge and the promise of the required transformative change as eloquently as aviation does. The sector's global economic weight, its contribution to global emissions, and its recognized impacts on biodiversity—from habitat loss and light pollution to the nature-jarring roar of aircraft engines— make it a real-life laboratory for transformative change. The deliberate mutations that aviation must undertake entail strategic shifts, regulatory reform and whole-of-society uptake.

The Business Plan 2026–2028 of ICAO sends the right signal. It comprises a strategic goal dedicated to environmental sustainability, aiming at achieving net-zero carbon emissions by 2050 and mitigating aircraft noise and other negative externalities. The Plan also reflects alignment with the Sustainable Development Goals. This bodes well for the future of the sector and sends a powerful signal to the economy at large.

Peace with nature is within flying range

The transformation of aviation is welcome tailwind, but one sector alone cannot generate all the thrust the world needs to decouple socio-economic progress from the destruction of nature. All sectors, including shipping, tourism, fashion, manufacturing and agrifood systems must reengineer the way in which value is created. Our economies can no longer afford to treat vital ecosystem services as disposable commodities. Protecting biodiversity, the foundation of all life on Earth, must underpin new models that deliver for people and protect nature.

In 2020, António Guterres, Secretary-General of the United Nations, said that “peace with nature is the defining task of the 21st Century”. An ever-growing body of science confirms that business-as-usual is no longer viable. Inertia means that the planet will be left to hurtle towards dangerous biophysical tipping points. Runaway climate change and biodiversity loss would upend all life on Earth. Veering away from this self-inflicted cataclysm requires vision, knowledge and purpose. By packaging these three ingredients of success into 23 specific, measurable and time-bound action targets, the Global Biodiversity Framework serves as a flight plan the world should use to reach peace with nature.

Integrating Biodiversity and Nature-Based Solutions in Airport Operations

By Jennifer Desharnais (ACI)

Introduction

Biodiversity management has long been a part of airport operations, primarily for safety reasons. Wildlife hazard management helps mitigate risks like bird strikes, while habitat control—such as managing grass and trees—ensures visibility, prevents fires, and reduces erosion. However, as biodiversity declines globally and its links to climate change become clearer, airports increasingly recognize their role in not only managing biodiversity for safety but also in protecting and restoring ecosystems.

Airports and biodiversity may seem at odds. Aircraft operations can negatively impact ecosystems through habitat disruption, pollution, and noise. At the same time, airports can play an important role by effectively managing their territories, which can sometimes serve as biodiversity reservoirs. This can help balance operational safety with ecological preservation.

Regulatory frameworks, such as ICAO's Annex 16, address environmental protection in aviation. Airports now integrate biodiversity considerations into their sustainability strategies, ensuring that safety and conservation efforts are aligned.

Climate change impacts are also a growing concern for airports. Nature-based solutions (NBS)—such as wetland restoration, tree planting, and green infrastructure—can enhance climate resilience while supporting biodiversity.

Aligning with Global Sustainability Goals

Biodiversity encompasses all living organisms within an ecosystem, playing a crucial role in maintaining balance and providing essential resources like food, water, and shelter. Airports influence biodiversity through land use, water management, and air quality control. Aircraft operations and airport development may seem to be in contradiction with the goal of preserving biodiversity, but airports can in fact advance the UN's Sustainable Development Goals (SDGs) related to biodiversity protection, by integrating biodiversity management with infrastructure planning and operations while maintaining adequate safety levels.

Evolving Biodiversity Management Practices

Airports must manage wildlife and vegetation to ensure operational safety. Traditionally, this meant habitat elimination to deter hazardous wildlife. Guidance documents such as ICAO's Doc 9137 and the US Federal Aviation Administration's (FAA) guidelines on hazardous wildlife attractants provide standards for minimizing wildlife risks near airports. Modern approaches shift from outright species elimination to risk management, reconciling safety with conservation.

A key step is understanding local biodiversity through species inventories and habitat mapping. Identifying flight paths and habitat zones helps airports develop informed strategies that mitigate risks while preserving ecosystems.

Inventories are a way to improve data collected at airports in order to enhance the knowledge of wildlife behavior as part of wildlife risk management; the presence of certain habitats or species that may be protected or on the contrary should be dealt with (e.g., invasive alien species); and of the scientific community about the general biodiversity status.

Enhancing Biodiversity Through Landscape Management

An effective biodiversity strategy includes adapting landscape management plans. Vegetation and soil maintenance influence both biodiversity and operational safety, requiring site-specific approaches. While no universal plan applies, key objectives include:

- Reducing or eliminating chemical inputs.
- Increasing plant diversity to minimize monoculture lawns.
- Adjusting cutting height, timing, and frequency to support functional needs and local species.
- Recycling vegetation waste.

Minimizing mowing frequency can help wildlife complete life cycles while reducing attraction to hazardous species like raptors, which rely on open visibility to hunt.

Biodiversity management also extends beyond airport boundaries, as changes on-site can affect surrounding ecosystems. Migratory patterns and wildlife corridors must be considered to ensure sustainable, long-term biodiversity conservation.

Managing Noise, Light Pollution, and Environmental Impacts

Noise and light pollution add further complexity to biodiversity management. Many airports have extensive noise mitigation programs to protect local communities, but noise can also be used strategically for wildlife control—for example, using noise cannons to deter birds.

Light pollution is another challenge. Reducing unnecessary lighting is one of the simplest and most effective ways to minimize its impact on wildlife. Implementing shielded or downward-directed lighting can further help reduce disruption to nocturnal species.

For any airport project, environmental assessments are crucial to evaluating potential biodiversity impacts. A structured approach, following the principles of Avoid, Reduce, and Compensate, ensures that negative effects are minimized. Additionally, regulatory requirements—such as environmental impact assessments or reporting obligations for endangered species—must be factored into airport biodiversity strategies.

Nature-Based Solutions for Airports

Biodiversity loss and climate change are interconnected challenges. Nature-based solutions (NBS) provide a way to address both, enhancing resilience while restoring ecosystems. As defined by the International Union for Conservation of Nature (IUCN), NBS involve protecting, managing, or restoring natural ecosystems to provide environmental and social benefits.

Examples of NBS applicable to airports include:

- **Vegetation buffers** to stabilize slopes and reduce erosion.
- **Wetlands** to regulate flooding and improve water infiltration.
- **Coastal vegetation** (e.g., dunes, mangroves) to protect against storms.
- **Green roofs and permeable surfaces** to mitigate heat island effects and manage stormwater.

While NBS offer multiple benefits, not all solutions are suitable for airports. Each project must be carefully evaluated to ensure it does not introduce new wildlife hazards that could compromise flight safety. For example, converting paved surfaces into vegetated areas near terminals poses minimal risk, whereas creating wetlands near runways could attract birds and increase collision risks.

Strategic implementation of NBS can provide additional benefits, such as extended infrastructure lifespan, improved energy efficiency, and enhanced aesthetics. By integrating biodiversity conservation into airport design and operations, airports can play a proactive role in climate resilience while ensuring safe and efficient aviation activities.

Conclusion

Sustainable biodiversity management at airports requires a comprehensive approach that aligns safety requirements with conservation efforts. Raising awareness, conducting thorough ecological assessments, and implementing nature-based solutions can help airports contribute to biodiversity protection while maintaining safe operations. By integrating these principles, airports can be part of the global movement towards a more sustainable and resilient future. The ICAO Committee on Aviation Environmental Protection, CAEP WG2 – Airports and Operations will develop during the CAEP/14 cycle an Eco-Airport Toolkit e-publication on this topic.

Enhancing biodiversity by carbon sequestration through Nature-Based Solutions – Abidjan Airport Côte d'Ivoire

By Aly Ouattara (AERIA), Géraud de Saint-Seine (Soil.is - EGIS), Gaoussou Cisse (INP-HB/ GEESOIL)

Introduction

The aviation industry is increasingly seeking innovative methods to minimize its environmental impact while aligning with broader sustainability goals. To attain various certification levels within the Airport Carbon Accreditation (ACA) program and, more importantly, to fulfill specific and measurable objectives for managing and decreasing CO_2 emissions, airports are required to conduct a thorough inventory of their emission sources (scopes 1 and 2). This effort also entails monitoring the execution of reduction initiatives and compensation measures within these scopes. For residual emissions and those from third parties, such as ground handling services or airlines (Scope 3), airports must establish compensation mechanisms.

Félix Houphouët-Boigny (FHB) Airport in Abidjan, the second-largest city in West Africa, has been dedicated to sustainable development for over ten years. It became part of the ACA program in 2015 and made history by becoming the first airport in Africa to achieve Level 3+ Neutrality in 2017 and currently ACA 4+ (first airport in Africa). To counterbalance its remaining Scope 1 and 2 emissions, Abidjan International Airport (AERIA), the airport operator, has adopted globally recognized solutions grounded in international standards, including the Greenhouse Gas (GHG) Protocol, ISO 14064, and guidelines from the Intergovernmental Panel on Climate Change (IPCC).

In this context, EGIS, the technical partner of Abidjan's Félix Houphouët-Boigny International Airport for nearly thirty years, is assisting AERIA with its strategy, management, and operational efficiency. **Together, they have developed the Soil.is solution, a method based on natural carbon sequestration—where CO_2 is captured from the atmosphere and stored in soil and vegetation through photosynthesis. This nature-based approach also contributes to biodiversity restoration.** This collaboration exemplifies how underutilized airport land can be converted into productive ecological assets, highlighting the aviation sector's potential role in large-scale landscape restoration.

The concept and implementation of "Soil.is"

Soil.is is a natural solution focused on restoring degraded soils and increasing carbon sequestration by planting trees and hedges and improving soils with compost. The project is being implemented in four main areas:

- Re-vegetation of runway edges (green maintenance) to reduce soil erosion and improve green maintenance.
- Creation of a market garden and agroforestry belt.
- Restoration of a mangrove swamp on the airport site.

- A circular economy project based on the production of compost from organic waste from both the airport and agricultural sites.

Implementing these four main areas of work will make it possible to build up organic matter in the soil, reduce erosion, improve water retention and stimulate microbial activity, thereby creating favourable conditions for the sustainable restoration of the ecosystem. To launch the project, AERIA and its partner EGIS followed a number of practical steps.

In 2023, Egis organised a business consultation which led to the selection of a consortium of local companies to carry out the work. Also in 2023, as part of the re-vegetation of the runway edges, several pilot areas were developed with plantings of various species adapted to different soil types. The plant species were chosen for their low height (10 cm maximum), in order to limit the frequency of mowing for the operator (Figures 1 & 2).

In 2024, all four activities will continue. Planting for the market garden belt has begun. In coordination with the gardeners, tree and hedge species such as moringa, neem, soursop, vetiver and korsaflan have been selected and planted along the edges of the areas and between the market gardeners' plots.

FIGURE 1: Green maintenance focus around the airside signalization by using local grass species to reduce mowing frequencies.

FIGURE 2: Soil sampling along runways to assess carbon stock.

FIGURE 3: Construction of a wooden nursery to serve for mangrove propagules activities are managed with the support of local communities; co-construction workshops were key to engage them to enhancing biodiversity by mangrove restauration.

Results and co-benefits

Although no direct measurements of biodiversity (such as entomological monitoring, standardised species counts or floristic analyses) have yet been carried out, initial observations in the field already point to a strong positive impact. The initial planting of tree species (*teak, moringa, neem, gliricidia*) and hedges (*korsaflan, green jatropha, vetiver, pigeon pea*) quickly led to a restructuring of the vegetation cover, creating a more complex mosaic of habitats more conducive to the return of wildlife. Pollinating insects and beetles were once again observed on the site (Figure 4), an encouraging sign that ecological recovery is underway.

FIGURE 4: Image of a *Psilothrix viridicœrule* (Interaction between flora and fauna in an agricultural ecosystem).

This plant diversity not only promotes biodiversity but also limits soil erosion, improves water retention and increases resilience to climatic hazards. At the same time, preliminary analyses carried out at the edge of the runway revealed an increase in organic carbon content and probably in microbial activity from the first year. The newly planted grassland cover made a significant contribution to these dynamics. In terms of climate, a sequestration of 4.7 t of carbon/ha, or 17.2 t of CO_2 eq/ha, has already been measured in the first year, mainly in the form of biomass (Figure 5). Sequestration in the soil is set to intensify from the second year onwards.

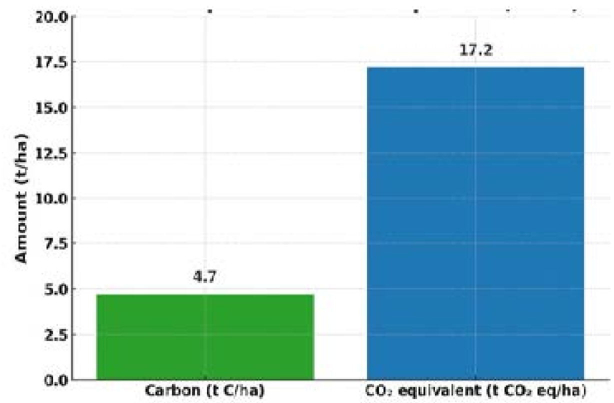


FIGURE 5: Carbon and CO_2 Equivalent Sequestration from grassland.

But the benefits of the project don't stop at carbon sequestration. The Soil.is solution is fully in line with AERIA's ESG (environmental, social and governance) strategies. From an environmental point of view, the participative selection of plant species with market gardeners means that fertilising, medicinal or slow-growing species can be favoured, thus limiting the need for chemical inputs and reducing mowing operations, particularly around overhead signalling infrastructures. Livestock effluent is also collected and recycled, preventing it from being discharged into the lagoon and feeding the production of agricultural compost. From an operational point of view, this solution offers tangible benefits: reduced erosion, less need to backfill runway edges, lower costs, etc. Emissions, and improve safety by limiting the exposure of maintenance staff in runway areas. Once the carbon credits have been certified, Soil.is should also enable the airport to offset more than 35% of its scopes 1 and 2 emissions, thereby reducing its purchases on the voluntary market.

The social impact of the project is also significant: over 200 market gardeners involved, more than 1,000 direct and indirect beneficiaries, training in agroecology, sustainable land management and waste recovery. The project is run in consultation with local communities (Figure 6), who co-design the solutions and reap the economic (fruit crops, beekeeping), nutritional and health benefits (medicinal species).

Soil.IS: A scalable model for the aviation sector

The promising results of the Soil.is project, as well as Abidjan airport's long-term commitment to sustainability, were highlighted at the "Airports Going Green" international conference in Chicago in November 2024. On this occasion, Mr. Aly Ouattara, as a keynote speaker underlined the strategic importance of the project for the airport operator**:**

"The implementation of Soil.is represents a significant advancement for Abidjan Airport. As a natural carbon sequestration solution, it serves as a set of strategies for mitigating and adapting to climate change. Furthermore, it reinforces the airport's commitment to sustainable practices and operations while preserving and enhancing biodiversity. This project also has a considerable social impact, fostering collaboration with local communities and contributing to the improvement of quality of life. Together, we cultivate a more sustainable future."

Conclusion

Beyond the case of Abidjan Airport, Soil.is is a scalable and replicable model for the aviation sector, perfectly in line with ICAO's vision of sustainability. **By integrating environmental protection into airport land-use planning, this nature-based solution offers an innovative framework for transforming underused land into a lever for climate mitigation and ecological regeneration.** Its flexible design means it can be adapted to a variety of climates, organic waste deposits, and social and ecological contexts. Partnerships between operators, researchers and local communities are at the heart of the model's success. Other airports can adopt this model to **enhance biodiversity by natural approach.**

FIGURE 6: Activities are managed with the support of local communities.

Harmonising Aviation Growth and Marine Biodiversity: HKIA's Innovative Approach

By Martin Putnam and Anita Wong (Hong Kong International Airport – HKIA)

Introduction

Prior to starting the Expansion of Hong Kong International Airport (HKIA) into a Three-Runway System (3RS) Project, the Airport Authority Hong Kong (AA) completed a comprehensive Environmental Impact Assessment (EIA), including assessment of impacts on nature and ecology. The 3RS Project involved substantial new land formation into the marine environment and the EIA demonstrated that with innovative construction approaches and a range of control and mitigation measures in place, the residual environmental impacts were found to be acceptable. A key mitigation was the designation of a new marine park adjacent to the expanded airport to help offset marine habitat lost to reclamation; the 2,400-hectare North Lantau Marine Park was established in November 2024 and links with two existing marine parks to form a 4,570-hectare combined marine protected area in waters near HKIA.

In addition to the statutory mitigation requirements from the 3RS Project EIA and environmental permit, AA also committed to a range of voluntary, beyond statutory initiatives as part of a Marine Ecology and Fisheries Enhancement Strategy (MEFES). This strategy incorporated a range of nature-positive initiatives aimed at further enhancing marine ecology and fisheries resources in Hong Kong's western waters. **This article provides an overview of HKIA's biodiversity strategy, specific enhancement initiatives implemented under the MEFES, lessons learned and reflections on balancing large-scale airport development with nature positive solutions.**

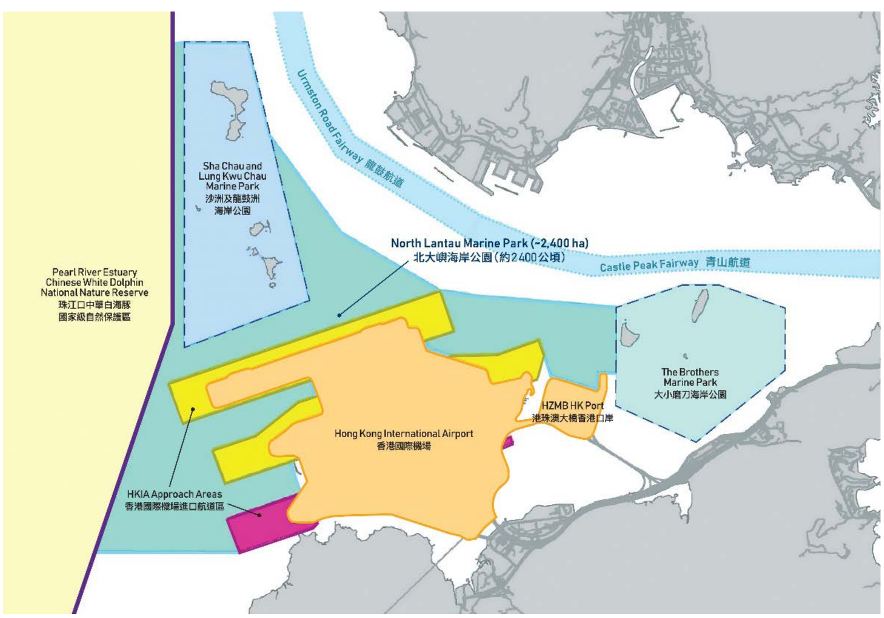


FIGURE 1: Designated North Lantau Marine Park linking with two existing marine parks.

HKIA's Biodiversity Strategy

HKIA is located north of Lantau Island in western Hong Kong waters and is surrounded by a range of marine and terrestrial habitats that are home to several species of significant ecological value. Nature and biodiversity are key considerations for AA, and through our MEFES commitments our biodiversity initiatives are intended to enhance the marine environment for the benefit of marine ecology, including for Chinese White Dolphins, an iconic species in waters near HKIA. Initiatives are also intended to enhance fisheries resources, providing support to fishing communities as well as encouraging more sustainable fishing operations. The following are some of our nature-positive initiatives under the MEFES.

Establishment of Enhancement Funds

In accordance with the 3RS environmental permit, AA established the Marine Ecology Enhancement Fund (MEEF) and Fisheries Enhancement Fund (FEF) in 2016, which are independent funds set up with the aim of enhancing the marine environment, ecology and fisheries resources. AA has injected a total of HK$400 million into the MEEF and FEF, with about HK$96 million granted from the funds to support marine ecology and fisheries projects since 2016.

Eco-Enhancement of HKIA's Seawalls

There are around 13 km of new seawall around the newly formed land. An opportunity was identified to modify the seawall structure to attract a greater diversity of marine flora and fauna. Several types of eco-enhanced concrete blocks were designed for different sections of the seawall, with over 500 blocks now installed. Eco-blocks feature rough surfaces, pits, holes, and rock pool features that facilitate the colonization of epifauna, increase microhabitat complexity, and provide protection and refuge for marine organisms. Post-installation monitoring surveys have shown that the number of sessile species (such as barnacles and mussels) and mobile species (such as limpets and crabs) on the eco-blocks is higher than on general seawall blocks nearby. This initiative has successfully increased microhabitat complexity and provided habitats for intertidal organisms.

FIGURE 2: Eco-enhanced vertical seawall blocks

FIGURE 3: Eco-enhanced blocks to be deployed on sloping seawall.

FIGURE 4: Bivalves in the water retention basin in a deployed rock-pool eco block.

FIGURE 5: Artificial Reef (AR) units from pilot trial.

FIGURE 6: Scale up deployment of AR units.

Artificial Reef (AR) Deployment

As well as enhancing existing seawall structures, AA also looked into potential benefits of deploying ARs in waters around HKIA. In 2021, AAHK deployed 100 artificial reef (AR) units in waters to the west of HKIA's South Runway as a pilot trial. The purpose of this deployment was to investigate ecological and fisheries value of ARs and one-year of post-deployment monitoring revealed a significantly higher abundance and coverage of mobile and colonization species on the deployed AR units. Encouraged by these positive results, AAHK is now carrying out a scaled-up AR deployment, with 500 additional AR units being deployed in restricted waters to the west of HKIA's Centre Runway. The ARs are designed with roughened surfaces to simulate the texture of natural reefs and can provide shelter for marine fauna, including fish (some released as part of AA's restocking efforts).

Shellfish Reef (SR) Deployment

In partnership with an NGO and a local university, AA investigated the value of deploying shellfish reefs (SRs) along parts of the airport seawall's subtidal zone in 2021. A pilot deployment using limestone along short sections of the seawall toe was initiated, with recycled oyster shells (collected from hotels and restaurants across Hong Kong for reuse) and live oysters sourced from nearby oyster farms added to the limestone base. The SR pilot proved cost-effective and proved the viability and effectiveness of SRs on new seawalls. Post-deployment monitoring identified good biodiversity benefits, including recording over five times higher species richness on the SR sections compared to at the start of the deployment. Given the success of the pilot SR deployment, a scaled-up SR deployment along a half kilometer section of the North Runway seawall was completed in September 2024. Monitoring is currently underway, and initial findings again show marked biodiversity benefits.

FIGURE 7: Bags of oysters being deployed to shellfish reef.

FIGURE 8: Fish eggs growing on oyster shells.

FIGURE 9: Release of fish fingerlings.

FIGURE 10: Preparing for fish fry release.

Fish Fry Release

After consulting with local fishing industry representatives, AAHK has also released approximately 28,000 commercially important fish species in stages in the waters west of HKIA, primarily to assess the restocking potential for enhancing fisheries resources. Monitoring after each release has made use of underwater visual and acoustic telemetry survey techniques, and these have shown that fish species are present within and near the release sites for an extended period after release. AAHK is currently planning to conduct a further restocking of approximately 50,000 fish fry, again within the restricted waters of HKIA, to tie in with Mainland China's National Fish Releasing Day on 6 June 2025.

Stakeholder Engagement

Successful implementation of various voluntary measures has required specialist knowledge and thorough understanding of the local marine environment. AA has engaged numerous stakeholders, including expert consultants, various government authorities, NGOs, fishing community representatives, and academic institutions, during both the development and implementation of enhancement measures. Regular engagement with external stakeholders has helped to ensure successful implementation. Details of all of our enhancement initiatives are also regularly shared with stakeholders through AAHK's Sustainability Reporting, the 3RS Project website, and at regular meetings with many stakeholders.

Demonstrating Success before Scaling Up

Post-deployment monitoring is a key feature of our enhancement initiatives and has in all cases shown that our pilot initiatives have been successful. For example, the AR pilot was successful in promoting the growth of mobile and sessile species, with hard coral and fish species observed inhabiting the ARs during monitoring. Similarly, findings from SR monitoring indicate significant biodiversity benefits, with over five times higher species richness recorded at the SRs compared to project onset. Demonstrated value at the pilot stage has paved the way for substantial scale-up and positive outcomes reinforce the value of the enhancement initiatives in promoting marine biodiversity and fisheries resources.

Innovation and Social Benefit

The ARs and SRs were designed with innovative features to promote the settlement of marine organisms and to provide shelter for marine flora and fauna. The use of recycled shells for SR deployment is a cost-effective and environmentally friendly approach with waste reduction benefit and additional benefits of creating further habitats for colonisation by other species. As well as enhancing marine biodiversity, these initiatives in many cases also have a strong social benefit, for example involving ongoing engagement with local communities such as fishers.

Lessons Learned

The implementation of these biodiversity-focused initiatives has provided valuable lessons for AA and other stakeholders – not least other project proponents considering large scale development with a footprint into the marine environment. Key lessons learned include the importance of regular and diverse stakeholder engagement, the value of pilot testing to assess the real-world viability of initiatives before committing to much larger (and more costly) scale-ups, and the importance of ongoing monitoring to evaluate the effectiveness of each of the enhancement measures being implemented. Other airports or large-scale developments with a significant ecological footprint may learn from AA's experiences:

1. **Engaging Stakeholders Early and Often**: Involve government authorities, NGOs, academic institutes, and local communities in the planning and implementation of biodiversity initiatives to ensure their success.
2. **Pilot Testing Initiatives**: Conduct pilot tests to assess the feasibility and effectiveness of proposed enhancement measures before implementing more costly scale ups.
3. **Monitoring and Adaptation**: Implement robust monitoring programs to evaluate the outcomes of biodiversity initiatives and adapt strategies as needed based on monitoring results.
4. **Promoting Innovation**: Explore innovative solutions when considering various initiatives, such as use of recycled materials and eco-enhancements to existing structures, to enhance biodiversity and promote sustainability.

Conclusion

The 3RS Project at HKIA has provided an opportunity for AA to implement a comprehensive and ambitious MEFES, going well beyond statutory requirements. Through initiatives such as eco-enhanced seawalls, artificial reef / shellfish reef deployments, and fish fry releases, AA has demonstrated the value of exploring and implementing voluntary nature-positive solutions in enhancing marine biodiversity and fisheries resources. There are valuable lessons and insights for other airport expansion initiatives or large-scale developments that may encroach into marine or terrestrial habitats. Making a long-term commitment to the MEFES has been highly important to our project success — large-scale development can be done hand in hand with taking a proactive approach on finding and implementing meaningful nature-positive solutions.

ICAO

CHAPTER SIXTEEN

Multistakeholder Cooperation

Advancements in Multistakeholder Cooperation Over the Last Triennium

By ICAO Secretariat

Climate change is a global challenge that all sectors need to work in collaboration to reduce emissions and mitigate the impacts on climate change, as well adapt to changing climate conditions. As the specialized UN agency for international civil aviation, ICAO continues to exercise its leadership on the sector's environmental matters, and cooperate with other sectors in advancing global climate actions. To this end, ICAO has actively engaged and collaborated with various other UN agencies, international organizations, and the aviation industry.

The ICAO's multistakeholder cooperation traditionally focused on understanding the impact of aviation on the environment as well as the development of SARPs. Over the years, ICAO has made significant progress in addressing international aviation emissions particularly: the 2016 agreement on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); the 2022 agreement on the long-term aspirational goal (LTAG) of net-zero carbon emissions by 2050; and the 2023 agreement on the ICAO Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF) and other Aviation Cleaner Energies. These ambitious initiatives and goals require continued cooperation to effectively address the climate change challenge and realize aviation's sustainable future. Further multistakeholder cooperation has taken place in the last triennium.

United Nations (UN) General Assembly — UN Decade of Sustainable Development

The United Nations General Assembly adopted a Resolution[1] on 19 December 2023 which included its decision to proclaim the first ever UN Decade of Sustainable Transport for a 10-year period beginning on 1 January 2026. While the consultation and drafting of the Implementation Plan for the UN Decade of Sustainable Development is ongoing, ICAO is committed to actively contribute to the process with inputs from the international aviation sector's perspective. This will help to raise awareness of the sector's role in advancing the UN Sustainable Development Goals (SDGs) and to mobilise innovative solutions, resources, and partnerships to drive a more sustainable future for international aviation.

United Nations Framework Convention on Climate Change (UNFCCC)

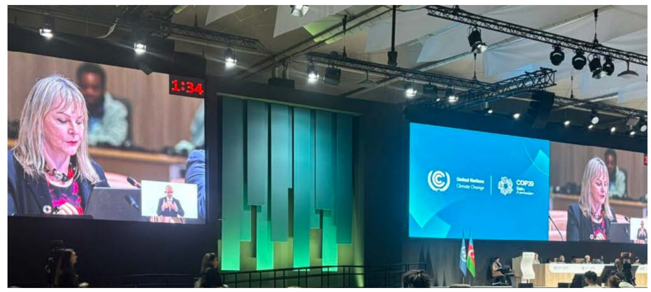
The **27th Conference of the Parties (COP27)** to the UNFCCC meeting, was held from 6 to 20 November 2022 in Sharm El Sheikh, Egypt. ICAO participated actively in various events at COP27 to showcase the outcomes of the 41st ICAO Assembly particularly the LTAG agreement.

1 https://docs.un.org/en/A/RES/78/148

During the opening session, ICAO delivered its statement under the agenda item "bunker fuel" (emissions from international aviation and maritime transport), supplemented by a written submission. The President of the ICAO Council, Mr. Salvatore Sciacchitano, took part in the High-level Summit roundtable on "Just Transition" and engaged in a series of bilateral meetings with senior representatives of States and international organizations. ICAO also organized a side event and contributed as a panellist in other sessions. All COP27 ICAO activities and outreach materials are available at the ICAO COP27 website.[2]

At **UNFCCC COP28** held from 30 November to 12 December 2023 in Dubai, UAE, ICAO provided its statement at the opening session, supplemented with a written submission, highlighting the outcomes of the 3rd Conference on Aviation and Alternative Fuels (CAAF/3) which took place just before COP28. The President of the ICAO Council participated in the COP28 High-level Presidency Roundtable on Energy Transition and showcased the results of CAAF/3 at the side event organized by ICAO, in partnership with the International Maritime Organization (IMO) and International Renewable Energy Agency (IRENA), with panelists from States and industry stakeholders. In addition, ICAO participated in several side events during the Energy and Transport days of the Conference, highlighting the ICAO Assembly outcomes, the implementation of the LTAG, and CAAF/3 outcomes. ICAO's activities and outreach materials are available at the ICAO COP28 website.[3]

The **UNFCCC COP29** was held from 11 to 22 November 2024, in Baku, Azerbaijan. Led by the President of the ICAO Council, Mr. Salvatore Sciacchitano, the ICAO delegation took part in discussions and hosted several events to inform Parties and relevant stakeholders of the latest developments achieved by ICAO and our Member States in addressing emissions from international aviation, with the details available on the ICAO COP29 webpage.[4]



On the opening day, ICAO hosted a briefing session titled "Implementing a Clean Energy Transition for International Aviation in support of the UN SDGs". The event highlighted ICAO's efforts in achieving the aviation sector's ambitions of Net Zero 2050 while ensuring that No Country is Left Behind in aviation's clean energy transition, contributing to the achievement of UN SDGs, including SDG #13 on climate action. The President of the ICAO Council also addressed the High-level Roundtable on Energy: Advancing Climate Mitigation Action, where he informed world leaders of the progress of aviation's clean energy transition. Several bilateral meetings also took place with the IMO, IRENA, UNFCCC, the Work Bank Group and the International Monetary Fund (IMF).

2 https://www.icao.int/environmental-protection/Pages/COP27.aspx.
3 https://www.icao.int/environmental-protection/Pages/COP28.aspx.
4 https://www.icao.int/environmental-protection/Pages/COP29.aspx.

In addition, ICAO continues to monitor and engage with the UNFCCC on matters related to Article 6 of the Paris Agreement, particularly regarding the eligibility of emissions units under CORSIA. Key areas of focus include guidance on avoiding double-counting and double-claiming. Ensuring effective alignment between Article 6 and CORSIA is crucial, as airline operators must meet their CORSIA offsetting requirements using eligible emissions units that fully comply with ICAO's quality and environmental integrity criteria.

The UNFCC COP meetings continue to serve as an important platform for ICAO to advocate and provide updates on the latest ICAO progress and planned actions for implementing the LTAG, CAAF/3 outcomes, and CORSIA. ICAO looks forward to making meaningful contributions to COP30, which will be held in Belém, Brazil, from 10 to 21 November 2025.

International Renewable Energy Agency (IRENA)

ICAO is strengthening its collaboration with IRENA with the signing of a Memorandum of Cooperation in October 2024[5], to cooperate and explore pathways to operationalize the ICAO Finvest Hub by facilitating the identification of financial resources for scaling up SAF, LCAF and other cleaner energy solutions.

ICAO also continues its advocacy and outreach efforts, including through the collaboration with States and financial institutions such as development banks and private equity entities by regional meetings, bilateral exchanges, and high-level meetings, to discuss financing needs, and possible means to support project implementation, and identify opportunities to increase access to public and private capital for aviation decarbonization projects, in line the request of the ICAO Assembly. More information on climate financing is provided in Chapter 9 – Climate Financing of this Report.

Financial Institutions and Energy Sector

As part of the preparation process toward CAAF/3, in March 2023, an informal meeting of the Council with several global and regional development banks (the African Development Bank, the Emirates Development Bank, the European Bank for Reconstruction and Development, the European Investment Bank, the Inter-American Development Bank, and the World Bank) and the Air Transport Action Group (ATAG) was convened to address the challenges and opportunities in decarbonizing international civil aviation.

In June 2023, the ICAO Council held two high-level exchanges on climate financing: one with private banks and investment firms and another with energy companies, focusing on the challenges and opportunities in aviation decarbonization. These discussions built on the inaugural high-level exchange with multilateral development banks in March 2023.

Further discussions on financing the transition to SAF and cleaner energies also took place between States, industry, and financing institutions at the 2023 ICAO

5 https://www.icao.int/Newsroom/Pages/ICAO-and-IRENA-join-forces-to-accelerate-access-to-financing-and-implementation-of-aviation-decarbonization-projects.aspx.

LTAG Stocktaking[6] and Pre-CAAF/3 Policy and Finance Consultation in July 2023, and at the 2024 ICAO LTAG Stocktaking in October 2024.[7]

The financing institutions and energy companies welcomed ICAO's initiative to accelerate aviation decarbonization and the LTAG and CAAF/3 outcomes (ICAO Global Framework) were considered as a key signal to the industry and financing community to unlock investments towards SAF, LCAF and other aviation cleaner energies. ICAO will continue to engage and cooperate with various stakeholders to facilitate access to financial resources to advance aviation decarbonization initiatives.

UN Environment Programme (UNEP)

Greening the Blue: UN System-wide Cooperation

ICAO continues to follow-up and cooperate with the UNEP on environmental matters within the UN system organizations. The UNEP Sustainable United Nations (SUN) Facility manages the "Greening the Blue" initiative, which is an UN-wide initiative to engage and support UN system organizations in the transition to integrate environmental considerations into their management decisions and actions. On an annual basis, the Greening the Blue report[8] provides information on the UN system's environmental footprint and efforts to adopt sustainable practices. ICAO actively contributed to the annual Greening the Blue report since its inception, as well as participated in other initiatives.

In particular, the ICAO Carbon Emissions Calculator (ICEC)[9] was officially adopted by the UN Environment Management Group (EMG) since 2009 as the official UN tool to calculate CO_2 emissions from UN-mission related air travel. In the 2024 Greening the Blue report, 58 UN entities[10] estimated the air-travel related portion of their UN inventories using the ICEC.

The ICEC methodology undergoes continuous updates to incorporate parameters such as the modelling of new aircraft types, revisions to the ICAO Fuel Formula and seat class configurations, in coordination with the work of the ICAO Committee on Aviation Environmental Protection (CAEP). Work is also ongoing to introduce more cabin class configurations in the model, from the two (economy and premium) to four (economy, premium economy, business and first) travel classes. An Application Programming Interface (API) has also been made available free of charge to the UN system and as a paid service to private organizations.

The ICEC will be further detailed in this Chapter under the article "ICAO Carbon Emissions Calculator (ICEC): a reference tool for estimating carbon emissions" by ICAO Secretariat.

Plastic pollution

ICAO closely monitors developments on the international legally binding instrument on plastic pollution, led by the UNEP Intergovernmental Negotiating Committee (INC). Subject to the availability of resources, ICAO should be ready to deliver its support for the ongoing aviation in-sector efforts on plastic pollution.

ICAO has already addressed the topic of plastics at the ICAO Green Airports Seminar[11], held in Athens, Greece in April 2024, which highlighted the need and the significant role of the aviation industry in the global efforts against plastic pollution. The Seminar is highlighted in detail in Chapter 12 – Green Airports of this Report. In addition, CAEP has developed guidance and best practices on this matter under the Eco Airport Toolkit Publication on Single-Use Plastics[12], published on the ICAO website.

6 https://www.icao.int/Meetings/Stocktaking2023/Pages/default.aspx.
7 https://www.icao.int/Meetings/LTAGStocktaking2024/Pages/default.aspx.
8 https://greeningtheblue.org/
9 https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx.
10 https://greeningtheblue.org/sites/default/files/interactive-report-landing/Annual-Report-2024-GtB.pdf.
11 https://www.icao.int/Meetings/greenairports2024/Pages/default.aspx.
12 https://www.icao.int/environmental-protection/Documents/Eco-Toolkit - Single Use Plastics.pdf.

United Nations Biodiversity Conference (COP15)

The 15th Conference of the Parties (COP15) to the Convention on Biological Diversity was held in December 2022 in Montreal, Canada, with theme of "Ecological Civilization – Building a Shared Future for All Life on Earth". During the High-level Segment of the conference, the Secretary General of ICAO provided a keynote statement, highlighting the recent ICAO achievements at the Assembly, and how ICAO's ongoing work (e.g. sustainability criteria and eligible emissions units for CORSIA, as well as sustainable airport operations) were relevant and support the achievement of post-2022 biodiversity framework.[13]

The ICAO Secretary General also provided a statement at the UN Heads of Agencies Dialogue[14] organized by the UN EMG, and participated in several bilateral meetings with high-level representatives of States and international organizations to discuss possible areas of cooperation.

Concluding remarks

As climate change remains a pressing global challenge, ICAO is committed to advancing efforts to address international aviation emissions in pursuit of the Long-Term Aspirational Goal (LTAG). This will involve strengthening and expanding collaboration with a wide range of stakeholders—including Member States, UN agencies, international organizations, and other relevant entities—to harness collective synergies in tackling the climate crisis.

13 https://www.youtube.com/watch?v=XtFzqLJKCRo&list=PLjpSs1uejVAnS4vr52XdS0ye22E4cPEI2&index=35.
14 https://enb.iisd.org/implementing-common-approach-biodiversity-post-2020-gbf?utm_medium=email&utm_campaign=ENB%20Update%20-%2016%20December%202022&utm_content=ENB%20Update%20-%2016%20December%202022+CID_99dad3f4383b5a3a0785c2edd6bab95d&utm_source=cm&utm_term=Read.

Working Together for Net-Zero by 2050: UNFCCC and ICAO's Joint Efforts

By Ryo Hamaguchi, Woojoo Kim, Bernd Hackmann and Stelios Pesmajoglou (UNFCCC)

The UNFCCC: Building Global Climate Ambition

The United Nations Framework Convention on Climate Change (UNFCCC), in force since 1994, is the primary international treaty addressing the threat of climate change. With near-universal membership (198 Parties), it forms the foundation of the international climate regime, complemented by the 1997 Kyoto Protocol and the 2015 Paris Agreement. Together, these instruments aim to stabilize atmospheric greenhouse gas (GHG) concentrations at safe levels and within timeframes that support ecological and socio-economic resilience.

Under the Paris Agreement, agreed in 2015, countries committed to limiting the global average temperature increase to well below 2°C, while pursuing efforts to cap temperature rise at 1.5°C above pre-industrial levels. Achieving these temperature goals requires peaking global GHG emissions rapidly, followed by steep reductions to reach global net-zero emissions in the second half of the century. This objective requires all sectors to put forward ambitious mitigation strategies.

The Paris Agreement introduced a robust architecture of mitigation, adaptation, means of implementation (finance, technology, capacity building) and transparency, and set in motion a dynamic process of increasing ambition through Global Stocktakes (GSTs) to be completed every five years, as well as new and more ambitious nationally determined contributions (NDCs).

Distinguishing Responsibilities: Domestic vs. International Aviation Emissions

Thirty years after the Convention's entry into force and ten years after that of the Paris Agreement, implementation of mitigation action on a global scale and across all sectors needs further strengthening.

According to the World Meteorological Organization,[1] 2024 was registered as the warmest year on record, exceeding pre-industrial levels by 1.5°C for the first time in recorded history. UNFCCC's 2024 synthesis report of NDCs projected that the global average temperature is on course to reach 2.1–2.8°C even with full implementation of all current NDC targets and the International Civil Aviation Organization (ICAO) mid-term global aspirational goal.

The overall achievement of the Paris Agreement's long-term global average temperature goals does not distinguish between emissions sources, whether from international aviation or other sectors. However, emissions from domestic and international aviation are managed differently.

The Intergovernmental Panel on Climate Change (IPCC) provides the methodological basis for reporting aviation emissions to the UNFCCC. Domestic aviation emissions are included in national totals under the UNFCCC. International aviation emissions, those from flights between two or more countries, are estimated as part of national GHG inventories, but are not attributed to individual countries

1 https://library.wmo.int/records/item/69455-state-of-the-global-climate-2024

under the UNFCCC and are not included in national totals; instead, they are reported separately.[2]

While under the UNFCCC process, the focus has been on emissions from domestic sources, emissions from international aviation—estimated at 1.2% of global GHG emissions[3]— are addressed through ICAO as recognized in both UNFCCC and Paris Agreement negotiations. This distinction underpins the division of responsibilities: countries account for domestic emissions under their NDCs, while international aviation emissions are managed through ICAO-led initiatives, including the ICAO Long-Term Aspirational Goal (LTAG) and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

UNFCCC–ICAO Linkages: Parallel and Complementary Action

The UNFCCC and ICAO have a long-standing cooperation that spans the last 30 years, going back to the 1st Conference of the Parties (COP1) to the Convention, in 1995, which invited ICAO to update Parties to the UNFCCC on its efforts to address emissions from fuels used in international aviation.[4] In response, ICAO has been providing regular reports on its progress in addressing international aviation emissions at each UNFCCC session.

The cooperation between UNFCCC and ICAO is becoming increasingly critical as the climate crisis intensifies. In this regard, while governments have started developing new and more ambitious NDCs under the Paris Agreement –due in 2025 – ICAO, its Member States and industry stakeholders have advanced their efforts in mitigating GHG emissions from international aviation.

Over the years, governments (working through both UN entities) have been engaging in comparable activities towards the achievement of respective goals and ambitions, as highlighted below.

UNFCCC	ICAO
Global Stocktake (GST) outcomes	LTAG and ICAO Global Framework for SAF, LCAF and other Aviation Cleaner Energies
Nationally Determined Contributions	State Action Plans
Article 6 mechanisms	CORSIA
New Collective Quantified Goal (NCQG)	ICAO Finvest Hub
Transparency Framework and BTRs	LTAG monitoring and reporting, CORSIA Monitoring, Reporting and Verification (MRV)
Adaptation Framework	Aviation adaptation work (e.g., resilience planning)

These connections reflect a whole-of-government and all-sectors approach to decarbonization and climate resilience.

Mitigation and Decarbonization

The first Global Stocktake (GST1) outcome at COP28 called for a just and equitable transition away from fossil fuels, emphasizing renewable energies, energy efficiency and low-carbon fuels.[5] This aligns with ICAO's LTAG for net-zero carbon emissions from international aviation by 2050 and the Global Framework for Sustainable Aviation Fuels (SAF), Lower Carbon Aviation Fuels (LCAF), and other Aviation Cleaner Energies.[6] ICAO estimates that SAF and similar fuels could potentially contribute up to 55% of the emissions reductions needed to meet the LTAG target.[7]

Market-Based Mechanisms

Article 6 of the Paris Agreement enables international carbon markets. At COP29, Parties finalized the operational framework for carbon markets under Article 6 of the Paris Agreement that allows for higher mitigation ambitions in a cost-effective manner, including the rules for authorizing the trade of carbon credits and operationalizing the associated registries.[8] In parallel, ICAO's CORSIA addresses emissions from international flights which cannot be addressed through in-sector measures alone.

2 The IPCC definition for domestic/international emissions is based on the country that supplies the aviation fuel, which is different to the ICAO definition that is based on the nationality of the carrier that uses the aviation fuel.
3 https://unfccc.int/documents/641792
4 https://unfccc.int/resource/docs/cop1/07a01.pdf#page=15
5 https://unfccc.int/sites/default/files/resource/1_CMA.5.pdf
6 https://www.icao.int/Meetings/CAAF3/Documents/ICAO%20Global%20Framework%20on%20Aviation%20Cleaner%20Energies_24Nov2023.pdf
7 https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx
8 https://unfccc.int/documents/644471

While differing in scope and design, both mechanisms contribute to cost-effective emissions reductions and environmental integrity.

Climate Finance and Investment

To bridge the climate finance gap, COP29 established the New Collective Quantified Goal (NCQG), calling on all actors to work together to enable the scaling up of financing for climate action in developing countries from all public and private sources to at least USD 1.3 trillion annually by 2035, and setting a target for developed countries to take the lead in mobilizing at least USD 300 billion per year for developing countries by 2035.[9]

ICAO, for its part, is operationalizing the Finvest Hub—a platform to facilitate private and public investments in sustainable aviation, particularly in developing countries.[10]

Looking Ahead to COP30 and ICAO Assembly 42

The Incoming COP30 President has called for a global ***Mutirão***—a collective effort—against climate change[11] and is currently engaging with other Parties on how to intensify efforts towards the achievement of the temperature goals of the Paris Agreement.

COP30 will mark the first test of the GST's influence on NDC ambition. Around 20 new or updated NDCs have been submitted so far, with more expected throughout 2025.[12] These new NDCs are anticipated to make further progress towards the achievement of global GHG emissions reductions of about 60% by 2035 relative to the 2019 level that are consistent with 1.5°C pathways according to the IPCC.[13] Their collective impact will be analyzed in the UNFCCC's 2025 synthesis report, which will be published before COP30.

Regarding the current implementation status, as of 15 April 2025, around 100 Parties had submitted their first biennial transparency reports (BTRs) that track progress in implementing their current and previous NDCs.[14] A synthesis report for these BTRs will also be published before COP30.

With the NCQG in place, the focus has now turned to mobilizing financial resources for the realization of the targets outlined in Parties' NDCs. This includes work on how to mobilize USD 1.3 trillion annually under the Baku to Belém Roadmap. The COP29 Presidency and the Incoming COP30 Presidency will produce a report summarizing the results of this work in advance of COP30.

The 42nd ICAO Assembly presents an opportunity to advance the work on GHG emissions from international aviation through making further progress on the achievement of the collective medium-term global aspirational goal of keeping global net carbon emissions from international aviation at the same level as in 2020, and of the LTAG, while further pursuing the implementation of ICAO CORSIA. A successful outcome of the 42nd ICAO Assembly can provide renewed impetus for a COP30 outcome that will drive further ambition and implementation.

Final Remarks

Achieving net-zero carbon emissions by 2050 is a global imperative. The UNFCCC and ICAO have distinct but complementary roles towards this goal. Through enhanced cooperation and coherent implementation of respective processes, including mitigation, market-based mechanisms, finance, and transparency, the international community can deliver on the promise of the Paris Agreement—ensuring a safe and sustainable future for all.

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9 https://unfccc.int/documents/644460
10 https://www4.unfccc.int/sites/SubmissionsStaging/Documents/202411091958---ICAO%20Submission_SBSTA61_Final.pdf?_gl=1*1w4zi4e*_ga*MTg5MTI4MjczNi4xNzMwMTA3Njcw*_ga_7ZZWT14N79*MTc0NDgzNjgyMi42MjguMS4xNzQ0ODM2ODM1LjAuMC4w
11 https://cop30.br/en/brazilian-presidency/letters-from-the-presidency/letter-from-the-brazilian-presidency
12 https://unfccc.int/NDCREG
13 IPCC. 2023. *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team, H Lee, and J Romero (eds.). Geneva: IPCC. Available at https://www.ipcc.ch/report/ar6/syr/ .
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ICAO Carbon Emissions Calculator (ICEC): a reference tool for estimating carbon emissions

By ICAO Secretariat

As part of the ICAO's leadership role on all matters in addressing aviation emissions, ICAO developed and udaptes the ICAO Carbon Emissions Calculator (ICEC), which provides a standardized, transparent method for estimating carbon emissions from air travel, and it is the only internationally-approved tool of its kind.

To undertake this effort, ICAO developed a publicly available methodology[1], through the ICAO Committee on Aviation Environmental Protection (CAEP), to calculate carbon dioxide (CO_2) emissions from air travel. This methodology provides the basis for the ICEC[2], which allows the estimation of CO_2 emissions attributed to passengers and cargo transported by air on a specific route.

The ICEC is available in different interfaces such as:

- An online version publicly accessible from the ICAO website[3].
- An API[4] that allows automatic integration with software, webpages, or mobile applications released by third-party organizations
- Tailored standalone tools and databases developed on ad-hoc basis for third parties.

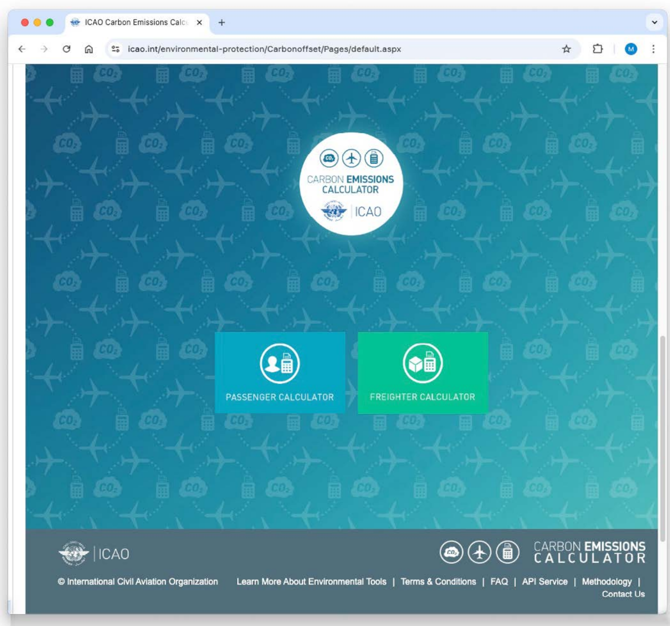

FIGURE 1: ICAO Carbon Emissions Calculator online version.

The methodology used by the ICAO calculator[1] incorporates the best publicly available industry data to account for key factors such as aircraft types, route specific data, passenger load factors and cargo carried. The ICAO fuel formula (IFF) is used to estimate aircraft fuel consumption based on the distance flown.

1 https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology ICAO Carbon Calculator_v11-2018.pdf
2 https://applications.icao.int/icec
3 http://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx
4 https://www.icao.int/environmental-protection/CarbonOffset/Pages/ICEC-API-Pricing-Table.aspx

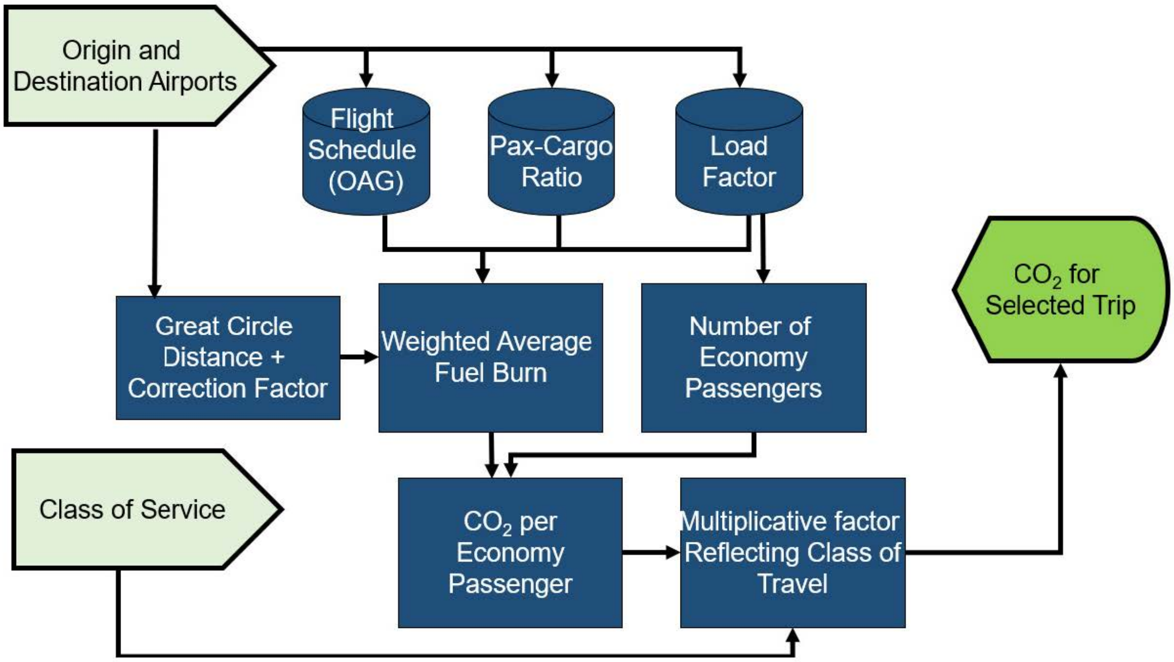

FIGURE 2: ICAO Carbon Emissions Calculator methodology and databases.

Although the only user inputs required for the ICEC tool are origin/ destination airports and the class of service, the ICAO calculator uses a series of databases - including the global airline schedules data, Cargo/ Passengers Ratio, Load Factors, and aircraft seat configuration - to generate accurate emissions estimates (see Figure 2).

The ICAO methodology is continuously refined by a dedicated group of technical experts from CAEP, and the databases used by ICEC are regularly updated to ensure accuracy and reliability.

Recent enhancements to the ICAO Carbon Emissions Calculator (ICEC)

Following growing interest from the UN, the general public, and freight forwarders in receiving CO_2 information on air cargo shipments, ICAO has extended the capabilities of its Carbon Calculator to estimate carbon emissions associated with these activities. This new cargo function is accessible from the updated online interface of the ICEC (see also Figure 1).

The ICEC methodology and online tool were recently revised to increase the number of cabin classes modeled from two (economy class and premium classes) to four (economy class, premium class, business class, and first class). This enhancement improves the accuracy of ICEC, as the previous model may have overestimated the number of economy seats on a given airline, potentially underestimating the carbon footprint per seat across cabin classes.

Using publicly available data—such as U.S. BTS data, which was previously used to develop ICAO's Fuel Formulae—new aircraft types have been added to the IFF database, resulting in 4,190 new city pairs operated exclusively by these newly introduced aircraft types.

Finally, ICAO is advancing work to provide ICEC users with information on the availability of SAF at certain airports, based on data collected through the ICAO Airports SAF tracker[5].

5 https://www.icao.int/environmental-protection/SAF/Pages/Airports.aspx

UN-system-wide use of the ICAO Carbon Emissions Calculator (ICEC)

In April 2009, the UN Environmental Management Group (EMG)[6] adopted the ICAO Carbon Emissions Calculator as the official tool for all UN entities to quantify their air travel CO_2 footprint, in support of the UN Climate Neutral initiative. Since then, interfaces to the calculator have been made available to UN environmental sustainability focal points, travel offices, and enterprise resource planning (ERP) systems, as well as through a special agreement with CRS companies such as Amadeus. Some UN travel offices have integrated the ICAO Calculator directly into their travel reservation and approval systems, providing real-time information to assist travel planning decisions.

Almost all organizations that report their greenhouse gas (GHG) inventories to the UN EMG Greening the Blue[7] initiative are using the ICAO Calculator. The adoption of the ICAO Calculator, as a common UN methodology and interface across the UN system, facilitates the aggregation of air travel emissions data, ensuring integrity and consistency in reported inventories.

The ICAO Calculator is also used to estimate the carbon emissions generated by major UN meetings, including the UNFCCC COPs, the UN Climate Summit, and the UN Environmental Assembly.

ICAO continues to actively support all UN agencies in quantifying and managing their air travel emissions by regularly updating the ICAO Carbon Emissions Calculator and providing ongoing technical assistance.

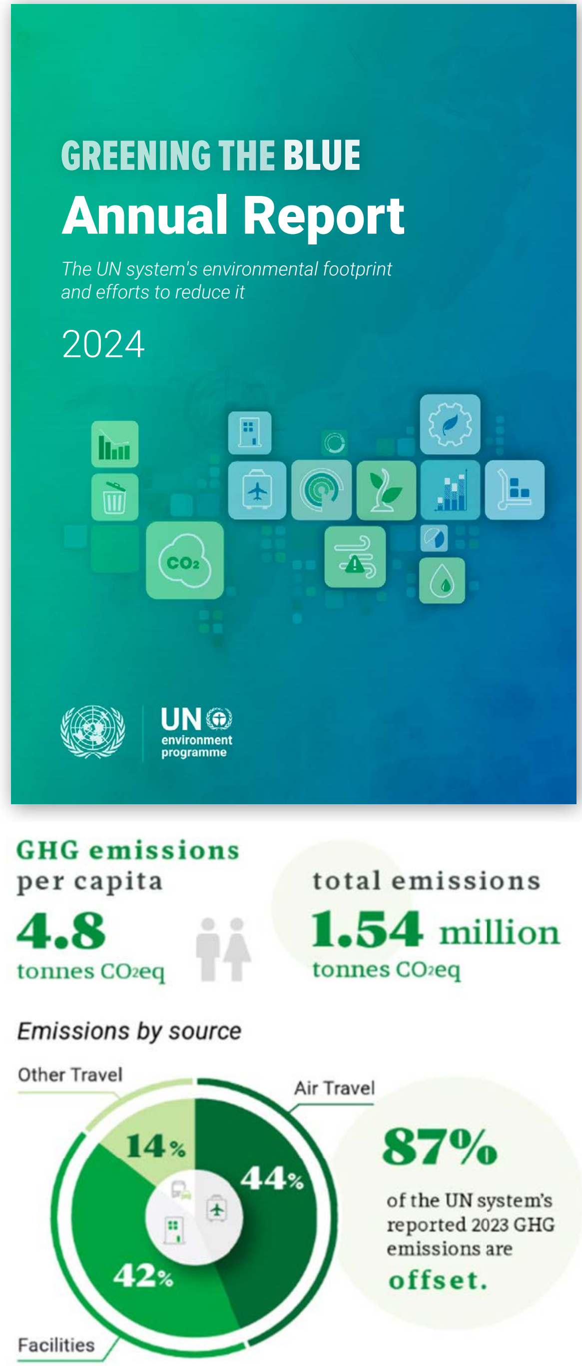

FIGURE 3: UN Greening the Blue Report and GHG Emissions inventory.

6 https://unemg.org/
7 https://greeningtheblue.org/interactive-report/2024.html#greenhouse

The Role of Aviation in the UN Decade of Sustainable Transport 2026–2035

By Riina Jussila (UN-DESA)

United Nations Department of Economic and Social Affairs (UN-DESA)

ICAO's long-standing cooperation with UN-DESA continues including through provision of technical inputs to UN General Assembly mandated processes and the organization of various UN system wide events.

Rooted in the United Nations Charter and guided by the transformative 2030 Agenda for Sustainable Development, DESA upholds the development pillar of the United Nations. It does this by providing intergovernmental support, analysis and capacity-building on various areas of sustainable development.

The Role of Aviation in the UN Decade of Sustainable Transport 2026–2035

In 2023, the General Assembly declared the first ever United Nations Decade of Sustainable Transport to start in 2026. Through the resolution A/78/148 titled "Strengthening the links between all modes of transport to achieve the Sustainable Development Goals" Member States also requested DESA to develop an Implementation Plan for the UN Decade of Sustainable Transport, in collaboration with the UN Regional Commissions and in consultation with the Member States, the United Nations system and all other relevant stakeholders.

The UN Decade of Sustainable Transport will be an opportunity to raise awareness of transport's crucial role in advancing the Sustainable Development Goals (SDGs) and to gather and rally new solutions, resources and partnerships to advance sustainable transport globally. It will encourage action on all modes of transport — aviation, maritime and inland transport.

While there is no single dedicated SDG for transport, it is reflected in several SDG targets and recognized as an enabler for achieving many of the goals. ICAO has provided technical input to the development of the Implementation Plan to ensure that aviation's role in advancing the SDGs will be well reflected in the Plan. The Plan will address transport's — and aviation's — linkages with topic such as resilient infrastructure development, economic growth, trade, global supply chains, food security, promotion of health, energy efficiency, and climate change. The Implementation Plan will serve as a framework to encourage and reflect the international aviation sector's actions towards sustainable development throughout the UN Decade of Sustainable Transport 2026–2035.

Partnering to Bolster Impact: the Sustainable Mobility for All (SuM4All) initiative experience

By Shokraneh Minovi (World Bank & SuM4All)

Partnerships are critical to advancing sustainable mobility goals because they enable collaboration, leverage diverse expertise and resources, and drive collective action toward complex challenges that no single sector or organization can solve alone.

The **Sustainable Mobility for All (SuM4All)** initiative, hosted by the World Bank, is a global, multi-stakeholder partnership of over 60 international organizations that aims to steer the global mobility sector toward sustainable, inclusive, efficient, and safe transport systems. Members include multilateral development banks, United Nations agencies (including ICAO), bilateral donor organizations, non-governmental organizations, civil society, and academic institutions.

SuM4All is one of the few partnerships embracing all modes of transport, including aviation, public transport, rural, maritime, active mobility, rail, and road transport. While SuM4All's core work has historically focused on ground transport, its collaborative framework increasingly intersects with other modes of transport including aviation stakeholders as the push for comprehensive, sustainable mobility grows.

SuM4All provides a platform for coordinated advocacy where aviation stakeholders can participate in global dialogues on climate action in transport, advance global campaigns to reduce aviation emissions, and deliberate on shared frameworks and action agendas. Some examples of these collaborations include:

- SuM4All collaborates with aviation stakeholders, including ICAO (International Civil Aviation Organization) and IATA (International Air Transport Association)—to discuss policies that support the Sustainable Development Goals (SDGs). Activities include promoting low-carbon aviation policies, encouraging sustainable aviation fuel (SAF) adoption, and supporting decarbonization roadmaps aligned with the Paris Agreement temperature goals.
- SuM4All's Global Mobility Database and Global Tracking Framework facilitate data-driven decision-making by consolidating transport sector metrics, including from aviation. They work with aviation actors to improve emissions tracking, safety standards, and connectivity metrics, and include aviation in broader mobility assessments.
- SuM4All engages in cross-sectoral research initiatives, leveraging expertise from aviation organizations to explore sustainable transport technologies and innovation, study the integration of multimodal transport systems, including air travel in land-air logistics chains, and identify barriers to equitable access to air transport, especially for developing regions.

In summary, SuM4All's partnerships with aviation stakeholders adopt a systems-level approach to sustainability—reflecting aviation's contributions to environmental, social, and economic sustainability.

Paving the Way to Sustainable Aviation

SAF is widely recognized as the most critical lever in the aviation industry's path to net-zero carbon emissions by 2050, expected to deliver **up to 58 percent** of the total emissions reductions required according to the World Bank Report from 2022. These fuels can significantly lower lifecycle emissions compared to conventional jet fuel. Its compatibility with existing aircraft and infrastructure makes it a near-term solution with long-term impact, positioning SAF at the heart of aviation's decarbonization strategy. For these reasons, the World Bank is actively supporting efforts to scale up SAF development and deployment, making it a key priority on its sustainable transport agenda.

Enabling Greener Skies: The World Bank's Role in Advancing Sustainable Aviation

The World Bank is committed to developing a sustainable air transport sector in the Global South, and among its objectives, the multilateral institution aims to support the growth of the SAF industry and the implementation of airport and air navigation operational improvements in developing countries.

Regarding SAF production globally, countries outside the Organisation for Economic Co-operation and Development (OECD) remain significantly underrepresented in the SAF supply chain, often relegated to just exporting raw feedstocks while importing refined SAF. This difference is due mainly to the significant capital investment needed to expand SAF production. Projections by the World Bank indicate that scaling SAF globally will require annual greenfield investments of up to $124 billion, culminating in over 370 SAF–producing facilities by the late 2030s and early 2040s. The size of this investment underscores the opportunity for developing countries to move beyond raw material exportation to becoming integral players in SAF production.

In this sense, the Bank has acknowledged the opportunities and potential of the African continent within the SAF value chain, as the continent's aviation sector faces the dual challenge of reducing emissions amid rapid growth. Despite high costs, limited infrastructure, and fragmented policies, coordinated efforts and investments could enable Africa to become a key global player in sustainable aviation. Developing a local SAF industry would offer both environmental and economic benefits, including lower emissions, reduced reliance on imported fuel, job creation, and improved energy security.

The World Bank is partnering with national governments and private stakeholders to support a collaborative transition to SAF in Africa. A study is underway to assess SAF production costs and technologies in four high-potential countries: Kenya, Ethiopia, Nigeria, and South Africa. These countries offer strategic advantages due to their feedstock availability, infrastructure, and policy frameworks. Kenya focuses on used cooking oil (UCO) and castor; Ethiopia leverages sugarcane and municipal solid waste (MSW); South Africa has industrial capacity and Fischer Tropsch (FT) expertise; and Nigeria benefits from refining capacity and airport proximity. Together, they highlight Africa's strong potential in the SAF value chain.

Achieving scalable SAF production in Africa requires addressing two key cost drivers: risk premiums—due to higher capital and financing costs in African markets—and green premiums—the additional cost of choosing sustainable fuels over conventional jet fuel. Investment de-risking could significantly reduce SAF production costs, but a substantial green premium remains. For example, SAF still costs 47–69% more than jet fuel in countries like Kenya, Ethiopia, and South Africa. Support from multilateral development banks, through concessional loans, grants, and blended finance, is essential to bridge these gaps. With the right financial mechanisms, Africa—especially Kenya, Ethiopia, Nigeria, and South Africa—has strong potential to become a key player in the global SAF supply chain.

As noted above, the World Bank's support for sustainable aviation goes beyond SAF industry development; it also assists developing countries in reducing aviation-related GHG emissions through operational improvements in airport infrastructure and air navigation systems.

The World Bank is supporting climate-smart airport upgrades across regions. In Haiti, improvements to the taxiway system at Port-au-Prince Airport (PAP) are expected to cut GHG emissions by 1.25 million kg of CO_2

annually, thanks to reduced aircraft turnaround times and fuel consumption. In China, the Shangrao Sanqingshan Airport, built in 2018 with Bank support, showcases sustainable design with features like energy-efficient systems, stormwater reuse, and ground source heat pumps. It achieved EDGE certification, with 24% energy, 42% water, and 38% material savings, and enhanced regional connectivity. In Saint Lucia, the installation of a new Instrument Landing System (ILS) at Hewanorra Airport (UVF) will reduce flight delays and diversions in poor weather, while energy-efficient lighting and equipment will further cut emissions—supporting the Port of Spain Declaration goal of reducing CO_2 emissions by 40,000 tons per year through performance-based navigation (PBN). These initiatives highlight how targeted investments can improve operational efficiency, resilience, and environmental performance in the air transport sector.

Driving Change Through Cross-Sector Collaboration

Fostering **multistakeholder partnerships** that bridge aviation with other modes of transport is key to creating a **cohesive and sustainable global transport ecosystem**. To achieve this, strategies must focus on collaboration, integration, and shared goals that address environmental, economic, and social challenges.

To bridge aviation with other transport modes, stakeholders should enhance collaboration on **common sustainability targets**, such as net-zero emissions by 2050 and inclusive mobility while respecting the unique characteristics of each sector and the leadership roles of their respective organizations. Governments, aviation authorities, and transport sectors could work together in policy forums and regulatory frameworks to create a unified vision for sustainable mobility.

Creating **multimodal hubs**—integrated transport terminals that combine air, rail, and road networks—enhances connectivity and reduces inefficiencies. By investing in smart infrastructure and digital solutions, stakeholders can enable seamless transitions between transport modes. Technological innovations like Mobility-as-a-Service (MaaS) platforms, electric aviation (eVTOLs), and SAF are key to reducing carbon footprints across all transport sectors and ensuring a more interconnected, sustainable transport ecosystem.

Successful integration of aviation with other transport modes requires broad **stakeholder engagement**, including **governments**, **private sector actors**, and **civil society**. This is where SuM4All plays an integral part by involving all relevant parties across all transport sectors to help create a cohesive environment and facilitate smoother integration between air, rail, and road systems.

Message from the Secretary-General of the International Transport Forum (ITF)

By Young Tae Kim (IFT)

Aviation has long played a vital role in connecting people, communities and economies across the globe. It is one of the defining enablers of global mobility. But like all sectors, it must now rise to the challenge of operating sustainably in a changing climate. The imperative is to ensure connectivity can continue without placing undue strain on the environment. Achieving this goal will require both innovation and policy action, underpinned by sustained international cooperation.

As the only intergovernmental organisation covering all modes of transport, the International Transport Forum (ITF) works to support countries in this transition. By generating evidence, convening partners and identifying practical solutions, the ITF aims to help governments and industry navigate the complex path towards sustainable transport systems — aviation included.

The ITF's partnership with the International Civil Aviation Organization (ICAO) reflects this commitment. Since 2015, the two organisations have worked together through a formal Memorandum of Co-operation, focusing on key areas such as liberalisation, infrastructure, safety and environmental sustainability. This agreement, which was renewed in 2019 and again in 2024, has deepened the collaboration between our technical and policy communities.

A prominent example is ITF's contribution to international policy discussions on sustainable aviation fuels (SAF). In 2023, the ITF released Sustainable Aviation Fuels: A Global Policy Perspective, a report that takes stock of national SAF strategies and offers guidance on how to accelerate deployment. The report draws directly from discussions held at the 41st ICAO Assembly, which helped shape its structure and recommendations.

The report identifies four areas for policy action. First, it emphasises the importance of credible long-term signals to guide investment. Without stable demand expectations, market actors are unlikely to invest at the scale required. Second, the report calls for clearer and more harmonised sustainability frameworks. Differing criteria across jurisdictions risk undermining confidence, distorting markets, and fragmenting supply chains. Third, the report recommends well-designed support mechanisms to reduce risk for early investors and technology developers. These may include contracts-for-difference, blending mandates, or price floors, adapted to national circumstances. Finally, the report highlights the importance of international coordination. Because aviation is a global sector, fragmented approaches to SAF deployment can limit effectiveness and create inefficiencies. Aligning technical standards, sustainability benchmarks and reporting systems across borders will be critical to accelerating the global scale-up of SAF production and use.

The ITF also engages directly in global climate policy processes. As co-focal point for transport under the UNFCCC's Marrakech Partnership, the ITF helps foster exchanges between national governments and non-Party stakeholders, including cities, industry and civil society. At COP 29, the organisation launched a guide to support the integration of transport into countries' Nationally Determined Contributions. This is a step towards giving the sector the prominence it warrants in national decarbonisation plans.

Evidence remains the foundation of all effective policy. ITF's Transport Climate Action Directory is an open-access repository featuring over 80 mitigation measures across all transport modes. Among aviation-specific resources, it includes detailed information and references on strategies such as SAF deployment, improved aircraft efficiency and enhanced air traffic management. The directory, which was formally endorsed by UN Climate Change, is designed to help decision-makers identify and implement the most impactful options in accordance with national context and priorities.

Sustainability and equity go hand in hand. The ITF works with member countries to assess investment pathways, facilitate knowledge exchange, and provide capacity-building opportunities. We also advocate for a just transition: one that respects workers, strengthens communities, and ensures that the benefits of sustainable mobility are shared widely.

Working with the private sector is another integral part of ITF's approach. The ITF Corporate Partnership Board, established in 2013, aims to bring business leaders into the policy conversation. It has supported projects on automation, artificial intelligence, shared mobility and emerging business models. It also provides a platform to amplify innovative solutions from the Global South and promote inclusion, focusing on gender equality and youth engagement.

There is no single pathway to decarbonising aviation. But there is a shared responsibility to act. The ITF remains committed to supporting this transformation, both as a source of policy insight and as a platform for collaboration. With the support of our broad network of partner governments and organisations, including ICAO, we can believe in a future where transport systems connect the world in efficient, accessible, and sustainable ways.

Message from the Executive Secretary of the Convention on Biological Diversity (CBD)

By Astrid Schomaker (CBD)

In a time of accelerating environmental degradation, the protection, restoration and sustain of biodiversity has emerged as a defining global challenge—one that calls for urgent, collective and decisive action. As Executive Secretary of the Convention on Biological Diversity (CBD), I welcome the growing engagement of the International Civil Aviation Organization (ICAO) and its Member States in supporting efforts to halt biodiversity loss. Your participation in this global endeavor is not only timely—it is essential.

Biodiversity is the foundation of life on Earth. It sustains vital ecosystem services, supports climate stability, and underpins the resilience of our economies and societies. Yet biodiversity is being lost at an alarming rate, with profound consequences for people and planet alike. The adoption of the Kunming-Montreal Global Biodiversity Framework in 2022 marked a historic moment of international consensus and commitment. Now, the world must translate that vision into coordinated action which requires both intersectoral and multistakeholder collaboration on a scale we have not seen before.

The drivers of biodiversity loss are complex, interconnected, and deeply embedded in our economies and our lives. Reversing this trend demands bold, system-wide responses. It also demands that all segments of society—governments, industries, civil society, indigenous people and local communities, women, youth, scientists, and international bodies—work together with shared purpose and mutual accountability.

In this context, ICAO's leadership in working towards aligning aviation with sustainability goals is very timely and welcome. But we must go further. The aviation sector has a powerful platform to convene and collaborate—bringing together policymakers, regulators, technology developers, financiers, and communities to explore solutions that protect ecosystems while enabling connectivity and economic development. This kind of broad-based, inclusive engagement is precisely what the Global Biodiversity Framework calls for.

I urge ICAO and its stakeholders to continue fostering partnerships—not only within the transport and environment sectors but across the full spectrum of actors whose decisions shape land use, infrastructure, technology, finance, and resource governance. Enhancing transparency, sharing data, aligning investments, and embedding biodiversity considerations across all levels of planning and operation will be key to success.

As we navigate the path ahead, let us remember that safeguarding nature is not a task for a few—it is a shared responsibility for all. Through deeper cooperation, collective ambition, and inclusive governance, we can chart a course where aviation thrives as part of a sustainable future.

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