International Civil Aviation Organization

INFORMATION PAPER

GROUP ON INTERNATIONAL AVIATION AND CLIMATE CHANGE (GIACC)

FOURTH MEETING

Montréal, 25 to 27 May 2009

Agenda Item 2: Review of aviation emissions-related activities within ICAO and internationally

GLOBAL AVIATION CO_2 EMISSIONS PROJECTIONS TO 2050

(Presented by the Secretariat)

1. INTRODUCTION

1.1 The paper attached in the Appendix has been written jointly by the Projections Task Group (PTG) of FESG, and the MODTF in response to a request by GIACC for global aviation CO_2 emissions projections to 2050 that includes results for 2012, 2020, and 2025. In the time available, two approaches have been adopted and the results from both approaches are presented in the attached paper, which should be considered illustrative. They demonstrate the order of magnitude of global aviation CO_2 emissions in 2050 under a range of assumptions, but with significant uncertainties given the time horizon.

2. CONCLUSIONS

2.1 Global aviation fuel burn is expected to grow from 200 Mega tonnes (Mt) in 2006 to between 280 and 880 Mt in 2050. Not accounting for the impact of alternative fuels, CO_2 is predicted to grow from 632 Mt in 2006 to the range of 890 to 2,800 Mt in 2050. However, the lower bound of the 2050 range is not considered plausible given the strong assumptions regarding behavioural change.

2.2 On a per-flight basis, efficiency is expected to continue to improve through 2050. However, even under the most aggressive technology forecast scenarios, this anticipated gain in efficiency from technological and operational measures does not offset the expected growth in demand driven emissions .

2.3 Therefore, an emissions “gap” relative to the 2006 (or earlier) levels will exist in the future that will require some form of intervention in order to achieve sustainability. Though not specifically assessed in this paper, a multi-faceted approach toward this objective may be possible from a combination of: alternative fuels, unforeseen technological advances, operational measures, and market based measures.

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APPENDIX

GLOBAL AVIATION CO_2 EMISSIONS PROJECTIONS TO 2050

INFORMATION PAPER FROM FESG PROJECTIONS TASK GROUP (PTG) AND MODELLING AND DATABASES TASK FORCE (MODTF)

SUMMARY

This paper has been written jointly by the Projections Task Group (PTG) of FESG, and the MODTF in response to a request by GIACC for global aviation (demand and) CO_2 emissions projections to 2050.

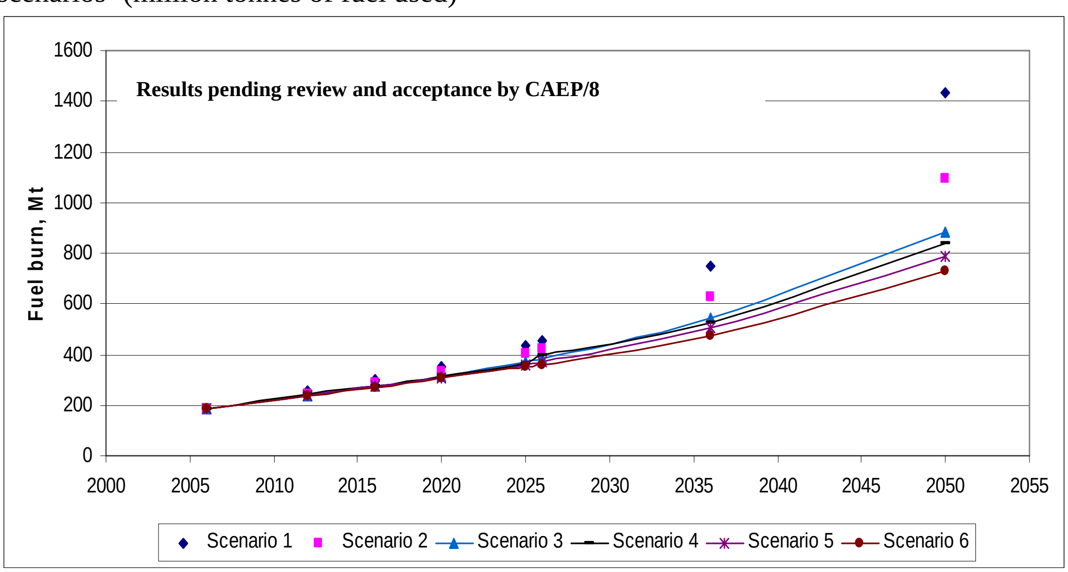
In the time available, two approaches have been adopted to deliver global aviation CO_2 emissions projections to 2050:

i) Extrapolate to 2050 the previously developed MODTF trend lines of fuel burn to 2036 (as presented to GIACC/3); and

ii) Combine the FESG PTG demand projections with the results of the MODTF fuel burn work to develop emissions projections to 2050. FESG PTG has previously developed global aviation demand projections to 2050 using different scenarios; these were combined with fuel burn improvement options as developed by MODTF to estimate fuel burn under different scenarios.

Results presented in this paper should be considered illustrative. They demonstrate the order of magnitude of global aviation CO_2 emissions in 2050 under a range of assumptions. The uncertainties when looking out to 2050 must be acknowledged when interpreting the results presented in this paper.

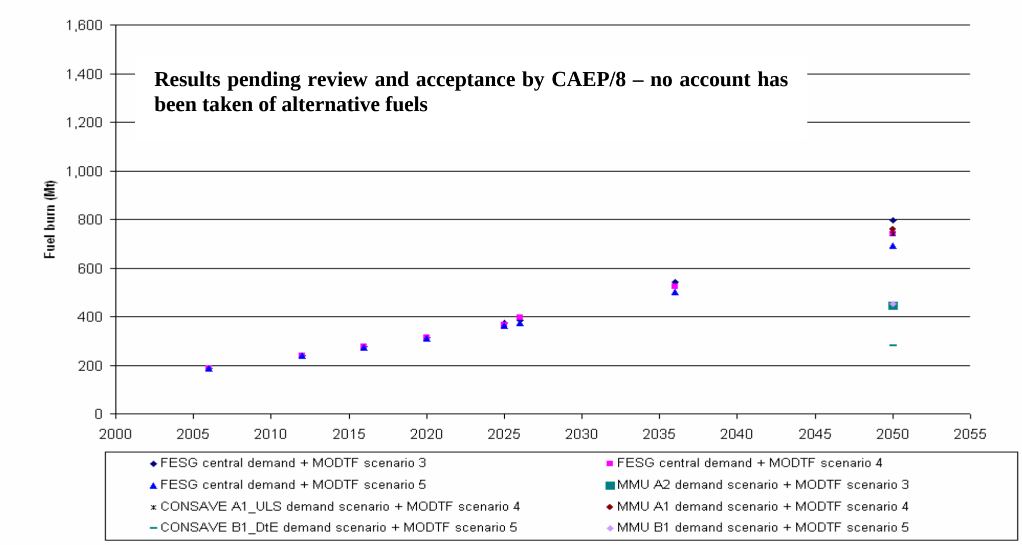
Figure S1: Approach i) - Annual global aviation fuel burn projections to 2050 for the range of MODTF scenarios[1] (million tonnes of fuel used)



[1] Defined in paragraph 13

Under this approach, the range of computed fuel burn in 2050 would lie between 730 Mt and 880 Mt. In terms of CO_2, this equates to an estimated range of some 2,300 Mt CO_2 to 2,800 Mt CO_2 in 2050. Scenarios 1 and 2 are shown for illustration but are not considered realistic as they assume no improvement in fuel efficiency other than using the technology already available. Likewise, scenarios 5 and 6 could be considered optimistic.

Figure S2: Approach ii) - Annual global aviation fuel burn projections to 2050 for the range of FESG PTG demand scenarios (million tonnes of fuel used)



Under the scenarios illustrated, which were themselves derived from the literature, fuel burn in 2050 from global commercial aviation could fall within the range of 280 Mt and 800 Mt. In terms of CO_2 emissions, this equates to a range in 2050 of around 890 Mt CO_2 to some 2,500 Mt CO_2[2].

Figure S2 illustrates the results using the underlying demand scenarios from the FESG PTG work, but combines each with the per annum fuel burn improvement trend of the MODTF modelling scenario which is most consistent with the particular demand scenario. Emissions projections to 2050 using the various FESG PTG demand scenarios do not vary significantly when other scenarios from MODTF are used (i.e. scenarios 3 to 5). This is because demand is generally the dominant driver of emissions, rather than technology/operations.

It is not possible to say what the actual fuel burn in 2050 will be given the significant uncertainties associated with the underlying demand and per annum fuel burn improvements. However, the spread of fuel burn results shown in Figure S2 is intended to illustrate potential emissions under different assumptions.

No assessment has been made of the extent to which aviation fuel will be available in the magnitudes projected here by 2050. Given the long term nature of these projections, it is not possible to comment on these considerations with certainty; however, it is plausible that the projected levels of traffic and demand would potentially be lower if in the future there were fuel supply limitations and/or increases in fuel prices.

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[2] The CONSAVE Down to Earth scenario is recognised by FESG PTG as not realistic given the strong assumptions regarding behavioural change.

The FESG PTG emissions projections results are broadly consistent with the projections of the previous FESG work in 1999 (as reported in Aviation and the Global Atmosphere, IPCC, 1999) which at that time did not consider that fuel availability would be a significant issue; with the CONSAVE work completed for the European Commission and with the work taken forward by MMU for the EU Quantify project.

At this stage, it has not been possible to explore the impact of alternative fuels on these projections. A sub-group within CAEP (WG3 FEMAH[3]) is currently working through the potential impact of alternative fuels on CO_2 emissions and will report upon completion.

- Summary end -

[3] WG3 – CAEP Technical working group on emissions. FEMAH – Fuel Efficiency Metric Ad Hoc Group.

Introduction: the task

1. The GIACC/3 meeting (16-19 February 2009, Montreal, Canada) requested that CAEP undertake a range of tasks over the coming months. Of relevance to the FESG[4] and MODTF[5] was the request for environmental trends/goals assessment to 2050.

2. The specific request, as clarified by the CAEP Secretariat, is to deliver global aviation CO_2 projections to 2050. GIACC noted in its request to FESG:

   "(CAEP's timeline is 2016, 2026 and 2036). CAEP will provide information for 2012, 2020 and 2025 based on interpolation of existing data. It can make an outline of possible scenarios based on broad brush assumptions for 2050 including what would happen under different alternative fuels uptake"

3. The emissions projections to 2050 must be delivered in time for consideration at the GIACC/4 meeting to be held on May 25-27, 2009.

4. This task is relevant to the two CAEP Working Groups, namely MODTF and FESG, because:

   - Global aviation fuel burn (and hence CO_2 emissions) for 2006, 2016, 2026 and 2036 consistent with the FESG CAEP/8 central traffic forecast (developed at the global level for passenger and freight services) has been computed by MODTF for a range of modelling scenarios[6]. Preliminary results have been presented by MODTF to GIACC/3[7]; this work included a range of assumptions regarding aircraft technology and operational improvements and has been developed further in this paper; and,

   - The FESG Projections Task Group (PTG) has developed global air traffic demand projections to 2050, under several scenarios. This work will be presented to the CAEP Steering Group in June 2009 and is used in this paper for the development of global aviation emissions projections.

5. As work of both the MODTF and FESG is relevant to the GIACC request, this information paper has been written jointly to allow the work of both groups to be reported in a single document.

6. Delivering this work in time for GIACC/4 has necessarily placed constraints on its scope. Fuel burn projections to 2050 presented in this paper therefore relate to standard kerosene fuel only as it has not been possible to carry out the analysis assuming alternative fuels.

7. **Results presented in this paper should be considered illustrative. They demonstrate the order of magnitude of global aviation CO_2 emissions in 2050 under a range of assumptions. The uncertainties when looking out to 2050 must be acknowledged when interpreting the results presented in this paper.**

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[4] Forecasting and Economic analysis Support Group, CAEP/8
[5] Modelling and Databases Task Force, CAEP/8
[6] The results presented in this document rely on second round modelling results from MODTF.
[7] These results were presented to GIACC/3 in a presentation made by the ICAO CAEP Secretariat. Ref. WP/5, WP/6, IP/1, Workshop on Aviation and Alternative Fuel
File: Giacc3_Pres_Waaf09[1].pdf

Objectives of this work

8. The objectives of this work were:

- To deliver global aviation CO_2 emissions projections to 2050 for a range of scenarios (as per the GIACC request) in time for GIACC/4
- To ensure the analysis provided is well-documented so that the underlying approaches, assumptions, data sources, plausibility checks and limitations are fully transparent

9. Two approaches have been adopted to fulfil these objectives and are described in the following sections.

Approaches to developing CO_2 emissions projections to 2050

10. Global aviation CO_2 emission projections to 2050 can be developed in a number of ways. However, given the need to be consistent across CAEP Working Groups, and in light of the need to deliver outputs for GIACC/4, the following two approaches were pursued:

i) extrapolate to 2050 the previously developed MODTF trend lines of fuel burn to 2036; and

ii) Combine the FESG PTG demand projections with the results of the MODTF fuel burn work to develop emissions projections to 2050. Specifically, the percent per annum fuel burn improvement per unit of demand (which considers fleet retirement and replacement, and various levels of technology and operational improvements) was computed from the MODTF environmental goals work and applied to the FESG PTG demand growth scenarios

11. These two approaches are further described in the following sections.

i): Extrapolating MODTF results to 2050

12. As part of the ICAO CAEP/8 Work Programme, MODTF is charged with "…conduct[ing] an updated trends [goals] assessment, for the baseline case (and forecasts), and various scenarios which consider technology and operational improvements…" To support this effort, MODTF modellers are computing future trends in aviation noise, local air quality emissions, and greenhouse gas (GHG) emissions.

13. MODTF has therefore computed fuel burn (and hence CO_2 emissions) consistent with the FESG CAEP/8 central demand forecast for 2006, 2016, 2026 and 2036 (and they are currently developing results for the FESG CAEP/8 low demand growth scenario). Fuel burn has been computed for a range of modelling scenarios:

Scenario 1 (***Do Nothing***): This scenario assumes no improvements in aircraft technology beyond those available today and no improvements from communication, navigational and air traffic management (CNS/ATM) investment or from planned initiatives, e.g., those planned in NextGen[8] and SESAR[9].

Scenario 2 (***CAEP/7 Baseline***): This scenario includes the CNS/ATM improvements necessary to maintain current ATM efficiency levels, but does not include any technology improvements beyond those available today.

Scenario 3 (***Low Aircraft Technology and Moderate Operational Improvement***): In addition to including the improvements associated with the migration to the latest CNS/ATM initiatives, e.g., those planned in NextGen and SESAR (Scenario 2), this scenario includes fuel burn improvements of 0.95 percent per annum for all aircraft entering the fleet after 2006 and prior to 2015, and 0.57 percent per annum for all aircraft entering the fleet beginning in 2015 out to 2036. It also includes additional fleet-wide moderate operational improvements of 0.5, 1.4 and 2.3 percent in 2016, 2026 and 2036, respectively.

Scenario 4 (***Moderate Aircraft Technology and Operational Improvement***): In addition to including the improvements associated with the migration to the latest CNS/ATM initiatives, e.g., those planned in NextGen and SESAR (Scenario 2), this scenario includes fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide moderate operational improvements of 0.5, 1.4 and 2.3 percent by 2016, 2026 and 2036, respectively.

Scenario 5 (***Advanced Technology and Operational Improvement***): In addition to including the improvements associated with the migration to the latest CNS/ATM initiatives, e.g., those planned in NextGen and SESAR (Scenario 2), this scenario includes fuel burn improvements of 1.16 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements of 1.0, 1.6 and 3.0 percent by 2016, 2026 and 2036, respectively.

Scenario 6 (***Optimistic Technology and Operational Improvement***): In addition to including the improvements associated with the migration to the latest CNS/ATM initiatives, e.g., those planned in NextGen and SESAR (Scenario 2), this sensitivity study includes an optimistic fuel burn improvement of 1.5 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide optimistic operational improvements of 3.0, 6.0 and 6.0 percent by 2016, 2026 and 2036, respectively. This sensitivity study goes beyond the improvements based on industry-based recommendations.

14. In order for MODTF to provide data for the intermediate years requested by the GIACC (2012, 2020 and 2025) MODTF derived a best-fit line[10] which could be evaluated for any intermediate

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[8] The Next Generation Air Transportation System (NextGen) is the United States Federal Aviation Administration's (FAA) plan to modernize the National Airspace System (NAS) through 2025

[9] SESAR – Single European Sky ATM Research. Initiative launched by the European Commission in 2004 to reform (modernise) the architecture of European air traffic management (ATM).

[10] A fourth order polynomial.

year, including those requested by GIACC. A similar best-fit exponential function was derived for extrapolation beyond 2036 to 2050.

15. The results of the direct extrapolation of the MODTF fuel burn estimates are shown in Table 1 and Figure 1.

Table 1. Annual global aviation fuel burn for the range of MODTF scenarios, million tonnes of fuel (**Preliminary data – do not cite)**

	MODTF Scenarios					
Year	**1**	**2**	**3**	**4**	**5**	**6**
2006	**187**	**187**	**187**	**187**	**187**	**187**
2012	*258*	*243*	*240*	*240*	*238*	*238*
2016	**302**	**285**	**276**	**276**	**273**	**271**
2020	*352*	*333*	*316*	*314*	*310*	*305*
2025	*434*	*404*	*372*	*368*	*361*	*351*
2026	**454**	**420**	**385**	**397**	**372**	**361**
2036	**751**	**626**	**542**	**523**	**503**	**477**
2050	*1434*	*1094*	*883*	*835*	*790*	*730*

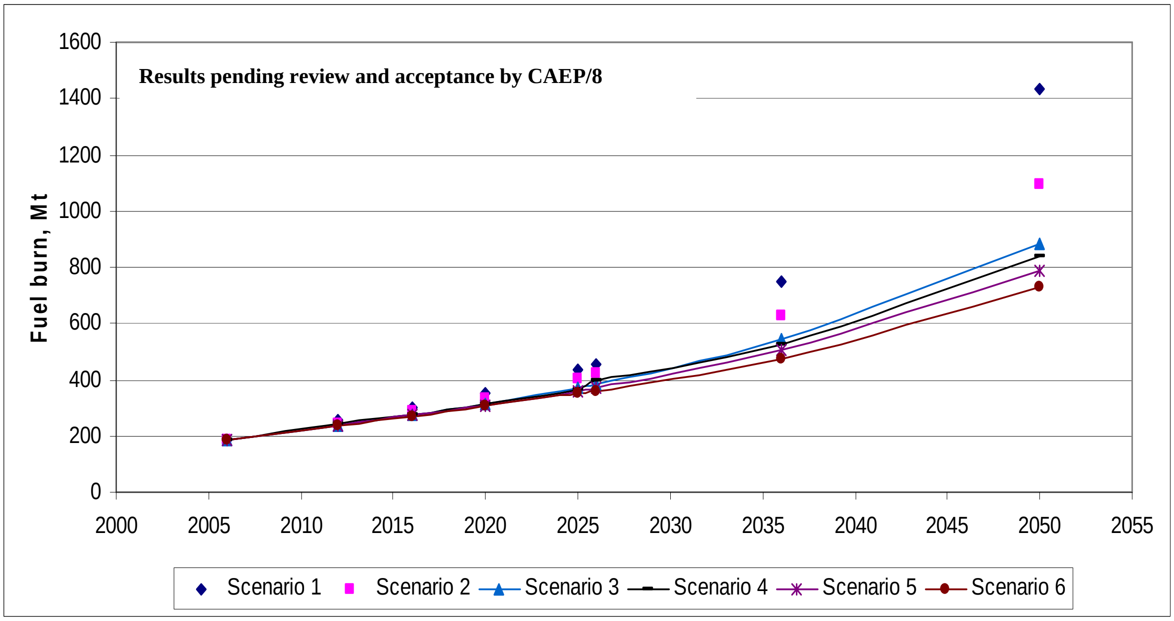
Note: figures in *italics* have been interpolated in order to meet the GIACC/4 request

16. The value of 187Mt fuel used as the 2006 baseline in this paper was taken directly from MODTF inventory data. This inventory did not include fuel usage by auxiliary power units nor fuel usage by VFR flights. Non-scheduled flights in regions for which radar data is not available were also not accounted for. Together these may amount to approximately 10 to 12% additional fuel usage.

17. For comparison, IEA report aviation fuel use of 236Mt for 2006. This value includes military and general aviation The AERO2k 2002 Inventory calculated military, general and commercial aviation fuel usage separately, with military and general aviation comprising approximately 12-13% of the total.

18. Taking these two approaches, the actual value of fuel used by commercial aviation in 2006 would appear to lie in the region of 200 to 205Mt.

Figure 1: Annual global aviation fuel burn projections to 2050 for the range of MODTF scenarios[11], (million tonnes of fuel used)



19. Figure 1 shows that under the fuel burn assumptions used in the MODTF scenarios 3, 4, 5 and 6 (assuming that demand grows in line with the trend of the FESG CAEP/8 central forecast), the range of computed fuel burn in 2050 would lie between 730 Mt and 880 Mt. In terms of CO_2, this equates to an estimated range of some 2,300 Mt CO_2 to 2,800 Mt CO_2[12] by 2050.

20. MODTF scenarios 1 and 2 are only shown for illustration as the assumptions used in these scenarios regarding fuel burn improvements are not considered to be a realistic outcome. It is highly unlikely that no further improvements in fuel efficiency would be delivered over this timeframe so these data points should be interpreted with caution. In addition, scenarios 5 and 6 may be considered optimistic and would be likely to require significant technological developments to occur so again, these results should be interpreted taking this into account.

21. The fuel burn scenarios presented in Figure 1 account for aggregate emissions from both domestic and international commercial aviation at the global level. The range of emission projections reflects the uncertainty when looking out to 2050 – indeed uncertainty increases the longer the time horizon being considered.

Limitations of the approach

22. As with any method of projecting demand and emissions over a long time horizon, there are uncertainties that will influence the actual outcome. The approach used to extrapolate the MODTF results offers the benefits of being consistent with the previous MODTF modelling work, as presented to GIACC/3. In addition, the fact that MODTF had already modelled fuel burn out to

[11] As defined in paragraph 13
[12] This is assuming a conversion factor of 3.15kg of CO_2 per 1.0kg of fuel.

2036 means that the projection only covers 14 years, leaving less scope for any extreme impact of simplifying assumptions.

23. Since MODTF results are currently only available for the FESG CAEP/8 central forecast, they do not reflect alternative demand scenarios. In addition, the extrapolation approach does not allow the effects of market maturity to be captured, which would constrain the growth in global aviation demand and hence in emissions.

24. Recognising these limitations, a second approach to developing emissions projections to 2050 has also been adopted by the FESG PTG.

ii): Using FESG PTG global air traffic projections to develop global aviation CO_2 emissions projections to 2050

25. As part of its current work programme, the FESG PTG has developed global aviation demand[13] projections to 2050 using a range of scenarios. The scenarios adopted are summarised in Box 1.

Box 1: scenarios used to develop global aviation demand projections to 2050:

1.Projection of the FESG FTG CAEP/8 forecast (3 scenarios)

The Forecast Task Group produced a consensus-based traffic forecast to 2026. They then extended this forecast forward to 2036 using an approach based on expert judgement and reflecting regional differences in market maturity (again based on judgement). This forecast extension has been rolled forward by PTG on the assumption that the rates of growth continue to reduce over time.

2. IPCC[14]/SRES based scenarios:

IPCC Special Report on Emission Scenarios (SRES (2000)) were designed to cover a broader range of topics than the previous (IS92) scenarios. These scenarios provide input for evaluating climatic and environmental consequences of future emissions, and for assessing alternative mitigation and adaptation strategies. Forty SRES scenarios were developed, covering the current range of uncertainties in emissions modelling. Grouped into four ‘families’ (A1, A2, B1 and B2), the scenarios examine trends in technological change and economic developments such as increase/decrease in income gap between developed and developing countries.

2(a) Manchester Metropolitan University (MMU) scenarios: (4 scenarios)

Aviation scenarios developed for the EU project Quantify based on the IPCC/SRES four marker scenarios (A1, A2, B1 and B2). The methodology used for projecting future passenger demand is based on the IPCC 1999 method (2b) with some qualitative interpretation of the detailed SRES storylines.

2(b) IPCC (The IPCC Special Report on Aviation and the Global Atmosphere, 1999) – updated with SRES GDP (4 scenarios)

These emission scenarios were primarily designed for driving global circulation models and to develop global climate change scenarios. ‘IS92’ scenarios were the first global scenarios to provide estimates for the full range of climate change emissions. They were adopted for use to provide the 50-year trends for the IPCC report on Aviation and the Global Atmosphere (1999). The IPCC report contains a total of six scenarios – the *ICAO/CAEP FESG scenarios* – developed by FESG by combining the IPCC 1992 scenarios - the IS92a, c and e scenarios - with two technology scenarios of ICCAIA (International Coordinating Council of Aerospace Industries Associations). The IPCC 1999 scenarios have been updated using the SRES GDP projections to replace the IS92 GDP projections.

[13] Passenger demand only.
[14] Intergovernmental Panel on Climate Change

2(c) CONSAVE scenarios (4 scenarios):

i) **"Unlimited Skies (ULS)",** market forces are assumed to address externalities by incentivising vigorous technological innovation. This helps to overcome potential barriers arising from the formidably high growth in air transport of this scenario

ULS is consistent with IPCC/SRES scenario A1 (A1G-Message)

ii) **"Regulatory Push & Pull (RPP)"**, strict governmental regulation provides for a "pulling-in" of desirable technologies and characteristics via regulation and incentives, and a "pushing-out" of undesirable ones. This is a high growth scenario.

RPP is consistent with IPCC/SRES A1 (A1T-Message)

iii) "**Fractured World (FW)"**, due to political, religious and social divergences, the world is divided into blocks with high tensions, occasional confrontations, terrorism, causing high security and standardisation problems/costs. This leads to low growth in inter-regional flights.

FW is consistent with IPCC/SRES A2 (A2Message)

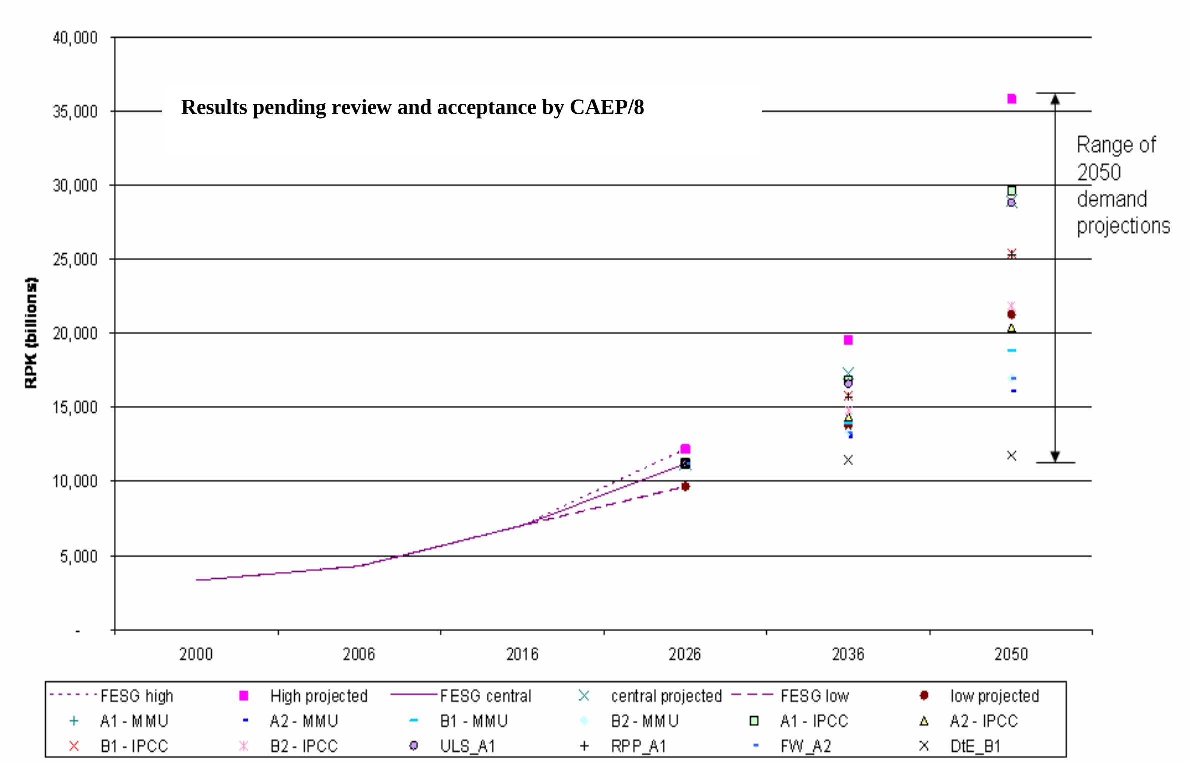
iv) "**Down to Earth (DtE)"**, the problem to achieve sustainability is addressed by uncompromising changes in lifestyles. Air transport, especially long distance trips, are regarded very critically for the mainstream, and the resulting demand is low

DtE is consistent with IPCC/SRES B1 (B1Message)

26. The projected level of air traffic demand to 2050 under these scenarios, as estimated by the FESG PTG as part of the FESG work programme, is shown in Figure 2. The detailed results are in Annex 3.

27. The range of traffic demand projections to 2050 demonstrates the extent to which long term demand is influenced by a range of factors on which each scenario takes its own view. Clearly, all of the specific assumptions within each scenario are subject to uncertainty (e.g. the degree of technological development) because no-one knows what the world will look like that far into the future. The scenarios have been used to show how traffic demand may change under different possible states of the world. It is therefore important to understand the underlying assumptions and storylines of each scenario discussed because it is those assumptions that drive the resulting air traffic demand.

Figure 2: Projections of global air traffic demand to 2050 based on different scenarios, as estimated by the FESG PTG[15]



[15] A detailed table of results can be seen in Annex 3

28. The demand projections for each scenario form a key component of the second approach to developing emissions projections to 2050. The approach relies on recognising that aviation CO_2 emissions are essentially driven by two key variables: underlying demand, and fleet-wide percent per annum improvement in fuel burn (which in turn considers fleet retirement and replacement, and various levels of technology and operational improvements).

29. Using the information from the MODTF approach above i.e. fuel burn under each modelling scenario (described in paragraph 13), and the level of air traffic demand from the FESG CAEP/8 central demand forecast, it is possible to calculate the “implied” fleet-wide per annum improvement in fuel burn.

30. The fleet-wide per annum improvement in fuel burn for each MODTF modelling scenario between 2006 and 2036 – expressed as fuel burn per unit of traffic demand – was therefore computed. This was then applied to each of the demand scenarios used by the FESG PTG to develop global traffic projections to year 2050 (as in Box 1) to provide a range of fuel burn values for each FESG PTG demand scenario[16].

31. Given that each of the FESG PTG demand scenarios has an underlying storyline, it was important that the fuel burn assumptions (i.e. the choice of MODTF fuel burn scenario from paragraph 13) are consistent with that storyline. For example, where the demand scenario is built on a storyline involving high fuel efficiency, clearly MODTF fuel burn scenarios 1 and 2 would not be appropriate[17].

32. Figure 3 presents the results of this process for a sample of the 15 FESG PTG demand scenarios described in Box 1 (some of the scenarios are plotted very close to, or even on top of, one-another). The full range of scenarios is represented, in that any FESG PTG scenarios not plotted in Figure 3 would fall within the displayed envelope.

33. The fuel burn in 2050 under each of the FESG PTG scenarios using each of the MODTF fuel burn modelling scenarios, rather than those that are strictly consistent with the underlying storylines, has been displayed diagrammatically, for illustration, in Annex 2.

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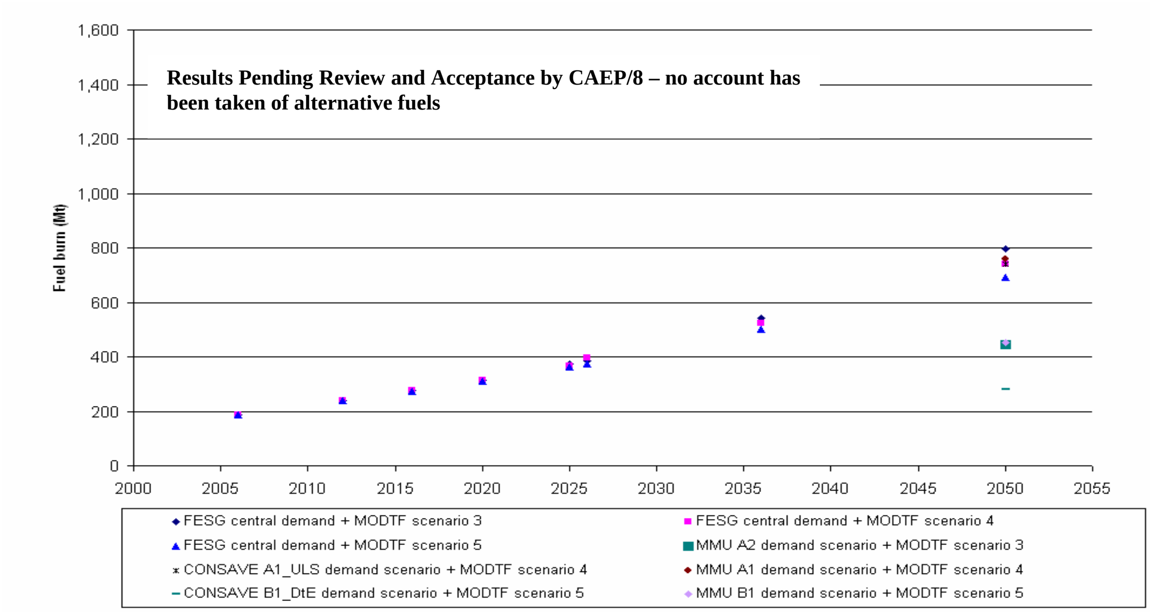
[16] The approach is therefore to use the computed fuel burn per unit demand, multiplied by level of demand from the FESG PTG, to give fuel burn projections.

[17] As these assume no further fuel efficiency improvement beyond that available today

Figure 3: Annual global aviation fuel burn projections to 2050 for the range of FESG PTG demand scenarios



34. The range of fuel burn values shown in Figure 3 shows that under the scenarios illustrated, fuel burn in 2050 from global commercial aviation could fall within the range of 280 Mt and 800 Mt. In terms of CO_2 emissions, this equates to a range in 2050 of around 890 Mt CO_2 to some 2,500 Mt CO_2.

35. It is not possible to say what the actual fuel burn in 2050 will be given the significant uncertainties associated with the underlying demand and per annum improvements. However, the spread of fuel burn results shown in Figure 3 is intended to illustrate potential emissions under different assumptions.

Limitations of the approach

36. The approach taken above has the benefit of retaining consistency with the MODTF environmental goals assessment work. However, as with any approach there are limitations.

37. The approach is simplistic as it assumes that the per annum improvement in fuel burn trends to 2036 continues for a further 14 years to 2050. This may miss some effects such as revolutionary technological advancement (e.g. hydrogen-powered aircraft), though in 14 years, it could be argued that this would not be likely to have a significant effect on the results given that this variable has been accounted for in the FESG PTG's underlying demand where appropriate – and demand is the main driver of emissions rather than per annum fuel burn improvement.

38. Figure 3 illustrates the results using the underlying demand scenarios from the FESG PTG work, but combines this with the per annum fuel burn improvement trend of the MODTF modelling scenarios which are most consistent with the demand scenario. For example, a demand scenario which has an underlying storyline of significant investment in technology would assume the MODTF scenario 5 as say MODTF scenario 1 or 2 would be highly inconsistent.

39. It is possible that other per annum improvement trends would be more appropriate for each demand scenario. Hence, this has been explored by FESG PTG and it was found that:

- Emissions projections to 2050 using the various FESG PTG demand scenarios do not vary significantly when other scenarios from MODTF are used (i.e. scenarios 3 to 5). For example, results are broadly similar with only a maximum 15% difference, whether low (scenario 3), moderate or advanced (scenario 5) technology/operational improvements are applied to underlying demand. As explained above, this is because demand is generally the dominant driver of emissions, rather than technology/operations.

- There are significant impacts on projected emissions however for those modelling scenarios which have no or very small per annum improvements (i.e. MODTF modelling scenarios 1 and 2: ‘do nothing’ and ‘CAEP/7 baseline).

40. No impact of alternative fuels has been assumed in these results. For a given level of fuel burn, emissions of CO_2 from aviation be expected to be lower if kerosene were replaced at least in part by for example, a sustainable biofuel or other low/zero-carbon fuel, assuming consideration of a full life cycle emissions.

41. No assessment has been made of the extent to which aviation fuel will be available in the magnitudes projected here by 2050. Given the long term nature of these projections, it is not possible to comment on these considerations with certainty; however, it is plausible that the projected levels of traffic and demand would potentially be lower if in the future there were fuel supply limitations and/or increases in fuel prices.

Plausibility checks

42. The results of the FESG PTG work for each of the underlying demand scenarios have been cross-checked against other emission projections to 2050 produced from different sources such as the CONSAVE project, IPCC work and recent work taken forward by MMU.

43. This comparison showed that the FESG PTG results were broadly consistent with the projections of the previous FESG work in 1999 (as reported in Aviation and the Global Atmosphere, IPCC, 1999); with the CONSAVE work completed for the European Commission and with the work taken forward by MMU for the EU Quantify project.

44. The aviation industry offered its view of fuel burn projections to 2050 to GIACC/3 through a presentation by ACI, CANSO, IATA and ICCAIA. This suggested that over the period 2006 to 2050, fuel burn would increase some 5-fold over the period. However, operational optimization, air traffic management improvements and the use of auxiliary power units (APU) could together reduce this increase to some 4½ -fold over the period.

45. This is broadly consistent with the growth projected in this paper where all but one of the scenarios[18] fall within the range of a 3- to 4.2 -fold increase in fuel burn over the period 2006 to 2050. It should be noted that the approach taken by ACI, CANSO, IATA and ICCAIA was an extrapolation to 2050 of a trend of emissions whereas the FESG PTG results account for market

[18] The only scenario lying outside of this range if a projection of the CONSAVE Down to Earth scenario which FESG PTG itself has recognised is not realistic given the strong assumptions regarding behavioural change.

maturity (i.e. a slowing of demand and emissions growth over time), hence this difference would be expected and is explained.

Alternative fuels

46. As explained above, the results in Figures 1 and 3 do not make any assumptions regarding the adoption of alternative fuels. Clearly, if for example, sustainable fuels were adopted across the whole fleet by 2050 then emissions of CO_2 could be significantly lower, assuming consideration of a full life cycle emissions. There remains uncertainty as to the extent to which overall emissions would be affected through the use of alternative fuels given the broader issues of availability and the energy used in their production.

47. A sub-group within CAEP (WG3 FEMAH[19]) is currently working through the potential impact of alternative fuels on CO_2 emissions.

Conclusions

48. This paper has shown that it is possible to illustrate projections of global aviation CO_2 emissions to 2050 and has been drafted jointly by FESG PTG and MODTF, so it collates all CAEP/8 work on emissions projections to 2050.

49. Further detail on the approach used is presented in Annex 1.

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[19] WG3 – CAEP Technical working group on emissions. FEMAH – Fuel Efficiency Metric Ad Hoc Group.

Annex 1: Detail on developing CO_2 emissions projections to 2050

Approach used

1. Recognising that the Modelling and Databases Task Force (MODTF) has undertaken work to compute emissions estimates to 2036 consistent with the FESG CAEP/8 central traffic forecasts, in the time available there were two options for taking this task forward:

    i) Extrapolate the MODTF emissions 2036 trend to 2050; and

    ii) use the FESG PTG demand scenarios combined with the per annum fuel burn improvement trends from the MODTF goals work

2. This requires using the results as supplied by MODTF, and calculating the per annum fuel burn improvement trends for each of their modelling scenarios. The relationship between Revenue Passenger Kilometres (RPKs, demand) and emissions has been used to develop emissions projections to 2050 for each of the FESG PTG demand scenarios.

3. Spreadsheet data was kindly supplied to the FESG PTG by MODTF, including the MODTF Round 2 emissions data (an earlier version of data to 2036 was presented to the GIACC/3 meeting).

4. These data were produced under the auspices of the GHG goals/trends assessment and present preliminary scenarios in global commercial aviation fuel burn[20], which include a diversity of assumptions regarding aircraft technology and operational improvements, as described in Para 13, and are currently based on the FESG CAEP/8 central traffic forecast. Similar data will be produced by MODTF for the FESG CAEP/8 low demand growth forecast.

5. The MODTF data are global fuel burn in megatonnes ($1kg \times 10^9$) associated with commercial aircraft fuel burn.[21] MODTF data are computed for a baseline year of 2006 and forecast years of 2016, 2026 and 2036.

Option i)

6. In order for the MODTF to provide data for the intermediate years requested by the GIACC (2012, 2020 and 2025) the MODTF derived a best-fit fourth-order polynomial for their data allowing interpolation of intermediate years.

7. The MODTF Exponential Curve fit (v2=b1*exp(b2*v1)) has been applied in this work to project the fuel burn (and CO_2 emissions) time series forward to 2050.

8. The results of direct extrapolation of the MODTF fuel data are shown in Table 1 and Figure 1.

Option ii)

9. This option uses the FESG PTG demand projections to 2050 and is a combination of the demand forecasts and the MODTF environmental goals scenarios. The MODTF work provided fuel burn data to 2036 using the FESG CAEP/8 central demand forecast together with the detailed

[20] Fuel burn as kerosene is easily translated to CO_2 emissions
[21] It does not include fuel burn associated with aviation-related operations (e.g., auxiliary power units, ground support equipment, etc.).

interpretation of the modelling scenarios (as in para 13) with regard to aircraft retirement and replacement, technology and operational improvements.

10. As noted, the MODTF fuel burn data for each modelling scenario are, in this work, based on the FESG CAEP/8 central demand forecast. Therefore it is possible to derive fleet-wide per annum improvements from the data (i.e. calculate the "implied" fuel efficiency that must have been underlying the fuel burn, given the levels of demand).

11. Whereas the MODTF fuel burn statistics are based on the FESG CAEP/8 central passenger and freight demand, the implied fuel efficiency is derived using FESG passenger demand only, thus when the implied fuel efficiency is applied to the FESG PTG passenger demand projections a constant correction for freight is made and the projected fuel usage implicitly includes a freight element.

12. For the purposes of the 2050 projections work, the six scenarios derived from the MODTF data have a curve fitted to the data points plotted for 2006, 2016, 2026 and 2036. A fleet-wide per annum improvement is computed to 2050 using the curve fit.

13. The derived per annum fuel burn improvement trends are then applied to the FESG PTG demand scenarios to 2050 to provide a range of fuel burn outcomes for each demand scenario. The data shown in Figure 3 are the 2050 fuel burn projections for each FESG PTG demand scenario. The figure plots the data resulting from applying the MODTF modelling assumptions.

Annex 2: Global aviation fuel burn under different MODTF modelling scenarios

14. In Figure A2.1 and A2.2 , the global aviation fuel burn obtained by applying each of the MODTF scenarios to the 15 FESG PTG demand scenarios is shown.

15. MODTF modelling scenario 4[22] has been chosen for illustration (and is shown as the solid bar plotted in the chart) as it reflects a level of fuel burn improvement that is considered challenging but achievable.

16. The "error bars" extending from the central block for each PTG scenario illustrate the fuel burn range that would result. It should be noted that the top of each "error bar" denotes the level of fuel burn resulting from applying MODTF scenario 1[23](maximum), the bottom is the fuel burn resulting from MODTF scenario 6 (minimum).

17. MODTF scenarios 1 and 2 are not considered realistic given the 40 year or so time horizon being considered. Stripping MODTF scenarios 1 and 2 out would leave a much narrower range of fuel burn for each FESG PTG demand scenario, as shown in Figure A2.2. As some of the fuel burn assumptions (derived from the MODTF scenarios) may not be consistent with the underlying storyline of the FESG PTG demand scenarios, the charts must therefore be interpreted with caution.

[22] Scenario 4 (Moderate Aircraft Technology and Operational Improvement). In addition to including the improvements associated with the migration to the latest CNS/ATM initiatives, e.g., those planned in NextGen and SESAR (Scenario 2), this scenario includes fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide moderate operational improvements of 0.5, 1.4 and 2.3 percent by 2016, 2026 and 2036, respectively.

[23] Scenario 1 (Do Nothing). This scenario assumes no improvements in aircraft technology beyond those available today and no improvements from communication, navigational and air traffic management (CNS/ATM) investment or from planned initiatives, e.g., those planned in NextGen and SESAR.

Figure A2.1: 2050 fuel burn scenarios based on FESG PTG demand projections under different MODTF scenarios 1 to 6

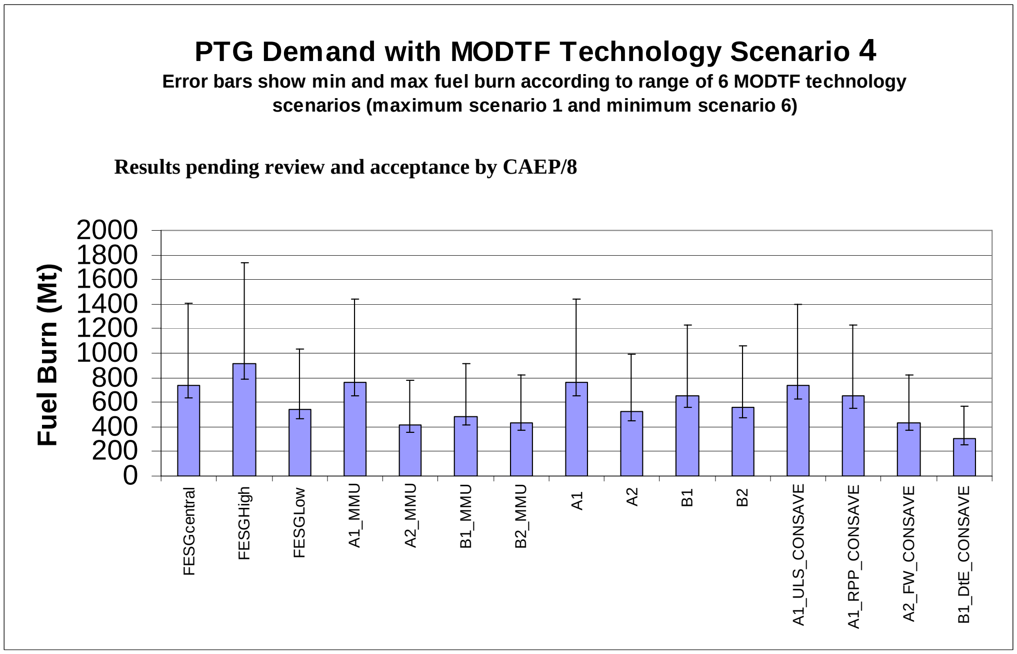

Figure A2.2: 2050 fuel burn scenarios based on FESG PTG demand projections under MODTF scenarios 3 to 6

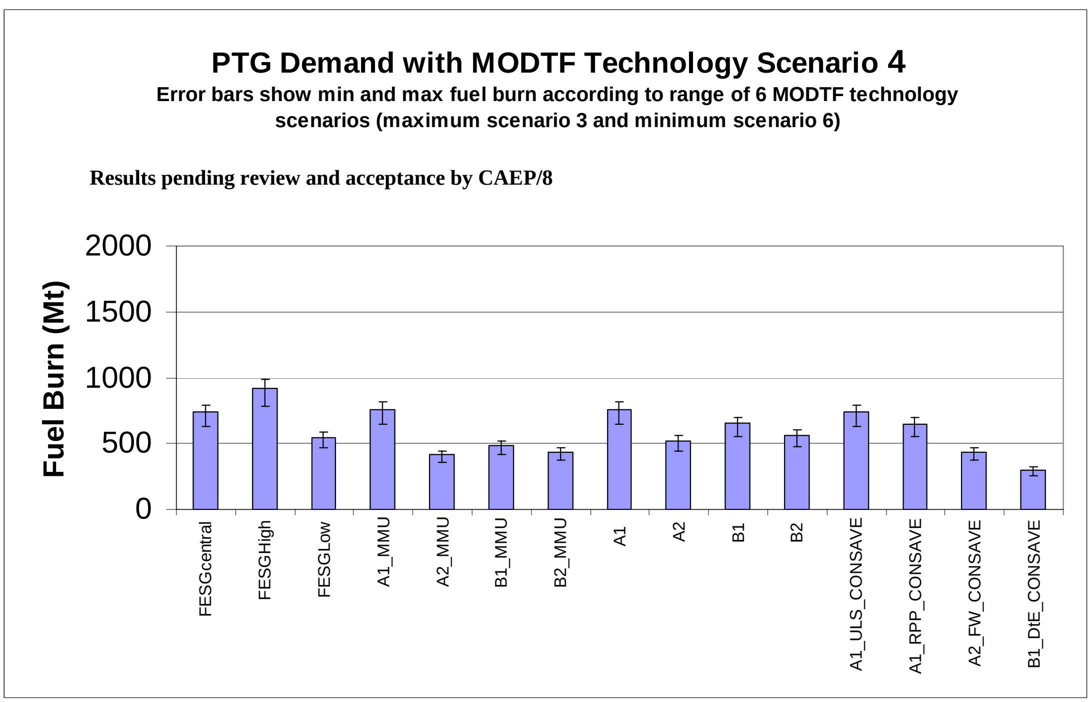

Table A2.1: Global aviation fuel burn projections for 2050 for range of FESG PTG scenarios

PTG Demand Scenario	2050 Fuel (Mt) with 6 MODTF fuel efficiency scenarios					
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
PTG Extension						
FESG Central	1403	998	795	741	693	634
FESG High	1739	1238	986	919	859	786
FESG Low	1031	734	584	545	509	466
MMU Quantify						
A1_MMU	1438	1023	815	760	710	650
A2_MMU	782	556	443	413	386	353
B1_MMU	915	651	518	483	452	413
B2_MMU	824	586	467	435	407	372
IPCC/SRES						
A1	1438	1023	815	760	710	650
A2	988	703	560	522	488	446
B1	1232	877	698	651	608	557
B2	1059	754	600	560	523	479
CONSAVE						
A1_ULS_CONSAVE	1397	994	792	738	690	631
A1_RPP_CONSAVE	1228	873	696	649	606	555
A2_FW_CONSAVE	823	586	467	435	407	372
B1_DtE_CONSAVE	570	406	323	301	282	258

Annex 3: Detailed results from the FESG PTG demand projections to 2050

Table A3.1: Extrapolated total global aviation demand to 2050 (RPK, billions) from 2026 using CONSAVE and MMU growth rates

	2006	**2016**	**2026**	**2036**	**2050**
FESG CAEP/8 Forecast				FTG Extension	-
High	4,271	7,330	12,175	*19,531*	
Central		7,026	11,199	*17,250*	
Low		6,534	9,651	*13,747*	
2050 PTG Extension (of the FESG FTG 2036 extension)					
High					*35,781*[24]
Central					*28,910*
Low					*21,255*
MMU scenarios					
A1				16,800	29,642
A2				13,033	16,118

[24] These values represent a further 10-year extension on top of the FESG CAEP/8 forecast 10-year extension and have been derived by the PTG using the methodology of declining growth rates as for the FESG FTG 2036 extension.

B1	13,913	18,853
B2	13,320	16,983
MMU mathematical function/IPCC 1999 method with SRES GDP		
A1	16,800	29,642
A2	14,364	20,354
B1	13,913	25,393
B2	14,790	21,832
CONSAVE		
A1_ULS	16,599	28,799
A1_RPP	15,727	25,300
A2_FW	13,317	16,971
B1_DtE	11,426	11,753

— END —