INTERNATIONAL CIVIL AVIATION ORGANIZATION

REPORT ON THE FEASIBILITY OF A LONG-TERM ASPIRATIONAL GOAL (LTAG) FOR INTERNATIONAL CIVIL AVIATION CO_2 EMISSION REDUCTIONS

Appendix R3 Results in the Climate Science Context

ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION
MARCH/2022

APPENDIX R3

RESULTS IN THE CLIMATE SCIENCE CONTEXT

1. EXECUTIVE SUMMARY

1.1 The LTAG-TG Terms of Reference require the Task Group to place the results of its analysis "within the context of the latest consensus scientific knowledge", this latter means "the latest consensus climate science primarily based on IPCC reports and ISG". CAEP-ISG provided a report to LTAG-TG (**Appendix S1**) to allow the latter to compare the international aviation CO_2 scenarios it has analysed to the carbon budgets provided by ISG (based on IPCC data).

1.2 This comparison provides factual information to allow decisionmakers to do their work and does not seek to advise on a share of global carbon budgets that international aviation should consume.

1.3 The LTAG analysis (set out in the methodology **Appendices M1-M5**) and the carbon budgets provided by ISG (**set out in Appendix S1**) are based on extensive analyses by LTAG and IPCC. Both analyses set out the associated uncertainties. The carbon budget work includes uncertainties associated with the individual contributing terms that relate to the global carbon emissions pathways compatible with increases in global mean surface temperature of no more than 1.5°C and 2°C over pre-industrial levels, and presents budgets in terms of percentile likelihood of falling within a specified temperature response.

1.4 **Cumulative CO_2 emissions over the period:** International aviation's share to 2050 of the remaining global carbon budget for 2°C from 2020 is projected to range from 1.1%–2.0% depending on the integrated scenario for international aviation (IS1–IS3,) and represent 3.1%–5.6% of the global carbon budget available for 1.5°C. To 2070, the corresponding shares are 1.4%–3.9% (of a global carbon budget for 2°C) and 4.1%–11.3% of the global carbon budget for 1.5°C. All figures are for the mid traffic forecast.

1.5 **Total annual CO_2 emissions in milestone years:** International aviation's share of global annual CO_2 emissions could grow from 1.5% in 2019 to representing between 1.6% and 1.9% of global emissions (2°C consistent global pathway) or between 2.5%–3.0% for a 1.5°C consistent pathway in 2030, depending upon the integrated scenario for international aviation (IS1–IS3). In 2050, the sector could represent 1.1%–5.3% of global emissions for a 2°C consistent global pathway, or between 9.9%–46.6% of a 1.5°C pathway, depending on the integrated scenario. By 2070 there is a large range of uncertainty but the sector could represent 4.6%–31.6% of global emissions for a 2°C consistent global pathway. For a 1.5°C consistent pathway, global CO_2 emissions are required to be net negative by 2070 (-4.48 $GtCO_2$) while international aviation emissions are projected to be positive (0.21–1.42 $GtCO_2$).

1.6 **Expected emissions trajectory:** In 2050, scenario IS1 results in a large (46.6%) consumption of the available CO_2 emissions for a global emissions pathway consistent with 1.5°C. By 2070, the IS1 fraction is also large at 31.6%, even for a 2°C consistent global pathway, with international aviation emissions being a little over twice those in 2019. In 2050, scenario IS2 represents a significant (24.2%) fraction of global CO_2 emissions consistent with 1.5°C in 2050. By 2070, the fraction used is still significant (13.4%) but relatively smaller in a 2°C consistent global pathway as IS2 emissions somewhat flatten in absolute terms to around 2019 annual emission rates. Scenario IS3 results in a fractional useage of <5% of available global CO_2 emissions consistent with a 2°C pathway throughout the analysis period. For a 1.5°C consistent pathway, the fraction associated with IS3 nearly doubles (9.9%) by 2050 and, while it remains positive in 2070, by which point global emissions would need to be net negative, it remains flat in absolute terms at around a third of 2019 annual emission rates.

2. INTRODUCTION

2.1 The CAEP LTAG-TG Terms of Reference (ToR) require the Task Group to:

2.1.1 "Gather data from internal sources (ICAO and CAEP) and external groups (new stakeholders and through workshops and stocktaking) to: […] understand the latest consensus climate science primarily based on IPCC reports and ISG;"

2.1.2 "Conduct final analysis of the scenarios to understand those impacts on CO_2 emissions including relating this to the actual 2020 levels. The […] results will be placed within the context of the latest consensus scientific knowledge."

2.2 Pursuant to its ToR, LTAG-TG in April 2021 requested that:

2.2.1 "ISG should examine the literature and summarize the amount of carbon dioxide (aka carbon budget) that can be released into the atmosphere while limiting the increase in global mean temperature to 1.5 and 2 degrees Celsius. These carbon budgets can then be compared against the aviation CO_2 scenarios being developed by LTAG-TG. The ISG should also capture the latest information on the impacts of non-CO_2 aviation emissions such that decision makers understand the relative impact of aviation CO_2 emissions and the non-CO_2 emissions on the climate."

2.3 The report of ISG to LTAG-TG, pursuant to that request, is provided at **Appendix S1: Climate Science Context**. The purpose of this appendix is to compare the international civil aviation CO_2 scenarios analysed by LTAG-TG to the carbon budgets provided by ISG through its report.

3. SCOPE

3.1 ISG, in Appendix S1, primarily uses the Sixth Assessment Report of IPCC WGI, published in August 2021 (IPCC (2021)), which updates elements of the IPCC Special Report on global warming of 1.5°C (IPCC (2018)), summarising the remaining allowed CO_2 emissions to reach 1.5 or 2°C. IPCC (2021) defines global pathways that could (with varying levels of confidence) be consistent with 1.5°C (SSP1-1.9) and 2°C (SSP1-2.4) temperature scenarios (See Figure 5 of Appendix S1). These are therefore not forecasts or projections. They also do not necessarily apportion emissions reduction 'effort' between sectors, and they are usually derived from higher-level assumptions.[1]

3.2 By contrast, the scenarios analysed by LTAG-TG are possible future scenarios for the development of the international civil aviation sector, representing the "range of readiness and attainability" as required by its ToR. They represent "combined in-sector scenarios of technology, fuels, and operations" (integrated scenarios) overlaid on three underlying demand/traffic scenarios. The LTAG analysis also

[1] The IPCC scenarios (Shared Socioeconomic Pathways, SSPs) cover a broader range of greenhouse gas and air pollutant futures than assessed in earlier IPCC reports that result in certain levels of global mean radiative forcing (which approximate to a range of global mean surface temperature increases over pre-industrial levels, e.g. SSP1.9 is a 1.9 W/m^2 pathway, appoximating to a 1.5°C outcome), and include high-CO_2 emissions pathways without climate change mitigation as well as new low-CO_2 emissions pathways. These pathways are defined around quantitative demographic, economic and technology scenarios considering challenges to both adaptation and mitigation.

assumes action in other sectors, as noted in the descriptions of its integrated scenarios. The scope of the LTAG-TG work does not include international civil aviation out-of-sector measures (e.g. CORSIA), whose contribution has not been accounted for in these assessments.

3.3 The two exercises are therefore very different in scope and methodology but, based on expert advice, CAEP advises that this is a valuable comparison to make, as both represent the best available assessments of future emissions trajectories for both the international aviation sector and the global economy as a whole.

3.4 This appendix considers the CO_2 emissions from international aviation after emissions reductions from aircraft technology, operations and fuels. **Appendices M3–M5** describe the emissions reduction measures that have been used in the LTAG integrated scenarios and **Appendices R1 and R2** respectively summarise the resulting emissions/reductions and compare these with the CAEP Trends.

3.5 Aviation's impact on emissions from other sectors (for example, increasing demand for aviation leading to decreased demand for, and therefore emissions from, other transport sectors, *vice versa* or other more complex relationships) has not been considered as it is out of the scope of LTAG-TG.

3.6 Both the LTAG-TG ToR and the wording of the request to ISG are phrased in terms of carbon dioxide, CO_2. Information provided by ISG in **Appendix S1** on contributions of e.g. CH_4, N_2O, fluorinated hydrocarbons to the global carbon budget are provided in terms of how other important greenhouse gases warm the atmosphere, and information on aviation non-CO_2 effects are for context only and not for comparison.

3.7 As a technical report, it is out of the scope of this appendix to advise on the share of global emissions that international aviation should represent in future, as this is a political decision. However, Appendix S1 does include factual information about the historical contribution of aviation (including international and domestic) to global emissions, again for the purposes of context only.

4. UNCERTAINTIES

4.1 Both the global carbon budgets provided by ISG and the results of the LTAG-TG analysis embed significant uncertainties, as with any attempt to develop trends 50 or 80 years out. These are described in detail in **Appendices M1–M5 and S1** and so are not rehearsed here but are significant. For example, IPCC 2018 suggests at least a ±50% possible variation for remaining carbon budgets for 1.5°C consistent pathways.

4.2 A key source of uncertainty around both sets of data is the role played by non-CO_2 effects, both from aviation on non-aviation activities. Both are described in **Appendix S1** but not considered in this comparison due to the relatively high levels of scientific uncertainty compared with the effects of CO_2.

4.3 The global carbon budgets provided by ISG are also expressed in terms of the 33rd, 50th and 67th percentile likelihoods of all pathways considered by IPCC to be consistent with the 1.5 and 2°C temperature goals. To reduce the number of variables and give sufficient confidence that a particular LTAG scenario is consistent with a particular carbon budget, only the 67% probability is considered here for both temperature goals. The 50% probability is presented in Attachment A.

5. CUMULATIVE CO_2 EMISSIONS OVER THE PERIOD

Basis for comparison

5.1 Cumulative emissions of CO_2 over the LTAG-TG analysis period are most relevant for scientific purposes as they are approximately linearly proportional to the global mean surface tempoerature response (see **Appendix S1**). However, this metric does not represent the contribution of international aviation CO_2 emissions in any given year. Emissions from the LTAG scenarios are quoted for the period 2020–2070 for consistency with the global carbon budgets provided by ISG. They are also quoted for the period 2020–2050 due to the frozen technology improvements after 2050 in all scenarios, which may result in an overestimate of international aviation emissions in that timeframe.

5.2 For context, the cumulative emissions of CO_2 from global aviation (1940–2019) were 33.7 billion (10^9) tonnes of CO_2 ($GtCO_2$), representing 1.5% of global CO_2 emissions from all sources, including land-use change, since 1750. Approximately 50% of the cumulative aviation CO_2 emissions were emitted in the last 20 years[2].

Global carbon budgets

5.3 The estimated maximum allowable cumulative net global anthropogenic CO_2 emissions from the start of 2020 to limit global warming to 1.5°C are 400 Gt at 67% probability.[3]

5.4 For a warming limit of 2°C, the remaining allowed carbon emissions are estimated to be 1150 Gt CO_2 at 67% probability.[4]

International aviation CO_2

5.5 A summary of the LTAG integrated scenarios' cumulative CO_2 emissions and their fractional usage of available carbon budgets is presented in Table 1. In the LTAG integrated scenario 0 (IS0, the 'baseline' scenario), cumulative emissions from international aviation are 28 (range 23–33[5]) Gt from 2020–2050. This represents 2.4% (range 2.0–2.8)% of the global carbon budget for 2°C and 7.0% (range 5.9–8.2[6])% for 1.5°C. From 2020–2070, cumulative emissions are 73 (range 58–87) Gt. This represents 6.3% (range 5.0–7.5)% of the global carbon budget for 2°C and 18.3% (range 14–22)% for 1.5°C.

5.6 In IS1, cumulative emissions from international aviation are around 23 (range 18-26) Gt from 2020–2050. This represents around 2.0% (range 1.6%–2.3%) of the global carbon budget for 2°C and around 5.6% (range 4.6%–6.5%) for 1.5°C. From 2020–2070 cumulative emissions are around 45 (range 34–56) Gt. This represents 3.9% (range 2.9%–4.8%) of the global carbon budget for 2°C and 11.3% (range 8.4%–13.9%) for 1.5°C.

5.7 In IS2, cumulative emissions from international aviation are 17 (range 14–20) Gt from 2020–2050. This represents 1.5% (range 1.2%–1.7%) of the global carbon budget for 2°C and 4.3% (range

[2] See https://doi.org/10.1016/j.atmosenv.2020.117834 and data and references therein (updated by one year).
[3] See Appendix S1, Table 1. For 50% probability the corresponding figure is 500 Gt. See Attachment A.
[4] *Ibid.* For 50% probability the corresponding figure is 1350 Gt. See Attachment A.
[5] The central figure represents the 'mid' traffic forecast. High and low figures represent the 'high' and 'low' traffic forecasts, respectively. See Appendix M2 for more information on the traffic forecasts.
[6] The central percentage figure represents the 'mid' traffic forecast. High and low percentage figures represent the 'high' and 'low' traffic forecasts, respectively. See Appendix M2 for more information on the traffic forecasts.

3.5%–5.0%) for 1.5°C. From 2020–2070 cumulative emissions are 28 (range 23–34) Gt. This represents 2.5% (range 2.0%–3.0%) of the global carbon budget for 2°C and 7.1% (range 5.8%–8.6%) for 1.5°C.

5.8 In IS3, cumulative emissions from international aviation are 12 (range 9–15) Gt from 2020–2050. This represents 1.1% (range 0.8%–1.3%) of the global carbon budget for 2°C and 3.1% (range 2.4%–3.7%) for 1.5°C. From 2020-2070 cumulative emissions are 16 (range 12-20) Gt. This represents 1.4% (range 1.1%–1.8%) of the global carbon budget for 2°C and 4.1% (range 3.0%–5.1%) for 1.5°C.

Table 1 Summary of the LTAG integrated scenarios' cumulative CO2 emissions and their fractional usage of available carbon budgets

	Residual international aviation CO_2 emissions	Percentage of global carbon budget for warming of		Residual international aviation CO_2 emissions	Percentage of global carbon budget for warming of	
	2020-2050 ($GtCO_2$)	1.5°C	2°C	2020-2070 ($GtCO_2$)	1.5°C	2°C
IS0	28	7.0%	2.4%	73	18.3%	6.3%
IS1	23	5.6%	2.0%	45	11.3%	3.9%
IS2	17	4.3%	1.5%	28	7.1%	2.5%
IS3	12	3.1%	1.1%	16	4.1%	1.4%

Summary

5.9 In summary, international aviation's share to 2050 of the remaining global carbon budget for 2°C from 2020 is projected to range from 1.1%–2.0% depending on the integrated scenario for international aviation (IS1–IS3,) and represent 3.1%–5.6% of the global carbon budget available for 1.5°C. To 2070, the corresponding shares are 1.4%–3.9% (of a global carbon budget for 2°C) and 4.1%–11.3% of the global carbon budget for 1.5°C. All figures are for the mid traffic forecast.

6. TOTAL ANNUAL EMISSIONS IN MILESTONE YEARS

Basis for comparison

6.1 As noted above, cumulative emissions do not represent the changing contribution of an individual sector to global emissions at particular points in time, particularly if the sector is on a dissimilar trajectory to the global economy as a whole. Annual emissions are also widely used in policy considerations and can help policy makers to understand the contribution of a sector in a given year.

6.2 Placing the emissions from the LTAG scenarios into the context of annual emissions consistent with the 1.5 and 2°C pathways at different points in time can therefore show how the contribution of international aviation could change over time. Years have been selected to represent the beginning, end and two intermediate points in the analysis period.

6.3 For context, the contribution of global aviation (international and domestic) to anthropogenic CO_2 emissions was around 2.4% in 2018.[7]

International aviation CO_2 in the context of global carbon budgets

6.4 Table 2 gives the annual emissions in milestone years derived from the example IPCC pathways for 1.5 and 2°C (second and third columns).[8] Alongside this, it shows the range of international aviation emissions for that year, based on the range of LTAG integrated scenarios (IS3–IS1, fourth column). Finally, it shows the range of possible contributions from international aviation as a percentage (fifth and sixth columns).

Table 2 Annual emissions in milestone years derived from the example IPCC pathways for 1.5 and 2°C

Year	Allowable annual emissions (IPCC via ISG)		Residual annual international aviation CO_2 emissions (from LTAG IS3-1)	International aviation percentage of total	
	1.5°C	2°C		1.5°C	2°C
2019/20*	39.69 Gt*	39.80 Gt*	0.60 Gt*	1.5%	1.5%
2030	22.85 Gt	34.73 Gt	0.57-0.67 Gt	2.5-3.0%	1.6-1.9%
2050	2.05 Gt	17.96 Gt	0.20-0.95 Gt	9.9-46.6%	1.1-5.3%
2070	-4.48 Gt	4.48 Gt	0.21-1.42 Gt	N/A	4.6-31.6%

Note: Global allowable annual emissions quoted are from IPCC SSPs for 2020 while the international aviation emissions quoted is the actual figure for 2019, representing a pre-COVID-19 year and consistent with the CORSIA baseline for the Pilot Phase.

Summary

6.5 In summary, international aviation's share of global annual CO_2 emissions could grow from 1.5% in 2019 to representing between 1.6% and 1.9% of global emissions (2°C consistent global pathway) or between 2.5%–3.0% for a 1.5°C consistent pathway in 2030, depending upon the integrated scenario for international aviation (IS1–IS3). In 2050, the sector could represent 1.1%–5.3% of global emissions for a 2°C consistent global pathway, or between 9.9%–46.6% of a 1.5°C pathway, depending on the integrated scenario. By 2070 there is a large range of uncertainty but the sector could represent 4.6%–31.6% of global emissions for a 2°C consistent global pathway. For a 1.5°C consistent pathway, global CO_2 emissions are required to be net negative by 2070 (-4.48 $GtCO_2$) while international aviation emissions are projected to be positive (0.21–1.42 $GtCO_2$).

[7] Lee et al. (2020), *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*, Atmos. Environ. 244, 117834, doi:https://doi.org/10.1016/j.atmosenv.2020.117834
[8] SSP1.9 and SSP2.6, respectively

7. EXPECTED EMISSIONS TRAJECTORY

Basis for comparison

7.1 A description of the overall trajectory, that is the change in emissions over time, can assist policy makers in understanding when in the period the emissions reductions are expected to occur assuming that they are not expected to reduce linearly.

Global carbon budgets

7.2 In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030, reaching net zero around 2050.[9]

7.3 For limiting global warming to below 2°C, CO_2 emissions are projected to decline by about 25% by 2030 in most pathways and reach net zero around 2070.

International aviation CO_2

7.4 Figures 1 and 2 show the international aviation CO_2 emissions from the three LTAG integrated scenarios in the context of the illustrative 1.5°C and 2°C consistent global emissions pathways from IPCC AR6 WGIII (2021).

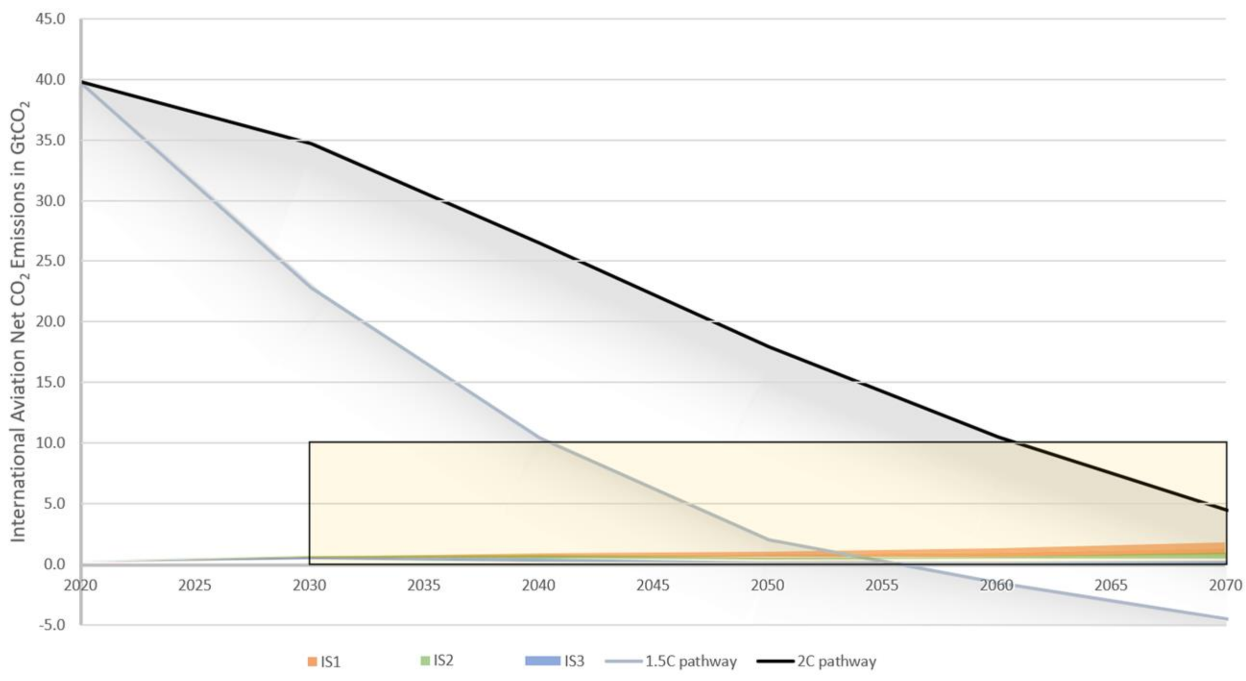

Figure 1 - International aviation CO2 emissions from the three LTAG integrated scenarios in the context of the illustrative 1.5°C and 2°C consistent global emissions pathways from IPCC AR6 WGIII (2021)

[9] See Appendix S1.

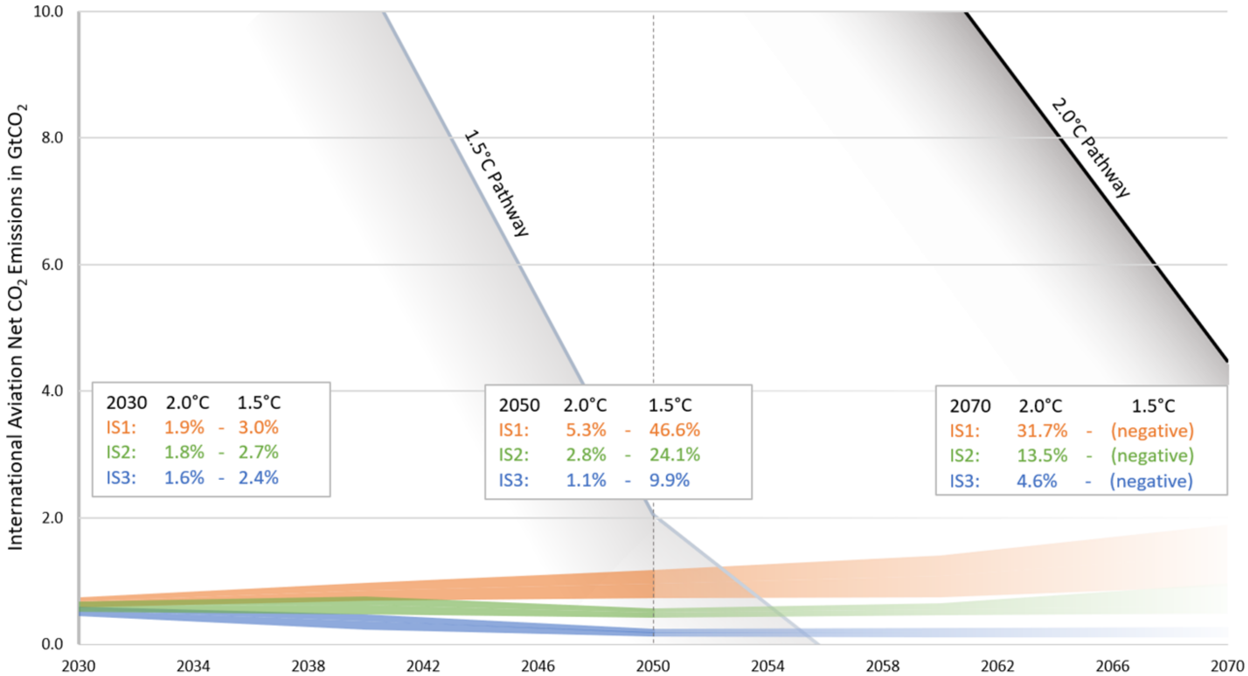

Figure 2 – Details on international aviation CO2 emissions from the three LTAG integrated scenarios in the context of the illustrative 1.5°C and 2°C consistent global emissions pathways from IPCC AR6 WGIII (2021)

Summary

7.5 In summary, in 2050, scenario IS1 results in a large (46.6%) consumption of the available CO_2 emissions for a global emissions pathway consistent with 1.5°C. By 2070, the IS1 fraction is also large at 31.6%, even for a 2°C consistent global pathway, with international aviation emissions being a little over twice those in 2019. In 2050, scenario IS2 represents a significant (24.2%) fraction of global CO_2 emissions consistent with 1.5°C in 2050. By 2070, the fraction used is still significant (13.4%) but relatively smaller in a 2°C consistent global pathway as IS2 emissions somewhat flatten in absolute terms to around 2019 annual emission rates. Scenario IS3 results in a fractional useage of <5% of available global CO_2 emissions consistent with a 2°C pathway throughout the analysis period. For a 1.5°C consistent pathway, the fraction associated with IS3 nearly doubles (9.9%) by 2050 and, while it remains positive in 2070, by which point global emissions would need to be net negative, it remains flat in absolute terms at around a third of 2019 annual emission rates.

— — — — — — — —

ATTACHMENT A TO APPENDIX R3

50th PERCENTILE COMPARISON

CUMULATIVE CO_2 EMISSIONS OVER THE PERIOD

A summary of the LTAG integrated scenarios' cumulative CO_2 emissions and their fractional usage of available carbon budgets is presented in Table 3. This uses the remaining carbon budgets for limiting the global temperature increase to 1.5 or 2°C *with 50% probability*. This means that, with these emissions levels, these temperature limits are equally as likely to be exceeded as they are to be met.

Table 3 - Summary of the LTAG integrated scenarios' cumulative CO2 emissions and their fractional usage of available carbon budgets

	Residual international aviation CO_2 emissions	Percentage of global carbon budget for warming of		Residual international aviation CO_2 emissions	Percentage of global carbon budget for warming of	
	2020-2050 ($GtCO_2$)	1.5°C	2°C	2020-2070 ($GtCO_2$)	1.5°C	2°C
IS0	28	5.6%	2.1%	73	14.6%	5.4%
IS1	23	4.5%	1.7%	45	9.1%	3.4%
IS2	17	3.5%	1.3%	28	5.7%	2.1%
IS3	12	2.5%	0.9%	16	3.3%	1.2%

— — — — — — — —