BRIEFING

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Towards Net-Zero Aviation State Action Plans

Authors: Shraeya Mithal and Dan Rutherford

BACKGROUND

On October 7, 2022, at its 41st Assembly, the International Civil Aviation Organization (ICAO) adopted a long-term aspirational goal (LTAG) to decarbonize aviation. Under the agreement, governments pledged to achieve net-zero carbon dioxide (CO_2) emissions by 2050 through policies to promote new technologies like low carbon fuels and zero emission planes. The agreement follows a string of climate commitments within United Nations organizations. Most notably, the Paris Climate Agreement of 2015 committed 194 countries to hold global warming to well below 2°C (WB2C), preferably at 1.5°C. Previous ICAO agreements like the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), adopted in 2016, rely on carbon offsets; under the LTAG, ICAO encourages countries to develop new in-sector technologies to reduce emissions directly.[1]

The agreement places the onus of action on member countries. It requests that countries submit a State Action Plan (SAP) detailing measures to reduce aviation emissions consistent with the 2050 net-zero target by June 2024. SAPs are voluntary planning and reporting tools that countries use to inform ICAO regarding aviation emissions reduction strategies and outline any environmental or economic impacts of those reductions. SAPs cover plans for aircraft purchases, new airports, fuels, and offsetting measures like the CORSIA initiative or carbon capture and storage to achieve the net-zero goal. SAPs have been a primary tool for countries to report to the ICAO on their current aviation-related emissions and aviation industry prospective developments.

Countries have submitted SAPs to the ICAO since 2013, but the new international agreement raises the stakes for action by member countries. Indeed, as countries begin

1 International Civil Aviation Organization (ICAO), "Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection—Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)," October 2022, https://www.icao.int/environmental-protection/CORSIA/Documents/Resolution_A41-22_CORSIA.pdf.

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to prepare new SAPs to support the LTAG agreement, member countries could benefit from clearer guidance from the ICAO on what information they should include in their SAPs. However, providing clearer guidance will be challenging; the agreement does not assign emission reduction goals to individual countries or their carriers or set interim targets to demonstrate progress by 2030, for example.

This briefing clarifies how SAPs can be improved to help achieve CO_2 emission reduction goals. Specifically, we identify information that is missing in current SAPs and highlight areas that could be clarified to help determine if SAPs present viable net-zero pathways. This paper starts with an overview of published decarbonization pathways, followed by our methodology for reviewing existing SAPs. We then compare our results with four country-level case studies and close with policy conclusions.

PATHS TO DECARBONIZE AVIATION

Rapid action to decarbonize the aviation sector is required; even achieving net-zero aviation emissions by 2050 does not necessarily ensure that the goals of the Paris Agreement will be fully achieved. Compatibility with temperature targets is assessed through cumulative emissions. This means that, depending on the pathway, reaching the same 2050 net-zero goal could equate to anywhere from a 1.6 to 2.3 degree C temperature increase if the aviation sector does not increase its share of global CO_2 emissions above 2019 levels.

In the lead-up to the 2022 net-zero agreement, various organizations developed decarbonization roadmaps.[2] These roadmaps detail the mix of sustainable aviation fuels (SAFs), technical and operational fuel efficiency improvements, zero-emission planes (ZEPs), and out-of-sector measures consistent with the target. Figure 1 illustrates that different net-zero paths lead to different 2050 global temperature increases by showing normalized aviation emissions from various net-zero roadmaps.

2 In addition to the four report discussed below, these also include: Federal Aviation Administration, "United States 2021 aviation climate action plan," (November 2021), https://www.faa.gov/sites/faa.gov/files/2021-11/Aviation_ Climate_Action_Plan.pdf; Department for Transport, "Jet zero strategy: Delivering net zero aviation by 2050," (July 2022), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/ %20attachment%20data/file/1095952/jet-zero-strategy.pdf; Mission Possible Partnership, "Making net-zero aviation possible: An industry backed, 1.5C-aligned transition strategy, (July 2022), https://missionpossiblepartnership.org/wp-content/%20uploads/2022/07/Making-Net-Zero-Aviation-possible.pdf.

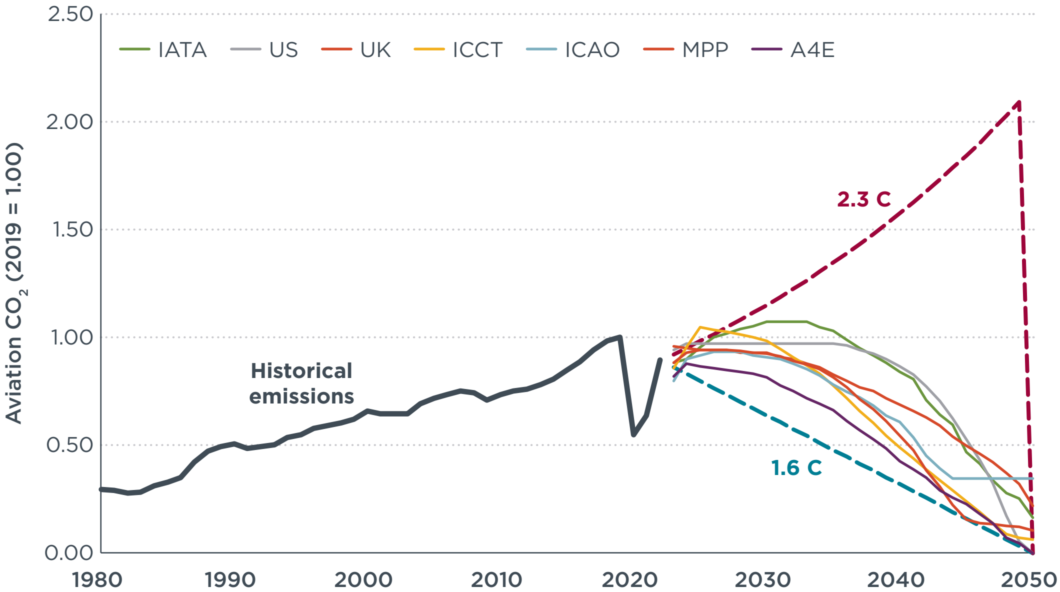

Figure 1. Historical and projected aviation CO_2 emissions by roadmap, 1980–2050.

In *Waypoint 2050*, the Air Transport Action Group's (ATAG) most aggressive scenario estimated that sustainable aviation fuels will provide more than half (53%) of cumulative CO_2 reductions through 2050, followed by ZEPs (24%), operational and infrastructural improvements (17%), and market-based measures (6%).[3] Airlines 4 Europe's *Destination 2050* roadmap made similar estimates. In their scenario, ZEPs and technical efficiency improvements contribute 38% of emissions reductions, SAFs 34%, SAF-induced demand change 12%, market-based measures 10%, and operational improvements 6%.[4] The *LTAG report* from the ICAO's Committee on Aviation Environmental Protection also determined that 63% of emissions reductions will come from SAFs, 13% from operational efficiency improvements (CCS) for residual emissions, and 2% from aircraft technologies.[5] The International Council on Clean Transportation's 2022 report *Vision 2050: Aligning Aviation with the Paris Agreement* estimated that the aviation sector could, in the most aggressive scenario, cut greenhouse gas (GHG) emissions consistent with a 1.75°C global warming scenario. In this scenario, SAFs contribute 62% of total mitigation through 2050, operational efficiency improvements 16%, technical efficiency improvements 13%, ZEPs 5%, and out-of-sector measures 5%.[6]

Collectively, these roadmaps show that early and aggressive action will be needed to achieve a net-zero goal. But despite a clear long-term goal, country-level commitments remain varied.

STATE ACTION PLANS

The ICAO recommends that countries include five elements in their SAPs: focal point information such as key stakeholders, airlines, and airports; baseline scenarios; mitigation measures; expected results; and assistance needed. Countries are also encouraged to identify specific limitations to the potential success of their SAPs, like funding, infrastructure, or resources. The ICAO has developed various tools to develop emission

3 Air Transport Action Group (ATAG), "Waypoint 20250," (September 2021), https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf.

4 Airlines 4 Europe (A4E), "Destination 2050 — A route to net zero European aviation," (February 2021), https://www.destination2050.eu/wp-content/uploads/2021/03/Destination2050_Report.pdf.

5 International Civil Aviation Organization (ICAO), "Report on the feasibility of a Long-Term Aspirational Goal (LTAG) for international civil aviation CO2 emission reductions," (March 2022), https://www.icao.int/environmental-protection/LTAG/Documents/ REPORT%20ON%20THE%20FEASIBILITY%20OF%20A%20LONG-TERM%20ASPIRATIONAL%20GOAL_en.pdf

6 ICCT, "Vision 2050."

estimates, such as the Action Plan on Emissions Reduction (APER),[7] ICAO Carbon Emissions Calculator (ICEC), Marginal Abatement Cost Curve (MACC), ICAO Fuel Savings Estimation Tool (IFSET), and Environmental Benefit Tool (EBT). By integrating these tools to help develop the five elements of their SAPs, countries would be able to produce more concrete SAPs with more defined emissions reduction path.

Within those five key elements, SAPs should also highlight cooperation between aviation stakeholders; mitigation and funding relevant to the countries' development status; streamlined policies to support zero-carbon technology; capacity-building opportunities; strategy for policy decisions; pathways for technology transfer; and any assistance needed to achieve the 2050 goal. Member states are expected to submit updated SAPs to the ICAO by June 2024.

The ICAO will serve as an advisory and monitoring body for the net-zero target, not an enforcement body. It aims to support individual countries' net-zero pathways with careful consideration of their available resources and future economic growth. SAPs should thus include clear emission targets, in-sector mitigation goals, and out-of-sector goals to address residual emissions and non-CO_2 impacts. Interim targets will serve to identify whether aviation is on a plausible pathway to net-zero CO_2 by 2050.

CRITERIA FOR ASSESSING CLARITY IN SAPS

This briefing draws upon the SMART analysis framework, which breaks data down between specific, measurable, achievable, relevant, and time-bound characteristics. The SMART framework allows analysts to review qualitative data more uniformly. Specifically, this briefing assesses SAPs through three of the five SMART dimensions: specific, measurable, and time bound.

Two SMART characteristics—achievable and relevant—have not been applied. Assessing achievability requires a level of analysis outside the scope of this briefing. And it is too early to assess relevance since there is currently no methodology for attributing the LTAG to individual countries.

The first dimension, specific, indicates concrete policies and/or reduction targets. An example of a specific measure is to improve the fuel efficiency of new aircraft by 10%. The second, measurable, defines the methodology with which goals should be tracked and measured. An example of a specific and measurable policy is to improve the fuel efficiency of new aircraft by 10% on ICAO's CO_2 certification procedure, compared to a 2019 baseline. The last characteristic, time-bound, assigns a timeframe by which the goal will be achieved. An example of a specific, measurable, and time-bound measure is to improve fuel efficiency of new aircraft by 10% on ICAO's CO_2 certification procedure compared to a 2019 baseline by 2030. We consider SAP language that has all three characteristics to be clear; clear SAPs can be more effectively assessed for their compatibility with the LTAG.

Of the 143 SAPs that have been submitted, 97 are publicly available and accessible in English.[8]

Of those, 12 were released after June 2022. We selected 17 SAPs for review based on their submission date, language, and World Bank income groups. We prioritized SAPs submitted after the June 2022 LTAG agreement to better represent SAPs geared toward the long-term goal. Our review stopped in April 2023.

7 The ICCT does not have visibility on the details of this tool. This tool is exclusively provided to Member States of the ICAO.

8 "State action plan assistance," International Civil Aviation Organization (ICAO), April 2023, https://www.icao.int/environmental-protection/pages/climatechange_actionplan.aspx.

Our review applied the premise that a clear SAP would address three areas with specific, measurable, and time-bound language: 1) long-term and interim emission targets; 2) in-sector goals (SAFs, operational efficiency, technical efficiency, and ZEPs); and 3) out-of-sector goals (emissions trading or carbon pricing measures; emissions offsetting measures, non-CO_2 climate forcers, and CCS).

1. **Clear targets** communicate an interim (2030–40) and long-term (2050) *target*. An interim target can define an emissions trajectory when paired with a 2050 target. A clear long-term target is necessary to assess a given country's emissions pathway.

2. **In-sector goals** represent technologies and practices that bring the most substantial decarbonization results.

    a) SAFs: Given their importance in the technology roadmaps described above, we examined three component measures of SAFs:

        i) Blending/volumetric targets: We assessed whether SAPs including specific information about blending share (%) or volumetric (gallon or L) targets.

        ii) GHG reduction targets: Emission reductions from blending or volumetric targets vary based on the life-cycle GHG emissions of a given fuel. We assessed whether SAPs indicated specific GHG reduction targets and how they would be measured. For example, a specific, measurable, and timebound GHG reduction goal could be to require SAFs to reduce life-cycle emissions (using the CORSIA framework for assessing the life-cycle emissions) by at least 50% compared to fossil jet fuel starting in 2030 on an energy basis measured in (gCO_2e/MJ).

        iii) Economic incentives: We assessed whether SAPs included information about specific incentive programs (including funding and other fiscal measures) and their timing (ex., a timeline for moving through phases from biofuel to more advanced fuels or timeframes for the implementation of economic incentives).

    b) Operational improvements: Examples of specific measures include targeted improvements in air traffic efficiency or flight time reductions. To assess measurability, we reviewed whether SAPs outlined an expected efficiency improvement (in percentage) or reduced flight time from a concrete baseline (e.g., calendar year 2019 operations).

    c) Technical efficiency: We assessed whether SAPs described specific measures to improve fuel efficiency. These could be measured by the ICAO CO_2 metric value, which assesses the fuel efficiency of an aircraft as a function of its weight or through reduction of average fleet age. Moreover, modernizing fleets is a strategy for improving fuel efficiency. For example, India's SAP outlines purchasing more Boeing 737 MAX aircraft, through Air India, to achieve 14–15% greater fuel efficiency compared to previous fleets.[9]

    d) ZEPs: ZEPs powered by hydrogen or electricity are still under development. We assessed whether SAPs specified measures like financial investments in programs. For measurability, we evaluated technologies by the percentage of emission reduction by market share. Finally, to determine whether this measure was time-bound, we searched for a defined target year for ZEPs to be introduced into the market.

9 Directorate General of Civil Aviation, "Managing the carbon footprint of India's civil aviation: India's Action Plan developed in response to the International Civil Aviation Organization (ICAO) 2010 Assembly Resolution A37-19," (June 2021), https://www.icao.int/environmental-protection/Lists/ActionPlan/Attachments/97/DGCA%20India%20SAP%202021%20(revised%20version).pdf.

3. **Out-of-sector goals** will be needed to reduce or offset residual CO_2 emissions and control short-lived climate pollutants emitted when aircraft burn fossil fuels (though these measures are not mentioned in the LTAG agreement).

    a) Emissions trading/carbon pricing, and emissions offsetting: We assessed whether SAPs included specific measures (e.g., mandates within emissions trading or carbon pricing schemes) and metrics (e.g., a carbon price or number of emissions allowances provided for airlines in a trading system). SAPs that indicate offsetting requirements for their carriers are specific, measurable, and timebound if they indicate adherence to all CORSIA rules.

    b) Non-CO_2 policies: Addressing non-CO_2 emissions could help abate aviation's contribution to warming in the near-term.[10] While non-CO_2 mitigation policies are still in development, we examined SAPs to find specific activity such as studies or research on non-CO_2 impacts; we also assessed SAPs to identify any metrics related to non-CO_2 emission mitigations. For example, Canada's SAP outlines plans to study contrail forming zones in Canadian airspace to potentially identify alternative routes to avoid persistent contrail formation.[11]

    c) CCS: Though still in development, CCS could support a net-zero goal either by providing a source of carbon (for e-fuels) or through permanent storage underground to address residual emissions. We examined SAPs for CCS implementation goals, i.e., specific mitigation goals measured million tonnes (Mt) by certain dates.

We considered measures to be time-bound if they included a phased program or dates for entry into service. For example, a reduction of 50% emissions by 2040 is a time-bound goal.

Table 1 surveys the 17 SAPs we assessed. An outlined circle denotes that a country's SAP target or measure is specific but neither measurable nor timebound. A shaded circle denotes that a country's SAP formulation is specific and either measurable or time bound. A combined outlined and shaded circle denotes an SAP formulation that is specific, measurable, and time bound. World Bank income brackets—high, upper-middle, lower-middle, and low—are indicated with colored shading.

10 Milan Klöwer et al., "Quantifying Aviation's Contribution to Global Warming," *Environmental Research Letters, 16*(10): 104027, https://doi.org/10.1088/1748-9326/ac286e.

11 Transport Canada, "Canada's aviation climate action plan 2022–2030," (2022), https://www.icao.int/ environmental-protection/Documents/ActionPlan/CANADAs-AVIATION-CLIMATE-ACTION-PLAN-2022-2030.pdf.

Table 1. Survey of SAPs.[12]

Goal	Focus	Measure	HIGH INCOME COUNTRIES							UPPER MIDDLE INCOME COUNTRIES					LOWER MIDDLE INCOME COUNTRIES				LOW INCOME COUNTRY	
			Australia (Oct-22)	European Union (Jun-21)	United Kingdom (Jul-21)	Switzerland (Jun-21)	United States (Feb-22)	Canada (Sep-22)	Japan (Mar-22)	Thailand (Nov-21)	Turkey (Oct-18)	China (Nov-22)	Argentina (Dec-21)	Brazil (Sep-22)	Philippines (Jun-22)	India (Jun-21)	Indonesia (Dec-21)	Viet Nam (Feb-22)	Sierra Leone (Sep-22)	Rwanda (Jun-22)
Targets		Clear interim (2030 or 2040) target	◉	–	–	–	–	◉	◉	–	–	–	◉	◉	◉	◉	–	–	–	–
		Clear 2050 target	◉	–	–	–	◉	–	◉	–	–	–	–	◉	◉	–	–	–	–	–
In-Sector	Technical Efficiency		●	○	◉	◉	◉	●	○	○	○	○	○	●	–	◉	●	–	○	◉
	Operational Efficiency			◉	◉	○	●	○		○	○	○	●	○	◉	–	●	–	○	
	Sustainable Aviation Fuels	Blending or volumetric target	◉	◉	–	◉	○	–	◉	–	–	–	–	–	–	–	◉	–	–	–
		GHG reduction target	◉	◉	◉	◉	◉	◉	◉	–	–	–	–	–	–	–	–	–	–	–
		Economic incentives for the uptake of SAF	◉	◉	◉	◉	◉	◉	◉	–	–	–	–	–	–	–	–	–	–	●
	Zero Emission Planes		–	○	○	○	●	◉	○	–	–	–	–	●	–	–	–	–	–	–
Out-of-Sector		Emissions trading or carbon pricing	–	◉	◉	◉		○	●	–	–	–	–	–	–	–	–	–	–	–
		Emissions offsetting	◉	◉	◉	◉	◉	◉	◉	◉	●	–	◉	◉	–	◉	◉	◉	●	–
		Carbon capture, utilization, and storage	–	–	–	–	–	○	–	○	–	–	○	–	–	–	–	–	●	–
		Non-CO_2 measures	–	–	–	–	–	○	–	–	–	–	○	–	–	–	–	–	–	–
Revenue Passenger-Kilometers (Billions) in 2019			217.1	1,770	364.8	52.92	1,890	203.6	274.1	161.3	151.2	1,167	49.19	166.6	73.02	139.7	248.3	83.09	NA	1.44
GDP per capita (World Bank, USD, 2021)			$60,443	$42,450	$46,510	$91,992	$70,249	$51,988	$39,313	$7,066	$9,661	$12,556	$10,636	$7,507	$3,461	$4,333	$2,257	$3,756	$480	$822
Aviation CO_2 Emissions per capita			0.76	0.34	0.47	0.56	0.54	0.474	0.206	0.20	0.155	0.07	0.10	0.07	0.06	0.05	0.02	0.07	NA	0.013

○ Specific ● Specific + Measurable or Time-Bound ◉ Specific, Measurable and Time-Bound

12 "GDP per capita (current US$)," The World Bank, 2023, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD; Xinyi Sola Zheng and Dan Rutherford, *Aviation Climate Finance Using a Global Frequent Flying Levy*, (Washington, D.C.: International Council on Clean Transportation, 2022), https://theicct.org/publication/global-aviation-frequent-flying-levy-sep22/. Where technical and operational efficiency cells are merged, SAPs did not distinguish between the two—as such, efficiency is graded across both.

A few trends are visible in Table 1. First, most countries have not yet included clear interim or long-term emissions targets in their SAPs. Six included an interim target or goal in their SAP; fewer (four) included a clear 2050 emissions target.

In contrast, 16 of the 17 SAPs include operational and technical efficiency measures. To improve operational efficiency, most SAPs target airport initiatives—like electrification of on-ground vehicles and improvement of airport waste management. High-income countries' SAPs cite strategies like wing and tube aircraft design changes. Lower-income countries cite strategies like engine washing and improving flight navigation to improve technical efficiency. Rwanda presents these two measures in its SAP and analyzes their potential emissions mitigation together. It set the measure to save approximately 46% of CO_2 emissions by 2030 compared to a business-as-usual scenario (as developed by ICAO tools).

Fourteen countries are involved in an emissions offsetting measures, like CORSIA. Indeed, CORSIA is central to many government plans for aviation.

Generally, the SAPs of high-income countries are clearer, with targets in both in- and out-of-sector measures; the SAPs of lower-income countries included less clarity in all categories. For example, clarity on SAFs drops dramatically between high-income and upper-middle-income countries. All high-income countries include specific, measurable, and time bound SAF policies. Outside of the high-income bracket, only Indonesia does. However, without a clear GHG reduction target, this SAF policy could promote crop-based biofuels (like palm oil in Indonesia) that can have higher GHG emissions than conventional jet fuel due to indirect life-cycle emissions.[13]

Similarly, only the SAPs of high-income countries address the potential of ZEPs (perhaps due to the low maturity and high cost of that technology). Zero-emission planes are likely to be introduced to mature aviation markets first, with adoption in lower-income countries later.[14]

SAP CASE STUDIES

The following case studies elaborate on the targets and measures identified in each SAP and provide examples of how they meet the specific, measurable, and time-bound criteria. SAPs were selected based publication language and date and by income group (to allow us to survey the breadth of available SAPs).[15] Where possible, newer SAPs, submitted post-LTAG agreement (October 2022) were selected to reflect updated work. We begin with Australia's SAP which provides clarity on most measures (Table 1). We then assess Brazil's SAP, which addresses most in-sector measures but with less clarity. Next, Indonesia's SAP does not address most in-sector measures but has some clarity. Finally, we assess Sierra Leone's SAP, which does not address most measures.

AUSTRALIA

Australia's SAP had the most clarity based on our assessment criteria.[16] Its SAP includes an interim and long-term target (a 43% domestic GHG reduction by 2030 compared to 2005 and reach net-zero domestic emissions by 2050) and addresses technical

13 Nikita Pavlenko and Stephanie Searle, *Assessing the Sustainability Implications of Alternative Aviation Fuels*, (Washington, D.C.: International Council on Clean Transportation, 2021), https://theicct.org/wp-content/uploads/2021/06/Alt-aviation-fuel-sustainability-mar2021.pdf.

14 ICCT, "Vision 2050."

15 "World Bank Country and Lending Groups," The World Bank, 2023, https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

16 Department of Infrastructure, Transport, Regional Development, Communications and the Arts, "Australia's State Action Plan—International Civil Aviation Organization (ICAO) Assembly Resolution A37-19 on climate change," (October 2022), https://www.icao.int/environmental-protection/Lists/States_Action_Plans/Attachments/ 4/202210%20Australia%20-%20State%20Action%20Plan.pdf.

and operational efficiency improvements and discusses emissions offsetting. Most measures refer to a baseline scenario and have time-bound targets. While missing ZEPs and non-CO_2 measures, its SAP lays out a clear and assessable path to the 2050 goal.

For in-sector goals, the plan addresses technical and operational efficiency. In technical efficiency, it cites a fleet-renewal strategy to improve fuel efficiency by 14–22% compared to older generations. Operationally, it aims to reduce CO_2 emissions per flight by 10% by 2030 through practices like continuous descent, route optimization, and flexible airspace. SAF-related policies include a blending target of 10% SAF use by 2030. Australia adheres to CORSIA standards for SAF GHG reduction eligibility. Additionally, in June 2022, Australia committed to invest up to USD 200 million through airlines like Qantas to accelerate the development of its SAF industry. This investment will generate a decrease in international and domestic flight emissions. Australia's SAP acknowledges the value of ZEPs but does not establish a market-entry year target or projected emissions reduction from their introduction.

In out-of-sector goals, Australia's SAP mentions an idea to develop an Indo-Pacific emissions trading scheme. It also reaffirms Australia's commitment to ACT-SAF (Assistance, Capacity-building, and Training) and ACT-CORSIA as means to emissions offsetting measures. The SAP does not address non-CO_2 or CCS measures.

Australia's plan points to the possibility that high-income countries may invest in low-readiness technologies not easily accessible to other countries. Australia's SAP can guide other high-income countries to identify low-readiness measures as part of updated SAPs in 2024.

BRAZIL

Brazil's SAP provides less clarity than Australia's.[17] Its SAP focuses on SAF developments, ZEPs, and operational efficiency improvements. However, the SAP does not address interim targets, SAF GHG reduction measures, or most out-of-sector goals. Its lack of clarity and critical information, like GHG reduction measures, makes its path to net-zero emissions more difficult to assess.

Brazil commits to reducing domestic emissions by 50% by 2030 and a 2050 goal of projected accumulated emissions reduction of 90 $MtCO_2$, relative to a 2019 efficiency baseline.

In technical efficiency improvements, Brazil's SAP identifies strategies like increasing load factor to improve fuel efficiency by 25.4% per seat — leading to 16% less fuel consumption (compared to earlier aircraft generations). In operational efficiency, the SAP references specific strategies like continuous climb and descent to improve fuel use but does not include any measurable or time-bound commitments. Similarly, it does not include a blending or volumetric SAF target or GHG reduction target. While Brazil builds an SAF strategy, maintaining eligibility for crop-based biofuels would reduce potential emissions reductions if its SAF policy fails to adhere to CORSIA's eligible fuel standards. Crop-based biofuels, like corn and soy, can have substantial indirect land-use change (ILUC) life-cycle emissions. Brazilian soy oil produced through the Hydrotreated Esters and Fatty Acids (HEFA) process emits roughly 67.4 gCO_2e/MJ (considering ILUC), 21.6 gCO_2e/MJ less than that of conventional jet fuel. While soy-based SAFs are considered alternatives to conventional jet fuel, they cannot reduce emissions enough to achieve a net-zero goal.[18] The SAP promotes the "Fuel of the Future" program to support the development and production of SAF. Finally,

17 Ministério da Infraestrutura, "Brazil's Action Plan on emissions reduction from Civil aviation," (September 2022), https://www.icao.int/environmental-protection/Documents/ActionPlan/Brazil%20Action%20Plan%20-%202022_EN.pdf.

18 Pavlenko and Searle, *Assessing the Sustainability Implications of Alternative Aviation Fuels*.

Brazil's SAP is one of the few that identifies ZEPs, like hydrogen and electric propulsion technologies. Brazil's SAP suggests exploring more sustainable aircraft, to transport up to 50 passengers, to help achieve its interim goal.

While the SAP does not address many out-of-sector measures, it reaffirms Brazil's participation in CORSIA post-2027 as part of its plan to offset future CO_2 emissions. Specifically, in 2021, Brazil determined that airlines should compensate for emissions exceeding a 2019 baseline—the plan directs companies to monitor, report, and verify emissions annually to its Agência Nacional de Aviação Civil.

Most of the goals of Brazil's SAP do not include measurable or time-bound targets; Brazil's emission trajectory, therefore, lacks clarity. If Brazil's updated SAP includes SAF GHG reduction measures, it will allow for clearer assessment of its compatibility with the 2050 goal.

INDONESIA

Indonesia's SAP emphasizes the country's future role in SAF production internationally.[19] The SAP does not address some critical measures and misses some crucial targets — like the GHG reduction target. Without a clear GHG reduction target, Indonesia's SAF targets (like Brazil's) leave the country's emissions trajectory unclear. Indonesia's SAP does not provide interim or long-term emissions reduction targets; however, some strategies have goal years between 2020 and 2050.

For in-sector goals, the SAP primarily discusses technical and operational efficiency improvements. Specifically, Indonesia aims to replace 5% of its fleet annually. In operational efficiency, the SAP identifies strategies to improve airspace management, air traffic flow management, and continuous climb and descent to reduce fuel use. Indonesia's SAP includes an SAF blending target of 5% by 2025, specifically from palm oil. However, studies have shown that palm oil has high life-cycle emissions and cannot be considered a low-carbon aviation fuel.[20] So, combining a clear blending target without matching GHG reduction targets does not clarify the plan's emissions trajectory. Indonesia's SAP does not identify economic incentives for SAF uptake or targets for ZEPs.

The SAP does not address out-of-sector goals beyond reaffirming the country's commitment to CORSIA and plans to participate post-2027 for offsetting aviation emissions.

Indonesia's current SAP lacks clarity based on our assessment criteria, specifically on the country's current emissions trajectory and SAF integrity target. Including more measurable and time-bound language in future iterations will clarify the country's path toward its decarbonization goal.

SIERRA LEONE

Sierra Leone's SAP is less clear based on our assessment criteria than the other case study SAPs.[21] It lacks specific, measurable, and time-bound goals and does not provide interim or long-term emissions goals. The SAP does address technical and operational efficiency improvements to grow aviation markets and reduce emissions, but does not

19 Directorate General of Civil Aviation of Indonesia, "Indonesia's Action Plan to reduce greenhouse gas emissions from aviation sector," (December 2021), https://www.icao.int/environmental-protection/Lists/States_Action_Plans/Attachments/41/Indonesia%20State%20Action%20Plan%202021.pdf.

20 Pavlenko and Searle, *Assessing the Sustainability Implications of Alternative Aviation Fuels*.

21 Sierra Leone Civil Aviation Authority, "Sierra Leone's Action Plan to reduce CO2 emission from international aviation," https://www.icao.int/environmental-protection/Lists/States_Action_Plans/Attachments/166/Sierra% 20Leone%20Action%20Plan%20to%20Reduce%20CO2%20Emmission%20from%20International%20Aviation.pdf.

include ZEPs, non-CO_2, emissions trading, CCS, or SAF measures. Its current emissions reduction targets are modest.

For in-sector goals, the SAP relies primarily on the expansion of Sierra Leon's aviation industry (e.g., developing new airport terminals, purchasing newer aircraft, and engine washing to improve aircraft fuel efficiency). Similarly, in operational efficiency, Sierra Leone plans to improve airspace management through performance-based navigation to reduce fuel use. Its SAP also identifies the maximization of aircraft load factor to reduce CO_2 emission.

Sierra Leone's SAP is unclear and not fully assessable. However, given that it is a low-income country with minimal emissions tracking data and resources, future iterations of Sierra Leone's SAP could include more robust low-carbon, low-cost mitigation strategies.

CONCLUSIONS

The seven high-income countries in Table 1 represented 55% of global aviation CO_2 emissions in 2019; the 10 upper-middle, lower-middle, and low-income countries in Table 1 represented 25%.[22]

While high-income countries' SAPs have more details on in- and out-of-sector measures, other areas (like CCS, non-CO_2 measures, and ZEPs) could be improved. Indeed, all SAPs require more detail on specific, measurable, and time-bound measures. Improving clarity will allow researchers and others to assess global net-zero compatibility. By considering specific emission mitigation measures, future assessments could estimate national emissions trajectories and global alignment with the decarbonization goal. Since SAPs must be updated by June 2024, countries can utilize various ICAO resources to improve their clarity and begin taking updated mitigation measures as soon as possible.

For example, within its recommended structure for SAPs and deadlines for submission, the ICAO highlights several tools and resources for data and emissions calculation:

1. To create clear interim and long-term goals, countries can refer to the ICAO's EBT.[23] The EBT can generate a baseline scenario for the aviation sector and emissions reductions from selected mitigation measures.
2. Specifically for fuel efficiency, countries can use the IFSET to estimate fuel use while comparing several aircraft and fuel use improvements. Countries can also refer to the IFSET to consider emissions trading and carbon pricing measures. It allows countries to compare various trading or pricing measures to select measures best suited to their respective development status.
3. When discussing efficiency, countries can refer to the MACC.[24] This tool selects up to 20 mitigation measures to facilitate selection, allowing countries to compare measures such as air traffic management and continuous climb and descent.
4. For SAF policies, countries might refer to the ACT-SAF Program. It guides countries in building SAF potential collaboratively with industry and government

22 Brandon Graver, Dan Rutherford, and Sola Zheng, *CO_2 Emissions from Commercial Aviation 2013, 2018, and* 2019, (Washington, D.C.: International Council on Clean Transportation, 2020), https://theicct.org/wp-content/ uploads/2021/06/CO2-commercial-aviation-oct2020.pdf.

23 "Environmental tools (E-tools)," ICAO, 2023, https://www.icao.int/environmental-protection/Pages/Tools.aspx.

24 "IFSET," ICAO, 2016, https://applications.icao.int/ifset?_gl=1*188jdus*_ga*MTA1OTM4MTAzNS4xNjU3MDQ3NT cz*_ga_992N3YDLBQ*MTY4MTgzMTA2Ni41Mi4xLjE2ODE4MzE2NTcuMC4wLjA.

stakeholders. The program has courses, relevant databases, and resources for countries to develop SAF deployment strategies.

5. Countries can refer to the ICEC[25] or the CORSIA Estimation and Reporting Tool (CERT)[26] to address emissions offsetting measures. ICEC calculates emissions for the number of passengers or volume of cargo traveling between two destinations. Similarly, CERT can support compliance with CORSIA rules for carbon offsetting.

State Action Plans clarify each nation's path to decarbonizing aviation. Some countries have made explicit commitments to SAF introduction, and others to technical efficiency. SAPs can support a differentiated approaches to implementing the LTAG agreement, as more mature markets kickstart emissions mitigation in the coming years. Emerging markets, in turn, can assess and adapt those efforts and any new tools or technologies developed. As the ICAO looks to June 2024, when countries are to submit updated plans, tracking and calculating countries' emissions will be at the forefront of discussion. Updated SAPs could improve by providing more clarity around interim targets and operational efficiency improvements.

Future research on this topic will explore differentiated targets based on development status and how LTAG implementation could differ across high- and low-income countries. The review of SAPs from this briefing allows for future discussions of clarity, compatibility, and adherence to the net-zero goal.

25 "ICAO Carbon Emissions Calculator (ICEC)," ICAO, 2023, https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx.

26 "ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)," ICAO, 2023, https://www.icao.int/environmental-protection/CORSIA/Pages/CERT.aspx.