Regulatory Impact Assessment

Information to Support the Rulemaking Processes of ICAO Member States for Implementation of the Integrated CO_2 and Noise Standards Stringencies

2026

International Civil Aviation Organization

EXECUTIVE SUMMARY

The International Civil Aviation Organization (ICAO) is a United Nations (UN) specialized agency, established by States in 1944 to manage the administration and governance of the *Convention on International Civil Aviation* (referred to as the Chicago Convention). ICAO works with the Convention's 193 Member States and industry groups to reach consensus on international civil aviation Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. Presently, there are over 10,000 such Standards and provisions contained in ICAO Annexes to the Chicago Convention. ICAO's ongoing mission is to support a global air transport network that meets or surpasses the social and economic development and broader connectivity needs of global businesses and passengers. While acknowledging the clear need to anticipate and manage the projected doubling of global air transport capacity by 2030 without unnecessary adverse impacts on system safety, efficiency, convenience or environmental performance, ICAO has established five comprehensive Strategic Objectives, namely: Safety, Air Navigation Capacity and Efficiency, Security and Facilitation, Economic Development of Air Transport, and Environmental Protection.

Improving the environmental performance of aviation is a challenge ICAO takes very seriously. In fulfilling its responsibilities, ICAO has four major environmental goals, which are to limit or reduce: 1) the number of people affected by significant aircraft noise, 2) the impact of aviation emissions on local air quality, and 3) the impact of aviation greenhouse gas emissions on the global climate; and 4) to ensure future resilience of air transport by adapting its infrastructure and operations to the consequences of climate change. To limit or reduce the impact of aviation greenhouse gas emissions on the global climate, in 2022 the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal. To support reaching the LTAG ICAO takes actions on revising current and adopting new SARPs for international aviation.

The ICAO Committee on Aviation Environmental Protection (CAEP) is a technical committee of the ICAO Council established in 1983. CAEP assists the Council in formulating new policies and adopting new SARPs related to aircraft noise and emissions, and more generally to aviation environmental impacts. CAEP undertakes specific studies, as requested by the Council. Its scope of activities encompasses noise, air quality and the Basket of Measures considered for reducing international aviation CO_2 emissions. CAEP is structured into Working Groups in order to progress tasks under the various environmental areas (noise, emissions, modelling, etc.).

During the CAEP/12 meeting in February 2022, the CAEP tasked Working Group 1 (WG1) on Noise, Working Group 3 (WG3) on Emissions, the Modelling and Database Group (MDG) and the Forecasting and Economic Studies Group (FESG) to conduct a dual stringency analysis. While historically CAEP has considered CO_2 Emissions and Noise stringency analyses independently (i.e., in different cycles), this was the first time both were analysed at the same time. It required a new and integrated approach to consider interdependencies between CO_2 emissions (fuel burn) and noise. The CAEP/13 integrated dual stringency analysis includes the assessment of stringency options (SOs) concerning (1) New Type (NT) standards for aeroplane CO_2 emissions and Noise and (2) the In-Production (InP) standard for aeroplane CO_2 emissions (only).

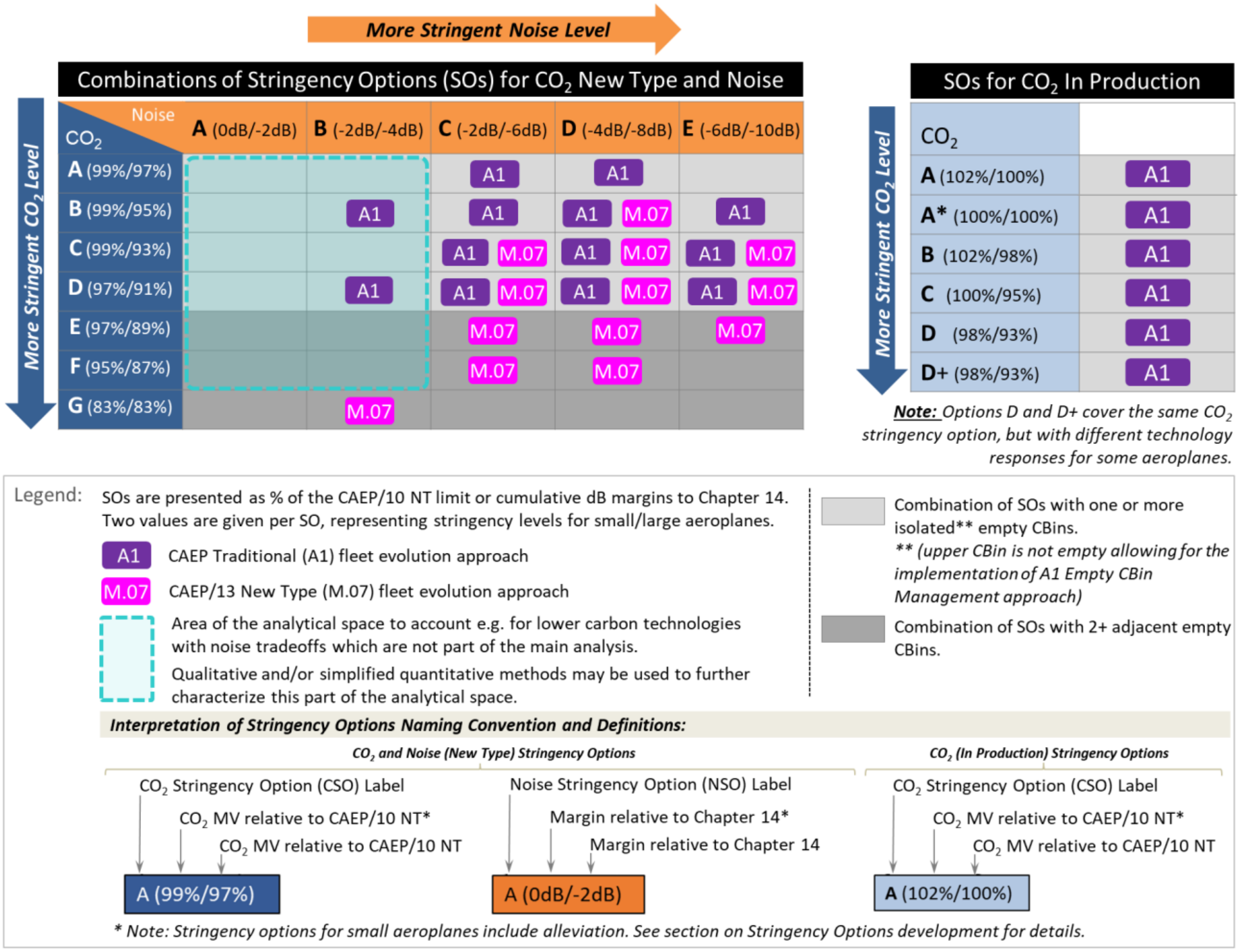
A Sample Problem conducted during the first year of the CAEP/13 cycle helped prepare for the Main Analysis (MA) for which inputs and results are presented in this report.

For the Main Analysis, data was collected for relevant in-production and project aeroplane types. For all relevant aeroplane types, data for CO_2 Metric Values (MV) and Noise levels were collected from publicly available certification databases, confidential Original Equipment Manufacturer (OEM) data, and/or secondary data sources when required.

To support the collection of technology responses per aeroplane type, the WG1 and WG3 developed initial SOs defined as a grid of constant offsets from the CAEP/10 NT and Chapter 14 limits for CO_2 and Noise respectively. Technology Response (TR) information for each SO has been provided by the OEMs based on a definition of Technical Feasibility agreed by WG1 and WG3. Considering these TRs and a set of guiding principles, WG1 and WG3 agreed on an adjusted set of 5 SOs for Noise and 7 SOs for CO_2 NT (35 combined SOs), as well as 6 SOs for CO_2 InP. To account for design constraints of small aeroplanes, alleviation has been integrated into these SOs, meaning that the SOs are less stringent for small aeroplanes than for large aeroplanes.

A set of 32 modeling scenarios was then down selected to assess the cost-effectiveness of the SOs. Two fleet evolution approaches ("A1" approach used in previous CAEP stringency analyses and the "M.07" approach developed during the CAEP/13 cycle) were used to model scenarios for NT SOs, and simulate different ways by which aeroplanes may respond to the CO_2 and/or Noise stringencies. The A1 approach was used to assess the CO_2 InP SOs.

The figure below describes the matrix of scenarios analyzed. Additional input assumptions required to conduct fleet evolution and system level analyses were established, including: (a) analysis time horizon through 2050, (b) 2029 applicability for CO_2 and Noise SOs for New Types, and 2035 for CO_2 In-Production SOs, (c) CAEP/13 COVID-19 traffic demand and fleet forecast with a 2018 base year, along with (d) methodologies for estimating a range of costs e.g., fuel burn costs (or savings), capital costs, direct operating costs (DOCs), and non-recurring costs (NRCs).



The cost-effectiveness results of the CAEP/13 Main Analysis combine outcomes of several modelling steps, including fleet evolution, CO_2 emissions (including NOx trade-offs) estimations (i.e., focusing on fuel burn and CO_2 emissions), noise impact estimations as well as costs implications for each SO analysed.

Fleet Evolution: Fleet evolution models were run for the baseline as well as for all scenarios for New Type and In-Production. The FESG ran fleet evolution models using two modelling approaches: (1) the CAEP Traditional (A1) fleet evolution approach (for both New Type and In-Production SOs) and (2) the CAEP/13 New Type (M.07) fleet evolution approach (for New Type SOs only). Under the A1 approach, aeroplanes have an immediate response when standards go into effect, whereas under the M.07 approach responses are delayed reflecting when new technologies may enter the market. For some SOs under the A1 approach, the FESG noted substantial changes in the composition of the modelled global fleet when transitioning from one combination of SOs to another. In these instances, some sub-market segments, also referred to as Competition Bins (CBins[1]), had no aeroplane available for fleet evolution, which require the use of larger aeroplanes from a higher CBin. The use of larger aeroplanes (i.e., with more seats) results in fewer operations (i.e., flights) to serve the same demand. Under the M.07 approach, aeroplanes revert to their

[1] Competition Bins (CBin) define both the broad market type (e.g., passenger) and the division of aeroplanes sizes/types within a market (e.g., large narrow body aeroplanes). A higher CBin would be an adjacent CBin containing larger aeroplanes (e.g., moving from small to large narrow body aeroplanes).

baseline configuration when no aeroplanes have a TR within a CBin. These fleet evolution effects have downstream impacts on fuel burn, CO_2 emissions, noise, Nitrogen oxides (NOx), and costs.

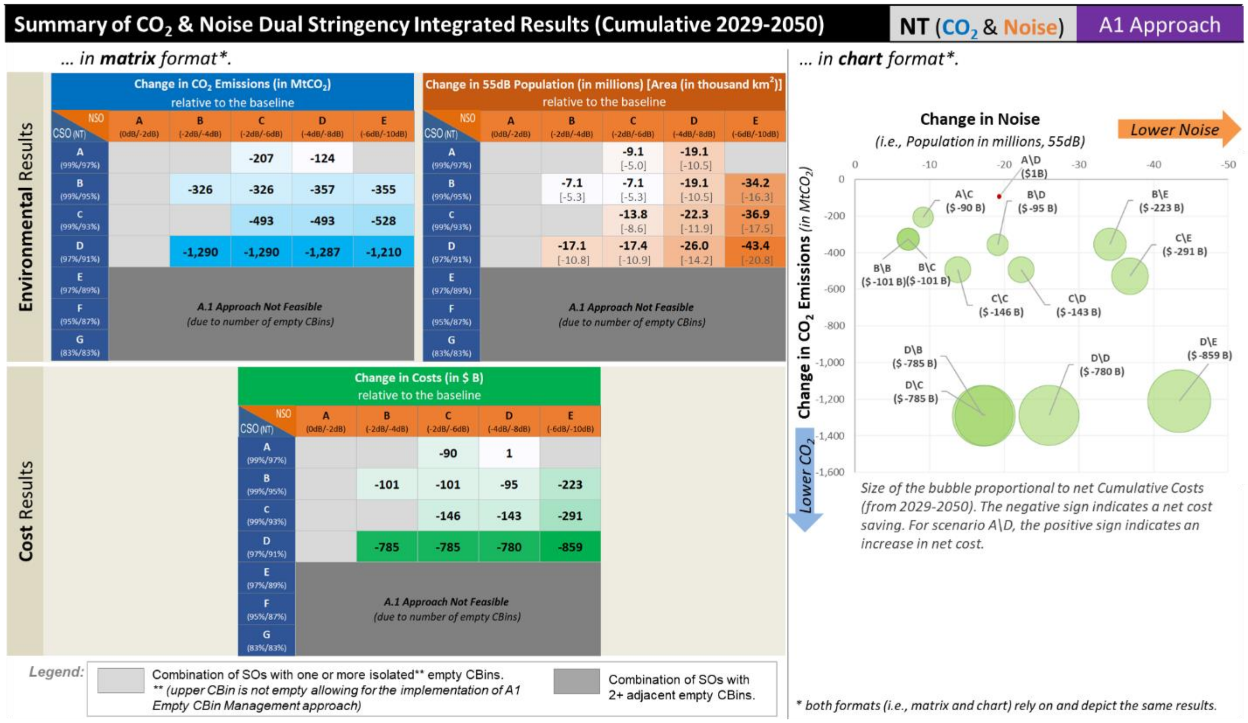
Fuel Burn and CO_2 emissions: Using the outcome of fleet evolution runs, the MDG ran GHG models for each scenario to estimate CO_2 emissions (including NOx trade-offs). The effects of a given scenario (i.e., impact of SOs on the fleet and its operations) were calculated using the same approach of "Scenario minus Baseline" used in prior CAEP stringency assessments. Based on input from WG3 and data from OEMs, the MDG also modelled interdependencies by assessing NOx emissions for each of the scenarios. The results on changes in fuel burn compared to the baseline are then converted to changes in combustion CO_2 emissions.

Noise: For each of the scenarios, the MDG-FESG conducted noise assessments for a subset of 103 airports globally. The results are reported as (1) change in noise contour area relative to the baseline for Day Night Average Sound Level (DNL) 55 dB and (2) change in population exposed relative to the baseline also for DNL 55 dB.

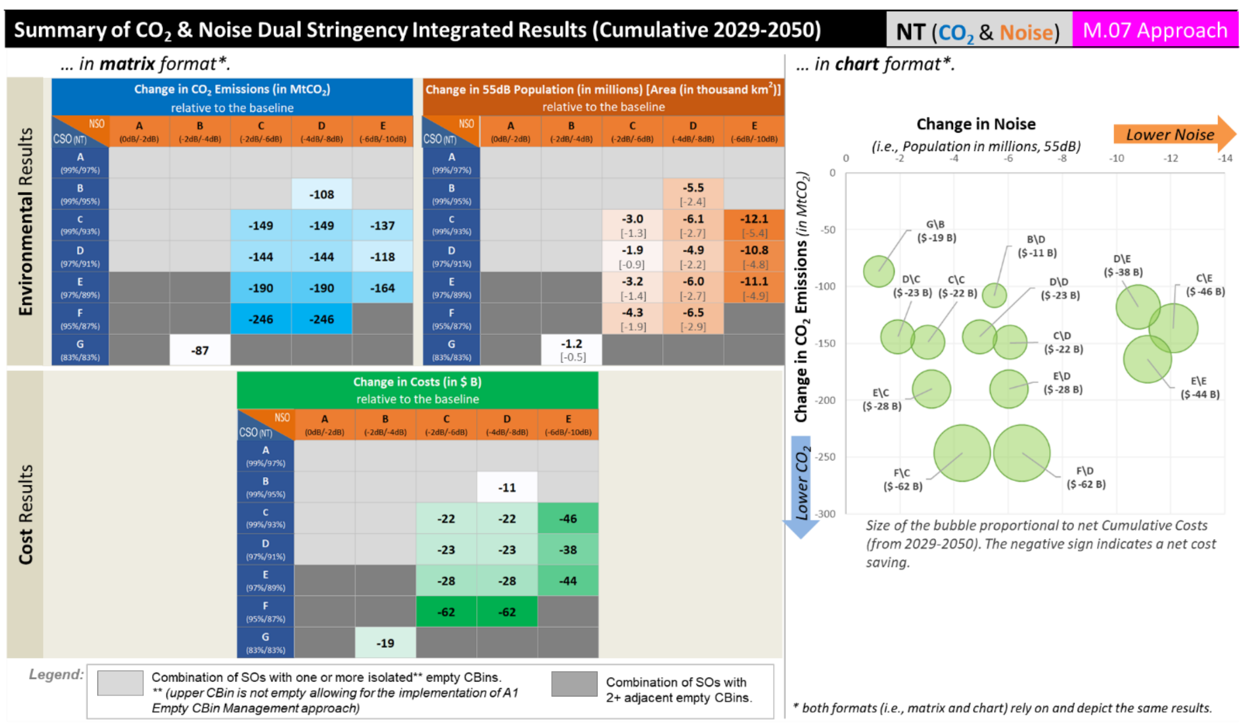
Costs results: The FESG translated the impacts of each scenario on the fleet and its operation into costs to OEMs and aeroplane operators. This includes fuel burn costs, capital costs, other DOCs, and NRCs. Although the NT and InP SOs have different applicability dates, all NT and InP cumulative costs are calculated over the same period 2029-2050 to enable comparability of relative (%) variations to baseline.

Integration of Environmental Impact and Cost Results: While historically the CAEP has focused on CO_2 or noise stringency analyses independently and conducted during different CAEP cycles, the CAEP/13 integrated dual stringency analyses bring new challenges in integrating and communicating results. Typical cost effectiveness metrics (i.e., environmental benefits divided by costs) cannot be developed. Given the vastly different characteristics and impacts of CO_2 emissions versus noise in terms of geographical scope, temporal duration, and mitigation measures, it was deemed impossible to combine changes in CO_2 emissions and noise impacts into a single metric without making a policy value judgement which may differ across regions and/or States. As such, the groups are reporting results on CO_2, noise, and costs side-by-side to allow CAEP Members to integrate policy judgements in their considerations. The figure below summarizes the key results for the A1 approach[2].

[2] Costs shown in the below figures reflect the change in total cumulative costs relative to the baseline scenario where a negative value is a reduction in total cumulative costs and a positive value is an increase in total cumulative costs. A negative total cumulative cost value may reflect both positive and negative changes in individual cost components (e.g., capital, fuel, other DOCs) relative to the baseline.



The figure below provides key results for the M.07 approach.

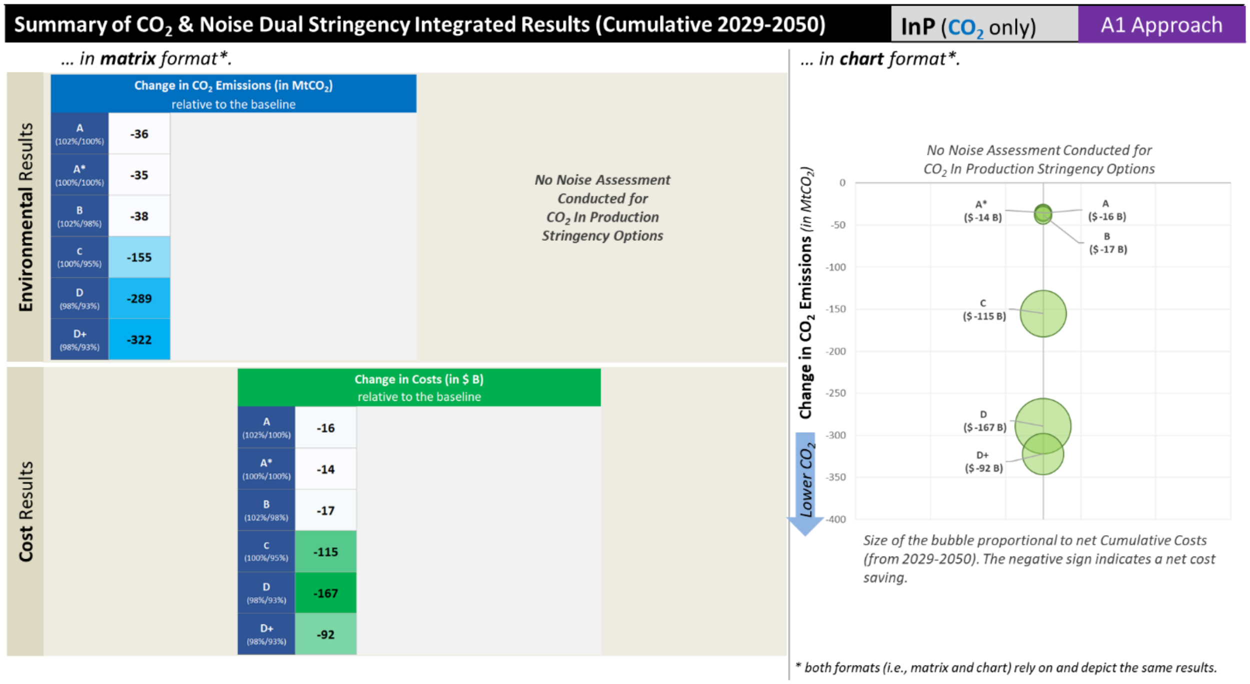


Interpretation of the results and observations require the careful consideration of the underlying assumptions and resulting fleet evolution changes. For example, the step change in fuel burn and costs from

CO_2 Stringency Option (CSO) C to CSO D under the A1 fleet evolution modelling approach is in large part driven by such fleet evolution dynamics.

Scenario rankings for cumulative cost and environmental results for both the A1 and M.07 approaches are presented in Figure 51 in Chapter 19.

Finally, the Figure below summarizes the key results of the assessment of In-Production CO_2 SOs.



Rankings for cumulative cost and environmental results for CO_2 InP SOs evaluated using the A1 approach are presented in Figure 77 in Chapter 25.

1. BACKGROUND AND INTRODUCTION

1.1 At the CAEP/12 meeting in February 2022, the CAEP agreed to and tasked WG1, WG3 and MDG-FESG to conduct a dual stringency analysis. The CAEP Steering Group (SG) in 2022 considered a "Status Report of the WG1, WG3, MDG-FESG Integrated CO_2/Noise Stringency Task", which focused on the development of inputs for the Sample Problem analysis.

1.2 This paper provides an overview of the Integrated Dual Stringency Analyses. It details the final results of the Main Analysis, and also includes complementary information. The report was jointly prepared by the WG1, WG3, and MDG-FESG.

1.3 Throughout the development of technical assessments and analyses on the integrated dual stringency, the coordination across the WG1, WG3, MDG and FESG was conducted through the Integrated Stringency Coordination Group (ISCG). The coordination work by ISCG was a critical part of addressing cross-cutting issues between the working groups (for example, but not limited to, proprietary data sharing or the preparation of joint WG1, WG3, MDG, and FESG IDS reports throughout the CAEP/13 cycle).

1.4 Background on prior CAEP Stringency Analyses

1.4.1 The ICAO has a long history of developing Standards, Recommended Practices and Procedures and/or guidance material dealing with the impact of aviation on the environment, including on aircraft and engine environmental standards. ICAO Annex 16 Volumes I, II and III contain the environmental certification standards that shall be observed by aircraft and engine designs. The development and update of the environmental certification Standards ensure that the benefits offered by technology are reflected in real reductions of aviation environmental impacts, while balancing environmental benefit with technological feasibility, economic viability, and the interdependency between environmental factors.

1.4.2 The CAEP has recently supported the Council and Assemblies on the following environmental standards:

a) NOx stringency (CAEP/8),

b) Noise stringency (CAEP/9),

c) CO_2 stringency (CAEP/10), and

d) Non-volatile particulate matter (nvPM) stringency (CAEP/11)

1.5 Introduction to Dual Stringency: Concept and High-Level Description

1.5.1 With the adoption of the CAEP/11 nvPM mass and nvPM number engine emission standards in 2019, the full range of the ICAO environmental standards are complete. However, the challenge was keeping this range of regulations up to date within the CAEP programme of work, considering the fast pace of technological progress. Furthermore, the integrated nature of the technological improvements required to meet more and more stringent regulatory levels, across noise, fuel efficiency/CO_2 emissions and engine emissions was clear. In 2019, the ICAO Independent Expert review of technology goals was undertaken as an integrated review in acknowledgement of the growing significance of interdependencies between noise and the various emissions regulations.[3] In 2022, the ICAO Independent

[3] ICAO, "*The Next Logical Step: Integrated ICAO Environmental Standards*", https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art28.pdf

Expert review was also built upon as part of the work of the ICAO CAEP Long Term Aspirational Goal Task Group (LTAG-TG) on the feasibility of a LTAG, in through the development of aeroplane technology scenarios and associated roadmaps.[4]

1.5.2 One solution to the timing of updating regulations was to conduct stringency analysis work for more than one regulation at a time within a single triennial CAEP cycle in the traditional manner. However, this approach does not address the technology integration question, and a more elegant solution proposed was to conduct a stringency analysis for technology improvements for example, at an aeroplane level and then at an engine level, in an integrated manner. In view of these challenges, at the CAEP/12 meeting, the CAEP agreed to the following new task: *"Conduct an integrated standard setting process for subsonic Aeroplane CO_2 Emissions and Landing and Take-off cycle (LTO) Noise with the outcome being more stringent regulatory levels of CO_2 emissions and LTO noise"*. This was a new task for the technical Working Groups of the Committee and required the development of new approaches whilst adhering to the CAEP Terms of Reference, including CO_2 and noise stringency interdependencies.

1.6 Purpose: Provide Analysis to Fulfil the CAEP Terms of Reference (TORs)

1.6.1 According to the CAEP Terms of Reference, the CAEP shall take into account the following:

(1) effectiveness and reliability of certification schemes from the viewpoint of technical feasibility, economic reasonableness and environmental benefit to be achieved;

(2) developments in other associated fields, e.g. land use planning, noise abatement operating procedures, emission control through operational practices, etc.;

(3) international and national programmes of research into control of aircraft noise and emissions from aircraft engines;

(4) the potential interdependence of measures taken to control noise and to control engine emissions.

1.6.2 These pillars of CAEP analysis guide CAEP in carrying out a comprehensive assessment of the costs and benefits of all the options which could be selected to form the new stringencies of the aeroplane noise and CO_2 emissions standards. Such dual standard setting process requires deep coordination across CAEP technical Working Groups and other pertinent technical representatives to guide the technical steps of this integrated standard setting process. The various elements of the analysis, such as, for example, the applicability scope, the options for potential regulatory limits, the associated cost elements and the applicability dates, were developed in a consistent and data-driven environment to the best extent possible. The interdependency factor in this analysis played a key role and required thorough investigation to ensure the analytical space was complete to support an informed decision-making on the dual standard stringency by ICAO.

[4] ICAO, "Report on the Feasibility of a Long Term Aspirational Goal (LTAG) for International Civil Aviation CO_2 Emissions Reductions", available at: https://www.icao.int/environmental-protection/LTAG/Pages/LTAGreport.aspx

1.7 Structure of the Report

1.7.1 This report provides a comprehensive documentation of the Dual CO_2 and Noise Stringency analyses conducted during the CAEP/13 by the WG1, WG3, MDG and FESG. This report is structured in the table below:

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| | |

Glossary of Terms

A1	CAEP traditional fleet evolution approach
AAT	Aircraft Assignment Tool
ADAP	Aviation Data and Analysis Panel
AEDT	Aviation Environmental Design Tool
ASK	Available Seat Kilometre
ASM	Available Seat Mile
BFFM2	Boeing Fuel Flow Method 2
BJ	Business Jet
BTS	Bureau of Transportation Statistics (U.S.)
CAEP	Committee on Aviation Environmental Protection
CAGR	Compound annual growth rate
CBin	Competition Bin
CEA	Cost-effectiveness Analyses
CFR	Code of Federal Regulations
CO_2	Carbon dioxide
COD	Common Operations Database
CSO	CO_2 Stringency Option
DB	Distance Band
DOC	Direct Operating Costs
DNL	Day Night Average Sound Level
EASA	European Union Aviation Safety Agency
ECBM	Empty Competition Bin Management
EEDB	ICAO Aircraft Engine Exhaust Emissions Databank
EIS	Entry Into Service
FB	Fleet Builder
FESG	Forecasting and Economic Analysis Support Group
FTK	Freight Tonne Kilometre
G&R	Growth and Replacement
GHG	Greenhouse Gas
GRdb	Growth and Replacement database
IEIR	Independent Expert Integrated Review (for Engines and Aircraft)
IATA	International Air Transport Association
IBAC	International Business Aviation Council
ICCAIA	International Coordinating Council of Aerospace Industries Association
IDS	Integrated Dual Stringency
ISCG	Integrated Stringency Coordination Group
InP	In Production
LTAG	Long Term Aspirational Goal
LTF	Long-Term Forecast
LTO	Landing and Take-off cycle
M.07	CAEP/13 New Type fleet evolution modeling approach
MA	Main Analysis
MAAL	Main Analysis Aircraft List
MDG	Modelling and Database Group
MTOM	Maximum Take Off Mass
MV	Metric Value
NB	Narrow Body
NPV	Net Present Value

NOx	Nitrogen oxides
NRC	Non-Recurring Cost
NSO	Noise Stringency Option
NT	New Type
O-D	Origin-Destination
OEM	Original Equipment Manufacturer
OoP	Out of Production
nvPM	Non-volatile particulate matter
PNGA	Potential Next Generation Aeroplane
RJ	Regional Jet
RG	Route Group
RGF	Reference Geometric Factor
RPK	Revenue Passenger Kilometre
RTK	Revenue Tonne Kilometre
SAF	Sustainable Aviation Fuel
SAR	Specific Air Range
SARP	Standards and Recommended Practices
SC	Seat Class
SG	Steering Group
SO	Stringency Option
TC	Type Certificate
TFD	Technical Feasibility Definition
TOR	Terms of Reference
TP	Turboprop
TR	Technology Response
TRL	Technology Readiness Level
UID	Unique Identification
US	United States
V&V	Verification and Validation
WACC	Weighted Average Cost of Capital
WB	Wide Body

1. APPROACH

1.1 To facilitate the understanding of the implications of making CO_2 and noise standards more stringent, in the context of the CAEP terms of reference, CAEP working groups were tasked to develop a cost-effectiveness analysis of the considered stringency increase (options) for the LTO noise and CO_2 standards for subsonic aeroplanes.

1.2 This technical analysis relies on complex modelling, driven by nominated experts from CAEP member states and observers, that is subject to data and methods development or maintenance. In order to secure the timeline and ensure an as smooth as possible development of the tools and subsequent technical analysis, CAEP experts developed the modelling in two steps: a Sample Problem and the Main Analysis. The following sections describe the approach developed and implemented by the WG1, WG3 and MDG-FESG.

1.3 Sample Problem Approach

1.3.1 The purpose of the Sample Problem for the CO_2/Noise Integrated Stringency Analysis was to implement a representative modelling process and approach that allows for exercising the integrated suite of methods, MDG-FESG models and databases, and other tools used for stringency analyses, with the goal to identify challenges and areas for improvement prior to the Main Analysis.

1.4 Main Analysis Approach

1.4.1 Figure 4 shows the approach for the CAEP/13 MA. The approach starts with data collection (steps 1–2). Those steps are important as they guarantee that the analysis is based on the best information available. This included industry and other various sources that may be deemed sensitive for use and communication across CAEP working groups. A data management process was setup to handle the sensitive nature of the data where needed. Step 3 built on the development of the Sample Problem Growth and Replacement database (GRdb) and supplementary data sources to develop a list of aeroplanes (i.e., GRdb entries) that correspond to the aeroplanes available in the base year as well as aeroplanes which will be available for future years limited to known in-production aeroplanes and imminent aeroplanes (i.e., aeroplanes that have been formally announced by aeroplane and engine manufacturers). This resulted in a Main Analysis Aircraft List (MAAL). WG3 & WG1 members collected and integrated CO_2 MV and Noise (and in some cases updates to MTOM) data from OEMs or using secondary data sources (step 4). The analysis of aeroplane performance levels (step 5) allowed for a development of Initial SOs for CO_2 (New Type and In Production) and Noise. Another important step consists in an assessment of the potential of future technologies for inclusion prior to the standards becoming applicable. This data set, called TR, is developed based on the SOs and characterises which aeroplane can eventually be made compliant, by the applicability date, to the standards that are being studied. As shown in Figure 4, the TRs for each GRdb entry and combination of SOs was provided by OEMs. This resulted in CO_2 MV and Noise values after TRs which were used to develop a reduced number of SOs with Alleviation for small aeroplanes (step 7). Using data and information integrated in the CAEP/13 GRdb (GRdb13) along with guiding principles provided by the MDG/FESG, the groups developed a set of scenarios to be analysed (also referred to as "down selection"). Finally, based on information and data through steps 4-7, the CAEP/13 GRdb13 was developed (step 9). Based on the available methodologies for standard setting development and incurred costs and resulting benefits, the MDG/FESG performed fleet evolution modelling (step 10), and downstream evaluation of costs and benefits (steps 11–12). The Main Analysis Cost ad hoc group and the FESG Direct Operating Cost task group developed assumptions towards costs (e.g., NRC, DOC).

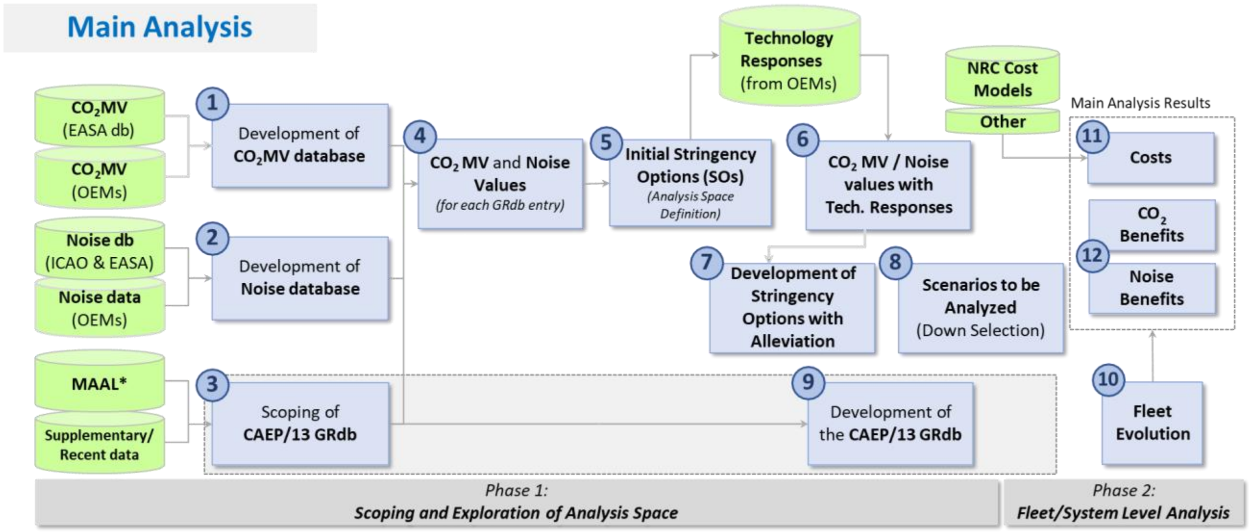


Figure 1: High level approach for the CO_2/Noise stringency Main Analysis

2. MAIN ANALYSIS INPUT: APPLICABILITY SCOPE

3.1 Applicability Scope of Stringency Options

The aeroplane noise and CO_2 emission standards that are subject to the Integrated Dual Stringency (IDS) process are found in Chapter 14 of ICAO Annex 16, Volume I and Chapter 2 of ICAO Annex 16, Volume III. The applicability scope of the current standards and the corresponding SOs includes subsonic jet aeroplanes and large propeller-driven aeroplanes, as specified further in the aforementioned Annex Chapters.

In the IDS process, SOs for NT standards have been assessed for both Noise and CO_2 emissions, for consideration at the CAEP/13 meeting. Furthermore, SOs for a CO_2 in-production standard have also been assessed in the IDS. Following the selection and recommendation by the CAEP of specific stringency levels for future Noise and CO_2 emissions standards, and their review and adoption by the Council, the updates to ICAO Annex 16, Volume I (Noise) and Volume III (CO_2 emissions) will be SARPs-related outcomes of the IDS process.

3.2 New-Type Applicability

In ICAO Annex 16, Volumes I and III, NT standards for Noise and CO_2 emissions apply to aeroplanes "for which the application for a type certificate was submitted on or after" a specific date. Based on airworthiness regulations (e.g. 14 Code of Federal Regulations (CFR) Part 21 in the United States (US), or European Union Aviation Safety Agency (EASA) Part 21), a new type certificate (TC) is required for any NT design, as well as for 'substantial' changes to existing type designs. Previous NT and/or in-production standards remain applicable to any derived versions of existing aeroplane designs that can be included on an existing TC[5].

The conditions for when a new TC is required for a derivative of an existing type design is determined by the Changed Product Rule. The Changed Product Rule refers to the airworthiness regulation that defines how major changes to TCs are certified. According to the internationally harmonized Changed Product Rule, a new TC is required if the certificating authority finds that the change in design, power, thrust, or weight is so extensive that a substantially complete investigation of compliance with the applicable regulations is required (see e.g. 14 CFR 21.A.19 in the US; 21.A.19 in EASA's Part 21). Any such changed product is also referred to as a 'substantial' change.

3.3 In-Production Applicability

In ICAO Annex 16, Volumes III, InP standards for CO_2 emissions apply to individual aeroplanes "for which a certificate of airworthiness was first issued on or after" a specific date. The date of issuance of an aeroplane's first certificate of airworthiness can be seen as an indicator or proxy that the corresponding aeroplane type is in production at this date.

It is worth noting that in the current ICAO CO_2 standards in Annex 16, Volume III, for CO_2 limits are stricter for NT aeroplanes than for InP aeroplanes. This principle is also reflected in the range of CO_2 NT and InP SOs in the IDS.

No InP standard exists in ICAO Annex 16, Volume I.

[5] Derived versions of existing aeroplane types need to comply with the (previous) NT standards that are applicable to the type design they are derived from. In-Production standards also apply to derived versions.

3. MAIN ANALYSIS INPUT: TECHNICAL FEASIBILITY DEFINITION

3.1 Technical Feasibility Definition

3.1.1 One of the key tenets of CAEP's ToR[6] is consideration of technical feasibility in developing environmental Standards and Recommended Practices (SARPs). Within the context of ICAO/CAEP, a definition of Technical Feasibility defines known technologies that contribute to quieter and/or cleaner aeroplanes. This tenet, along with the rest of CAEP's ToR, has served the aviation stakeholders over the past 50+ years by delivering more stringent environmental SARPs that are aimed at reducing the environmental impact of global civil aviation without compromising safety.

3.1.2 The WG1 and WG3 considered proposals towards Technical Feasibility Definitions. The groups reached a consensus on the following definition.

4.a	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG
Technical Feasibility Definition (TFD) "*In the context of technology for improved noise and emissions environmental performance to be used as part of the basis for the integrated analysis of dual standard setting for noise and CO_2, technical feasibility refers to any technology expected to be demonstrated to be safe and airworthy proven to Technology Readiness Level (TRL) 8 (actual system completed and 'flight qualified' through test and demonstration) by 2029 and available for application over a sufficient range of newly certificated aeroplanes.*"				

3.1.3 TRs were provided by OEMs, who reported a consistent use of the definition of technology feasibility. For the specific purpose of TRs in WG1 and WG3, technical feasibility refers to any technology expected to be demonstrated to be safe and airworthy proven to TRL8 (actual system completed and 'flight qualified' through test and demonstration) by 2029.

3.1.4 It should be noted that the definition was agreed with the assumption that for modelling purposes the CO_2 NT and Noise applicability dates would be 2029 (i.e., one date only and the same date for both noise and CO_2 NT). The CO_2 InP applicability date was agreed to be 2035.

[6] ICAO, Committee on Aviation Environmental Protection (CAEP) Terms of Reference, available at: www.icao.int/environmental-protection/Pages/Caep.aspx, last retrieved: July 31, 2023.

4. MAIN ANALYSIS INPUT: DATA FORMAT, SOURCES AND SCOPE

4.1 Scope of the Aeroplane Data

4.1.1 The Main Analysis Aircraft List (MAAL) lists all the aeroplanes in the scope of the work (i.e. current production and imminent aeroplanes). Its purpose was to take the Sample Problem GRdb list of aeroplanes, as well as input from members at the WG1/3-3 joint meeting, and within a month review and edit the list in order to create a MAAL that industry could use to provide CO_2/noise and other necessary data on those aeroplanes for the Main Analysis.

4.1.2 The resulting list of aeroplanes included 169 aeroplanes (i.e., entries). It was shared with industry to allow them to gather and provide data for their respective aeroplanes.

4.2 Development of the Main Analysis CO_2 MV database

4.2.1 The following sections describe the data collection process including data structure, sources, and the scope of the MA.

<table>
<tr><td>5.a</td><td><u>Summary of Assumption(s) for the Main Analysis</u></td><td>WG1</td><td>WG3</td><td>MDG-FESG</td></tr>
<tr><td colspan="5"><u>CO₂ Metric Values</u>
The CO_2 MV data for the MA relies on the following sources:
i. The EASA Aeroplane CO_2 Emissions Database (for CO_2-certified aeroplanes),
ii. CO_2 MV data provided by OEMs,
iii. Piano for Aircraft Emissions and Performance, if data was not available from i. and ii.

Note. – Regarding the use of Piano data as part of a gap filling methodology, the WG3 coordinated with the OEMs on the use of the Piano data for their specific aeroplanes when needed. The use of this data source followed the approval by the OEMs.</td></tr>
</table>

4.2.2 Data on CO_2 emissions MVs was required for each of the aeroplanes included in the Dual Stringency analyses. The ICAO CO_2 standard MV is defined as $(1/SAR)_{avg}/RGF^{0.24}$, where SAR is the Specific Air Range and RGF is a Reference Geometric Factor, consistent with the Annex 16, Volume III definitions.

4.2.3 Several data sources were used as input to the development of the MA CO_2 MV database, including: the EASA Aeroplane CO_2 Emissions Database[7] (for certified aeroplanes), CO_2 MV data provided by OEMs, and Aircraft Emissions and Performance data from Lissys Piano[8] as gap fillers when data was not available from other sources.

4.2.4 The 156 GRdb entries (i.e., aeroplanes to be included in the MA with excess entries such as unnecessary MTOM variants removed) from the MA GRdb13 (v3.5) include: 2 entries based on EASA

[7] EASA, "EASA Aeroplane CO_2 Emissions Database" version 30/05/2022, available at: https://www.easa.europa.eu/domains/environment/easa-aeroplane-co2-emissions-database-0, last retrieved: 03 June 2022.
[8] Lissys Ltd., "Piano - Aircraft Emissions and Performance", available at: https://www.lissys.uk/

Aeroplane CO_2 Emissions Database (for CO_2-certified aeroplanes), 115 for which CO_2 MV data was provided by OEMs, and 20 based on Aircraft Emissions and Performance data from Lissys Piano. Finally, some (19) entries do not require CO_2 MV data (e.g., out of production aeroplanes that are included for purposes of fleet evolution modelling).

4.3 Development of the Main Analysis Noise Database

5.b	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG

Noise Values

The Noise data used for the MA rely on the following sources:

i. Noise data provided by OEMs (including from certification data base on ICAO NoisedB or EASA Certification Noise Levels),

ii. The ICAO NoisedB, if data was not available from above sources,

iii. EASA Certification Noise Levels, if data was not available from ii.

4.3.1 Data on cumulative noise margins was required for each aeroplane considered in the main analyses. Historically, a previous version of the ICAO noise certification database (NoisedB) was used as an input to the GRdb for the CAEP/9 Noise Stringency analysis. For the CAEP/13 MA, noise data provided by OEMs along with data from the ICAO noise certification database (NoisedB) version 2.31.2[9] and the EASA Certification Noise Levels database[10] were used as noise sources.

4.3.2 Out of the 156 GRdb entries contained in the MA GRdb13 (v3.5) retained for the MA, 120 were based on noise data provided by OEMs, a subset of 9 aeroplanes were mapped to the EASA Noise Database, and 12 were from the ICAO noise certification database (NoisedB). Finally, 15 entries were not assigned noise values (e.g., out of production aeroplanes needed only for fleet evolution modelling purposes).

[9] ICAO NoisedB, available at:
https://noisedb.stac.aviation-civile.gouv.fr/

[10] EASA, "EASA Certification Noise Levels", available at: https://www.easa.europa.eu/domains/environment/easa-certification noise-levels, last retrieved: 6 June 2022.

5. MAIN ANALYSIS INPUT: STRINGENCY OPTIONS

5.1 Approach for Stringency Options Development

5.1.1 Starting with large aeroplanes (with MTOM greater than approximately 70 tonnes) and based on the initial set of SOs, an assessment of the minimum and maximum SOs was performed based on aeroplane Pass and Fix status after TRs (i.e., where aeroplanes would generally be available for fleet evolution).

5.1.2 An assessment of the drivers and needs for alleviation for small aeroplanes, and SOs for small aeroplanes were developed accordingly.

5.1.3 SOs for large and small aeroplanes were connected by means of a transition segment. For CO_2, the approach uses a smooth connection, i.e., monotonically increasing limit as a function of MTOM closer to the average behaviour of aeroplanes with MTOM between 46 tonnes and 70 tonnes rather than the plateau approach used for CAEP/10 limit lines. For Noise, SOs for large and small aeroplanes have been connected using a combination of an extended plateau beyond 35 tonnes and a reduced slope, compared to Chapter 14 limit lines, between the end of the plateau and a specific MTOM of either 63.7 tonnes or 73.1 tonnes depending on the SO.

5.2 Summary on CO_2 Stringency Options (SOs) for New Types

5.2.1 A set of 7 SOs for CO_2 NT, including 6 SOs (labelled A through F) that were expected to be the primary focus of the analysis with varying numbers of scenarios (including both A1 and M.07 approaches when appropriate). One SO (labelled G) was intended to test the boundary of the analytical space with M.07 approach.

6.a	Summary of Assumption(s) *for Main Analysis*	WG1	WG3	MDG-FESG

CO_2 Stringency Options for New Type

SOs defined from CAEP/10 NT Limit with constant percent offset defined as follow:

CSO#	A	B	C	D	E	F	G
Referenced from CAEP/10 NT (in %) ***(Large Aeroplanes)***	97 %	95 %	93 %	91 %	89 %	87 %	83 %
Referenced from CAEP/10 NT (in %) ***(Small Aeroplanes)***	99 %	99 %	99 %	97 %	97 %	95 %	83 %

Note: The connection between the small and large aeroplane SOs is between 46 and 60 t.

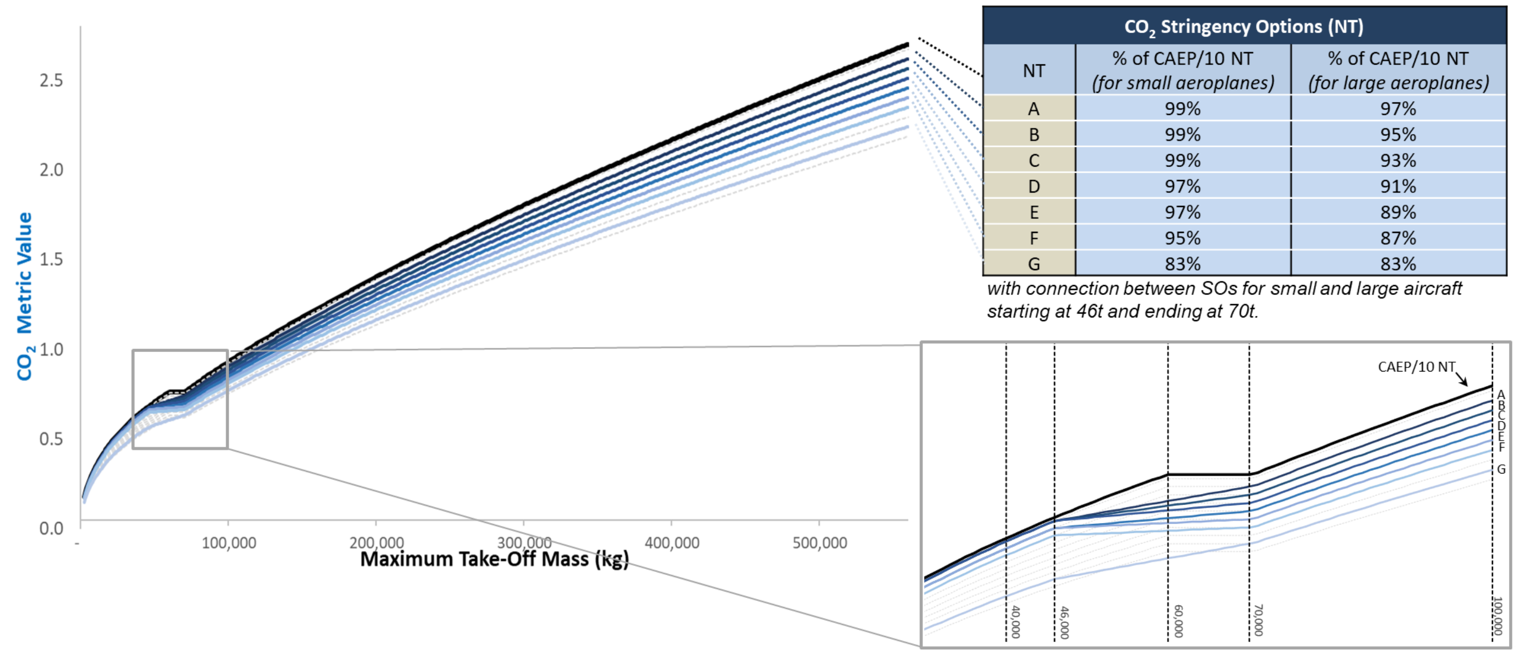


Figure 2: CO_2 New Type Stringency Options

Note: All logarithms are base-10 (e.g., $log_{10}MTOM$)

CSO (NT)	Weight Band 1			Weight Band 2			Weight Band 3		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
CAEP/10	1	60,000	1.00 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	60,000	70,395	0.764	70,395	999,999	1.00 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
A	1	46,000	0.99 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-1.14447+0.20910*log(MTOM))	70,000	999,999	0.97 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
B	1	46,000	0.99 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.91309+0.15948*log(MTOM))	70,000	999,999	0.95 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
C	1	46,000	0.99 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.67679+0.10880*log(MTOM))	70,000	999,999	0.93 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
D	1	46,000	0.97 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.67087+0.10563*log(MTOM))	70,000	999,999	0.91 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
E	1	46,000	0.97 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.42407+0.05270*log(MTOM))	70,000	999,999	0.89 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
F	1	46,000	0.95 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.41208+0.04819*log(MTOM))	70,000	999,999	0.87 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
G	1	46,000	0.83 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-1.44768+0.25771*log(MTOM))	70,000	999,999	0.83 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)

Figure 3: Equations for CO_2 New Type Stringency Options

5.3 Summary on Noise Stringency Options (SOs)

6.c	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG

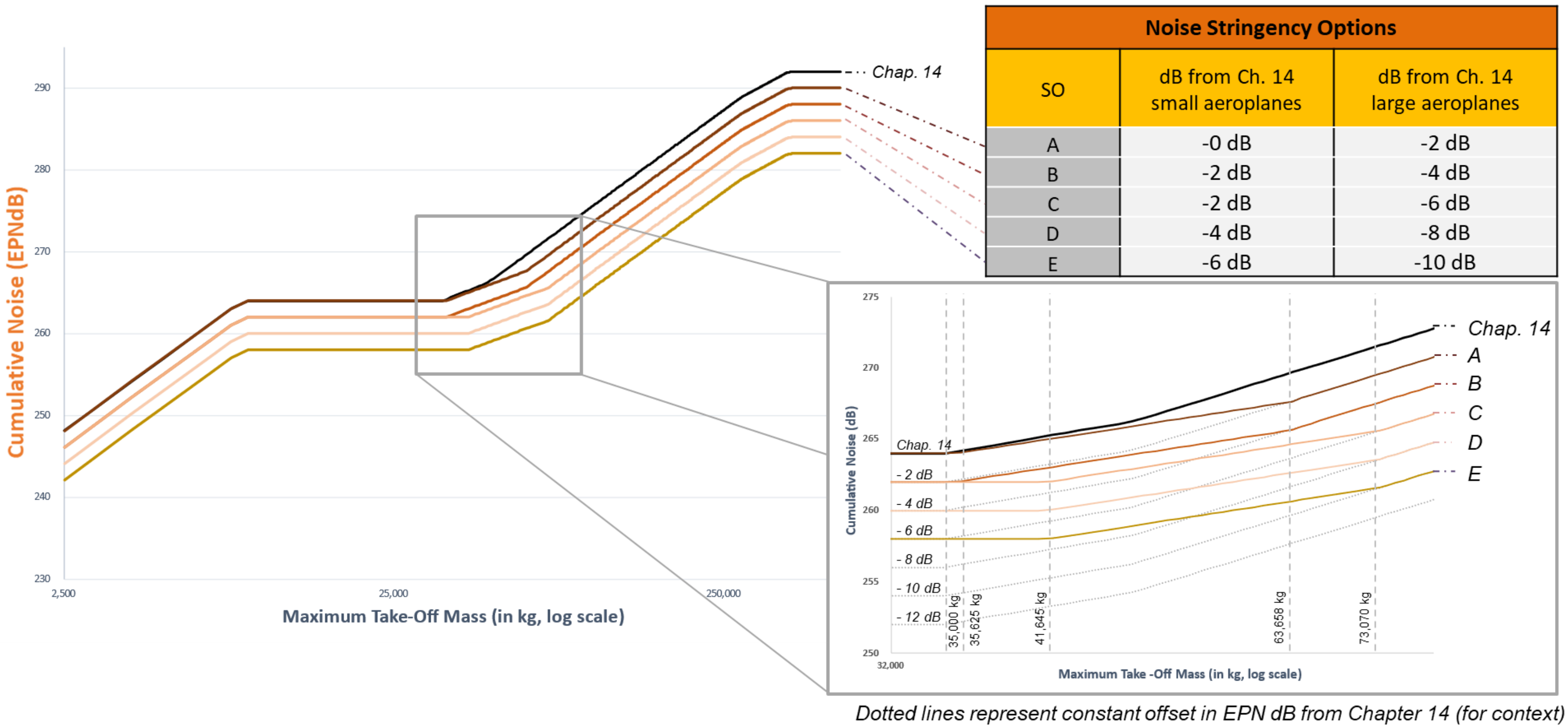
Noise Stringency Options

SOs defined from Noise Chapter 14 were developed using the following set of initial SOs for small and large aeroplanes:

NSO#	A	B	C	D	E
Offset from Chapter 14 (in dB) ***(Large Aeroplanes)***	- 2	- 4	- 6	- 8	-10
Offset from Chapter 14 (in dB) ***(Small Aeroplanes)***	0 (Ch. 14)	-2	- 2	- 4	- 6

Note: The transition between the small and large aeroplanes NSOs was based on a smooth transition approach (similar as with the CSOs but varying start and end MTOMs). See the table of Figure and Table of Equations below for details.

5.3.1 Based on the initial SOs, TRs, analyses and considerations on draft proposals by WG1/WG3 members and the International Coordinating Council of Aerospace Industries Associations (ICCAIA), the WG1 developed a set of 5 SOs for noise, NSO A to E, with alleviation built in for small aeroplanes. The less stringent options were designed to account for noise performance across the full range of aeroplanes (or full market) and to account for lower carbon technologies with noise trade-offs expected to reach TRL8 beyond 2029 which are not part of the main analysis.



Noise Stringency Options		
SO	dB from Ch. 14 small aeroplanes	dB from Ch. 14 large aeroplanes
A	-0 dB	-2 dB
B	-2 dB	-4 dB
C	-2 dB	-6 dB
D	-4 dB	-8 dB
E	-6 dB	-10 dB

Figure 4: Noise Stringency Options

***Note**: All logarithms are base-10 (e.g., $log_{10} MTOM$)*

NSO Cum. (2 Eng)	Weight Band 1			Weight Band 2			Weight Band 3			Weight Band 4		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
Ch14	0	2,000	245.30000	2,000	8,618	236.38294 + 29.52413*log(MTOM/1000)	8,618	35,000	264.00000	35,000	48,125	238.89678 + 16.25785*log(MTOM/1000)
A*	0	2,000	245.30000	2,000	8,618	236.38294 + 29.52413*log(MTOM/1000)	8,618	35,635	264.00000	35,635	62,524	241.07451 + 14.77278*log(MTOM/1000)
B**	0	2,000	243.30000	2,000	8,618	234.38294 + 29.52413*log(MTOM/1000)	8,618	35,635	262.00000	35,635	62,524	239.07451 + 14.77278*log(MTOM/1000)
C*	0	2,000	243.30000	2,000	8,618	234.38294 + 29.52413*log(MTOM/1000)	8,618	41,645	262.00000	41,645	73,070	238.07451 + 14.77278*log(MTOM/1000)
D*	0	2,000	241.30000	2,000	8,618	232.38294 + 29.52413*log(MTOM/1000)	8,618	41,645	260.00000	41,645	73,070	236.07451 + 14.77278*log(MTOM/1000)
E*	0	2,000	239.30000	2,000	8,618	230.38294 + 29.52413*log(MTOM/1000)	8,618	41,645	258.00000	41,645	73,070	234.07451 + 14.77278*log(MTOM/1000)

NSO Cum. (2 Eng)	Weight Band 5			Weight Band 6			Weight Band 7			Weight Band 8		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
Ch14	48,125	280,000	216.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	235.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	269.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	292.00000
A*	62,524	280,000	214.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	233.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	267.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	290.00000
B**	62,524	280,000	212.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	231.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	265.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	288.00000
C*	73,070	280,000	210.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	229.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	263.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	286.00000
D*	73,070	280,000	208.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	227.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	261.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	284.00000
E*	73,070	280,000	206.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	225.51025 + 21.79439*log(MTOM/1000)	385,000	400,000	259.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	282.00000

NSO Cum. (3 Eng)	Weight Band 1			Weight Band 2			Weight Band 3			Weight Band 4		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
Ch14	0	2,000	245.30000	2,000	8,618	236.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	264.00000	28,615	35,000	244.64514 + 13.28771*log(MTOM/1000)
A3*	0	2,000	245.30000	2,000	8,618	236.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	264.00000	28,615	35,000	244.64628 + 13.28697*log(MTOM/1000)
B3*	0	2,000	243.30000	2,000	8,618	234.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	262.00000	28,615	35,000	242.64628 + 13.28697*log(MTOM/1000)
C3*	0	2,000	243.30000	2,000	8,618	234.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	262.00000	28,615	35,000	242.64628 + 13.28697*log(MTOM/1000)
D3*	0	2,000	241.30000	2,000	8,618	232.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	260.00000	28,615	35,000	240.64628 + 13.28697*log(MTOM/1000)
E3*	0	2,000	239.30000	2,000	8,618	230.38294 + 29.52413*log(MTOM/1000)	8,618	28,615	258.00000	28,615	35,000	238.64628 + 13.28697*log(MTOM/1000)

NSO Cum. (3 Eng)	Weight Band 5a			Weight Band 5b			Weight Band 6			Weight Band 7			Weight Band 8		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
Ch14	35,000	280,000	219.54192 + 29.54556*log(MTOM/1000)	#N/A	#N/A	#N/A	280,000	385,000	238.51025 + 21.79439*log(MTOM/1000	385,000	400,000	272.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	295.0
A3*	35,000	81,779	227.92052 + 24.11924*log(MTOM/1000)	81,779	280,000	217.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	236.51025 + 21.79439*log(MTOM/1000	385,000	400,000	270.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	293.00000
B3*	35,000	81,779	225.92052 + 24.11924*log(MTOM/1000)	81,779	280,000	215.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	234.51025 + 21.79439*log(MTOM/1000	385,000	400,000	268.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	291.00000
C3*	35,000	81,779	234.29918 + 18.69288*log(MTOM/1000)	81,779	280,000	213.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	232.51025 + 21.79439*log(MTOM/1000	385,000	400,000	266.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	289.00000
D3*	35,000	81,779	232.29918 + 18.69288*log(MTOM/1000)	81,779	280,000	211.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	230.51025 + 21.79439*log(MTOM/1000	385,000	400,000	264.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	287.00000
E3*	35,000	81,779	230.29918 + 18.69288*log(MTOM/1000)	81,779	280,000	209.54192 + 29.54556*log(MTOM/1000)	280,000	385,000	228.51025 + 21.79439*log(MTOM/1000	385,000	400,000	262.86511 + 8.50668*log(MTOM/1000)	400,000	2,000,000	285.00000

Figure 5: Equations for Noise Stringency Options

5.3.2 Figure 9 shows the matrix comprised of the 7 CO_2 NT SOs combined with the 5 Noise NT SOs.

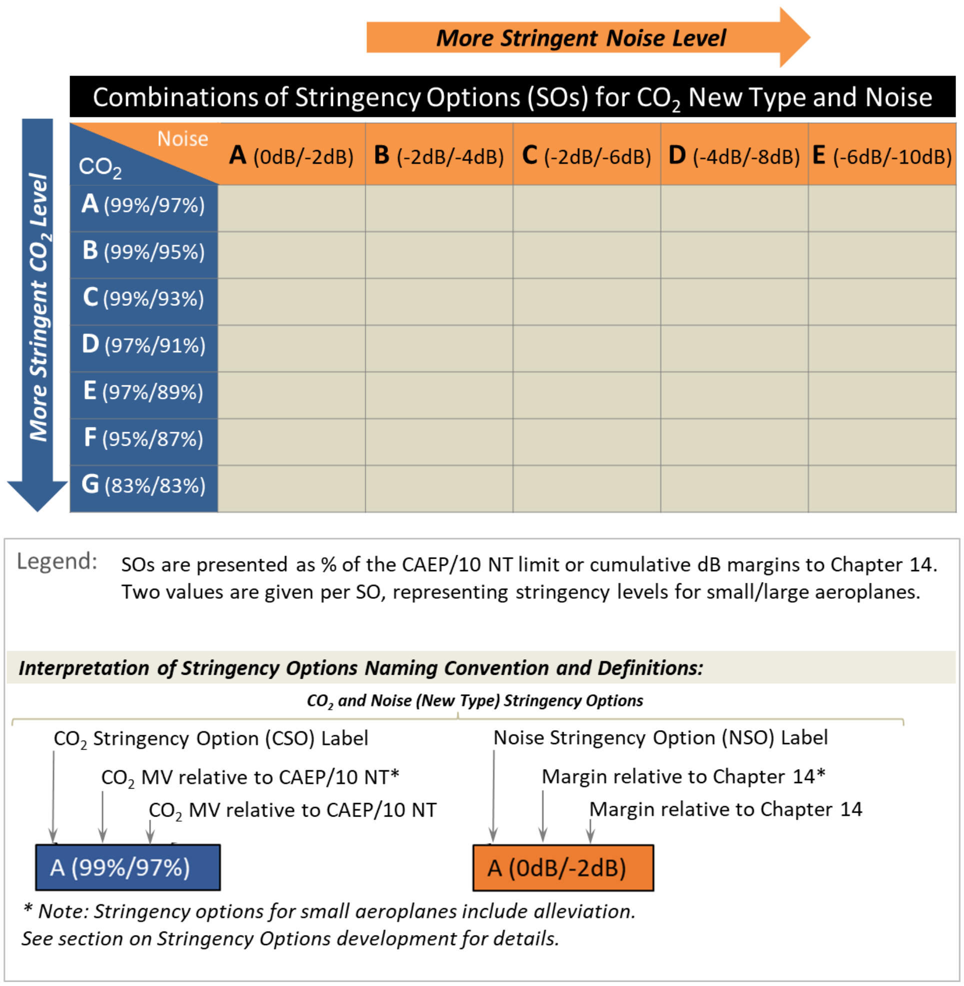


Figure 6: Summary of Combinations of CO_2 and Noise New Type (NT) Stringency Options

5.4 Introduction to Intermediate Stringency Options

5.4.1 During the process CAEP Members, highlighted the utility of investigating the areas between SOs to assist a potential decision at CAEP/13.

5.4.2 The WGs agreed to:

(1) explore the possibility to interpolate between SOs (where feasible), and

(2) collect complementary TRs data for intermediate SOs.

It should be noted that the complementary TRs data for intermediate SOs were not used to re-run analyses by MDG/FESG or interpolate results, but this complementary information provides contextual information for CAEP Members during potential discussions regarding intermediate SOs.

5.4.3 Intermediate SOs were developed for New Type CO_2 and Noise only (i.e., no intermediate SOs were assessed for CO_2 In-Production).

5.4.4 The following Intermediate SOs were developed for New Type CO_2:

a) CSO **A+** (in between CSOs A and B),

b) CSO **B+** (in between CSOs B and C),

c) CSO **C+** (in between CSOs C and D),

d) CSO **D+** (in between CSOs D and E), and

e) CSO **E+** (in between CSOs E and F).

Note: No Intermediate SO was developed in between CSOs F and G.

5.4.5 The following Intermediate SOs were developed for New Type Noise:

a) NSO **A+** (in between NSOs A and B),

b) NSO **B+** (in between NSOs B and C),

c) NSO **C+** (in between NSOs C and D), and

d) NSO **D+** (in between NSOs D and E).

5.4.6 Figure 10 shows a summary of SOs for CO_2 and Noise (NT) along with intermediate SOs (labelled as "...+"):

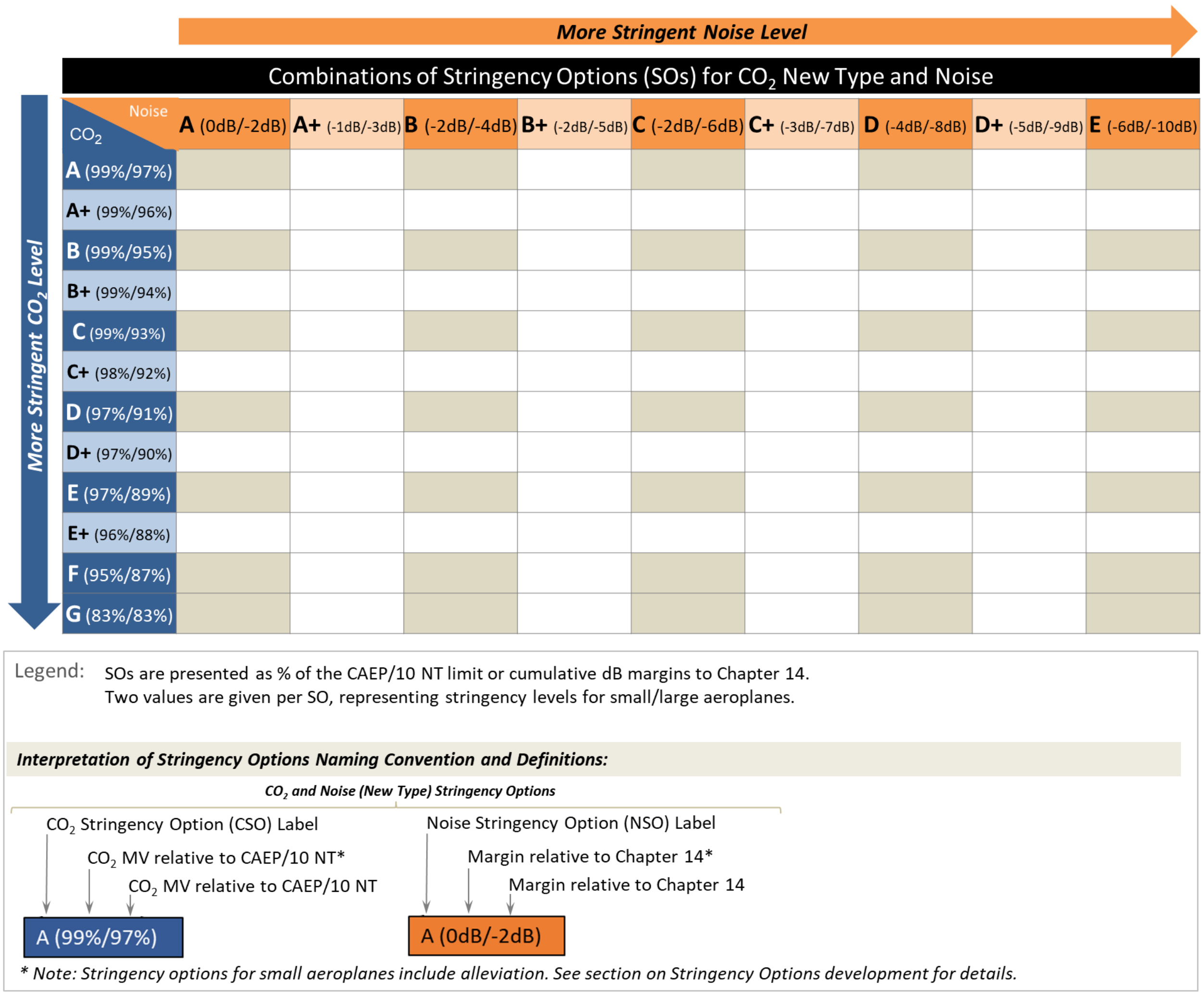


Figure 7: Summary of Stringency Options for CO_2 and Noise (NT) along with intermediate Stringency Options (labelled as "…+")

5.5 Summary on CO_2 SOs for In-Production Aeroplanes

5.5.1 Based on the initial SOs, TRs and based on analyses and considerations on draft proposals, the WG3 developed a set of 4 SOs for CO_2 InP for the purpose of further modelling.

5.5.2 The WG3 explicitly added an SO at 100%/100% of the CAEP/10 NT limit for small and large aeroplanes respectively. This additional SO corresponds to the CAEP/10 NT limit line without any additional alleviation for small aeroplanes, in line with past practice for engine NOx stringencies (where an earlier limit line was reused for the purpose of a new in-production/production cut-off standard). This SO was labelled A*.

5.5.3 As described in Section 4.2 of the paper, the WG3 also added a scenario labelled D+ based on a 93%/98% SO, i.e. the same stringency level as in Option D, but with alternative TRs.

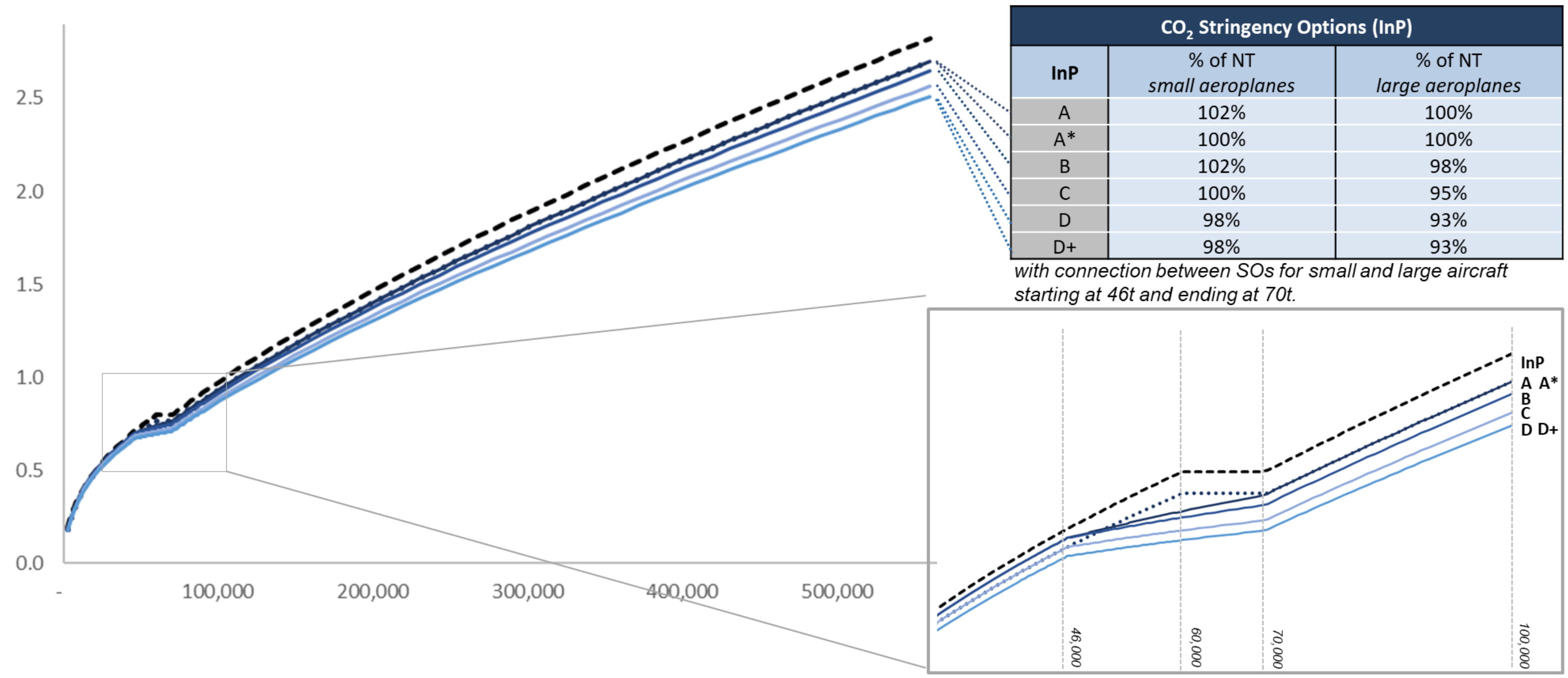
6. 6.b	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG

CO_2 Stringency Options for In Production

SOs defined from CAEP/10 New Type Stringency Limit with constant percent offset defined as follow:

CSO#	A	A*	B	C	D	D+
Referenced from CAEP/10 NT (in %) ***(Large Aeroplanes)***	100 %	100 %	98 %	95 %	93 %	93 %
Referenced from CAEP/10 NT (in %) ***(Small Aeroplanes)***	102 %	100 %	102 %	100 %	98 %	98 %

Note. – The CAEP/13 SOs for CO_2 InP are defined based on the CAEP/10 CO_2 NT stringency level (and not the CAEP/10 CO_2 InP stringency level). The connection between SOs for small and large aeroplanes starts at 46t and ends at 70t.



CO_2 Stringency Options (InP)		
InP	% of NT *small aeroplanes*	% of NT *large aeroplanes*
A	102%	100%
A*	100%	100%
B	102%	98%
C	100%	95%
D	98%	93%
D+	98%	93%

Figure 8: CO_2 In Production Stringency Options

***Note**: All logarithms are base-10 (e.g., $log_{10}MTOM$)*

CSO (InP)	Weight Band 1			Weight Band 2			Weight Band 3		
	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula	Min MTOM (kg)	Max MTOM (kg)	Formula
CAEP/10	1	60,000	1.00 * (10^(-2.57535+0.609766*log(MTOM) + -0.0191302*(log(MTOM))^2)	60,000	70,107	0.797	70,107	999,999	1.00 * (10^(-1.39353+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
A	1	46,000	1.02 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-1.13823+0.21054*log(MTOM))	70,000	999,999	1.00 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
A*	1	60,000	1.02 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	60,000	70,395	0.764	70,107	999,999	1.00 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
B	1	46,000	1.02 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.91387+0.16242*log(MTOM))	70,000	999,999	0.98 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
C	1	46,000	1.00 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.79711+0.13554*log(MTOM))	70,000	999,999	0.95 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
D	1	46,000	0.98 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.79395+0.13298*log(MTOM))	70,000	999,999	0.93 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)
D+	1	46,000	0.98 * (10^(-2.7378+0.68131*log(MTOM) + -0.0277861*(log(MTOM))^2)	46,000	70,000	10^(-0.79395+0.13298*log(MTOM))	70,000	999,999	0.93 * (10^(-1.412742+-0.020517*log(MTOM) + 0.0593831*(log(MTOM))^2)

Figure 9: Equations for CO_2 In Production Stringency Options

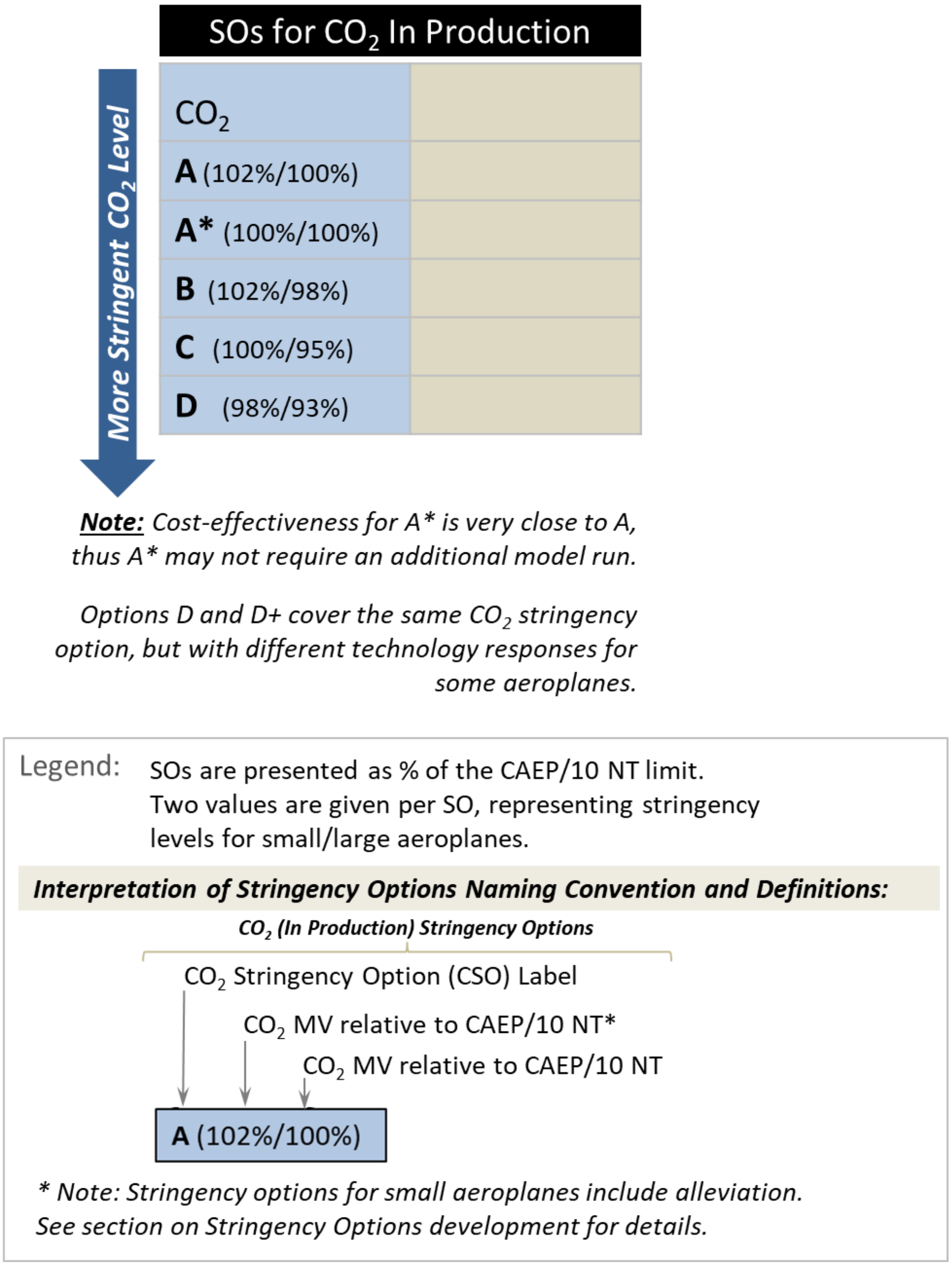


Figure 10: Summary of Set of CO_2 In Production Stringency Options

7. MAIN ANALYSIS (TECHNOLOGY) INPUT: TECHNOLOGY RESPONSES

7.a	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG
Set of Technology Responses For the purpose of the Main Analyses, TRs were provided by OEMs.				

7.1 Introduction

6.1.1 TRs are a key component of the stringency analyses. A TR reflects changes to an aeroplane's design and performance from a reference state (in-production aeroplanes) that does not meet stringency level(s) to a modified state that would meet the associated stringency level(s). For the MA, a *technology response* was defined as representing the changes in CO_2 MV and/or Noise cumulative values given the TFD. For a single stringency analysis, a potential TR would be defined as a change in a single dimension. For example, for a CO_2 standard stringency analysis, an aeroplane would have a potential TR of up to *x*% reduction in its CO_2 MV. For noise, an aeroplane could respond to a stringency up to *y* EPNdB. In a dual stringency analysis (e.g., CO_2 and Noise Stringency Analysis), a TR was characterized by a simultaneous change in CO_2 MV and Noise cumulative margins through independent or coupled design/technology modifications.

6.1.2 As with previous CAEP Stringency Analyses (i.e., CAEP/10 CO_2 Standard), the TRs are defined with a "continuous improvement approach" modelling assumption where, given a particular SO, the TR was defined as the changes in CO_2 MV and/or Noise cumulative values from the initial performance level (without a TR) to the stringency level exactly (and not beyond) even if the aeroplane could be fixed further. For example, an aeroplane that has the potential for a 6% in CO_2 MV improvement but only needs a 2.5% change in CO_2 MV to meet the CSO analysed (e.g., CSO B), the TR will be defined as 2.5 % (not 6%). This was valid for all aeroplanes not part of an aeroplane family. For aeroplane family and subject to individual OEM choices, all aeroplanes in a family can receive the same TR that corresponds to the minimum performing aeroplane (i.e., requiring the maximum TR to meet the SO).

6.1.3 A tiered approach for further characterizing TRs was considered. A "Fix 1" represented small changes to an in-production aeroplane such as a Performance Improvement Package (PIP). A "Fix 2" generally represented medium changes to an in-production aeroplane such as re-engine. Finally, a "Fix 3" represented a large change compared to the reference in-production aeroplane, which generally reflected a NT aeroplane (e.g., clean sheet design). This categorization was used to support the determination of costs.

7.2 Main Analysis Technology Responses

7.2.1 TR data provided by OEMs was reviewed and integrated in the MA GRdb13. Based on version 3.5 of the MA GRdb13, out of the 156 aeroplanes included in the MA 72 received a TR for CO_2 NT and/or Noise and 33 received a TR for CO_2 InP. For the 72 entries with a TR for CO_2 NT and/or Noise, 34 would result in a change in CO_2 MV only (i.e., no changes in Noise margins), 9 would result in a change in Noise only and 29 had a TR that would result in a change in both the CO_2 MV and cumulative Noise.

7.2.2 *Technology Responses to CO_2 NT SOs*: Figure 14 and Figure 15 show the distribution of the CO_2 MVs by aeroplane category in terms of margins to the CAEP/10 New-Type Limit, including also the margins after the maximum TRs as provided by the OEMs. The TR i.e., changes in CO_2 MV, range from 0% to -17.7% with an average of -3.6%.

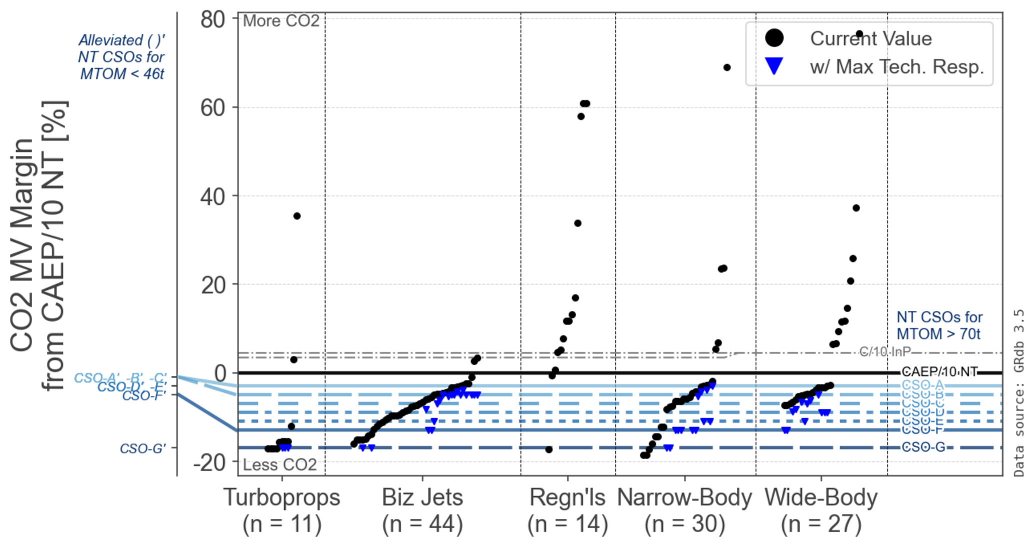


Figure 11: CO_2 New Type (NT): Anonymized CO_2 MV margin distribution with maximum technology responses

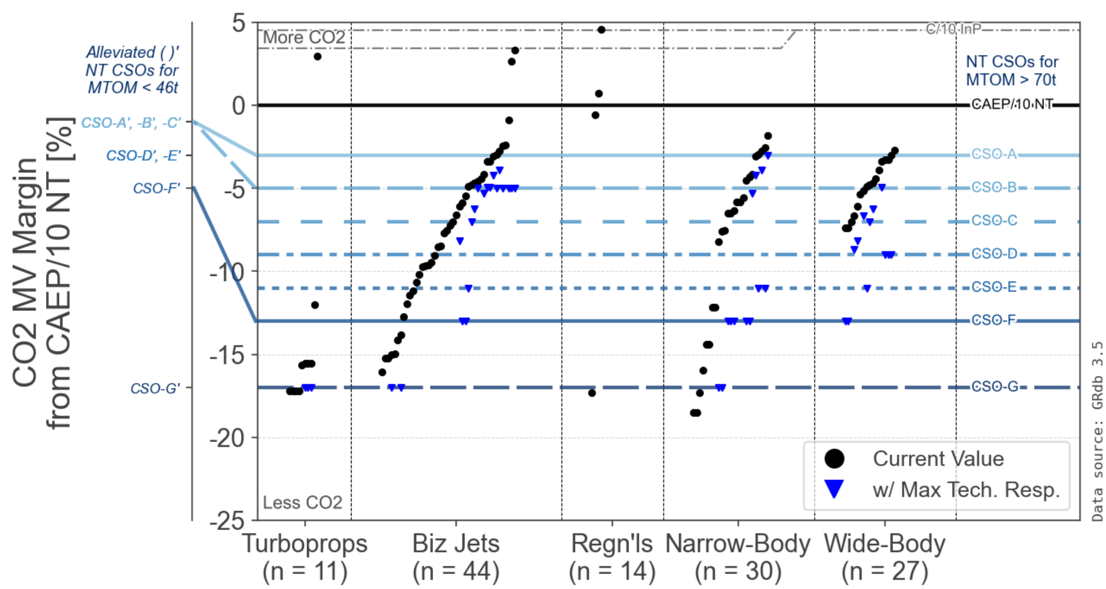


Figure 12: CO_2 New Type (NT): Anonymized CO_2 MV margin distribution with maximum technology responses with focus on the analytical space below the CAEP/10 New Type limit line

7.2.3 *Technology Responses to Noise NT SOs:* Figure 16 and Figure 17 show the distribution of the cumulative noise margin by aeroplane category in terms of margins to the Chapter 14 Limit, including also the margins after the maximum TRs as provided by the OEMs. TR to Noise NT SOs range from 0 to –6.7 EPNdB with an average of -0.4 EPNdB.

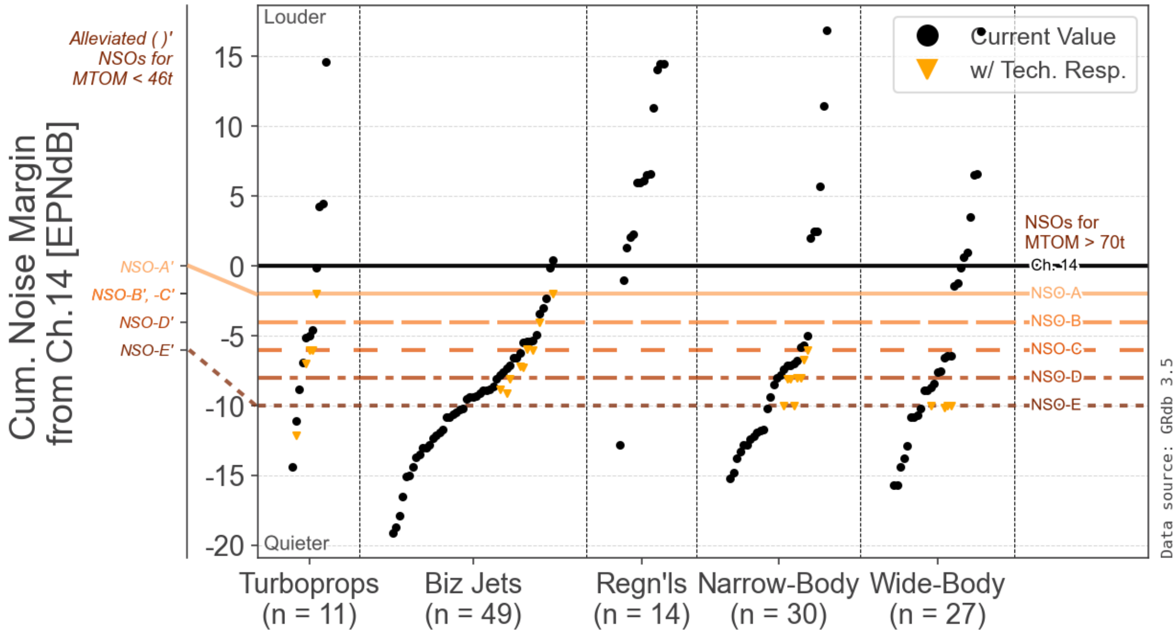


Figure 13: Anonymized cumulative noise margin distribution with maximum technology responses

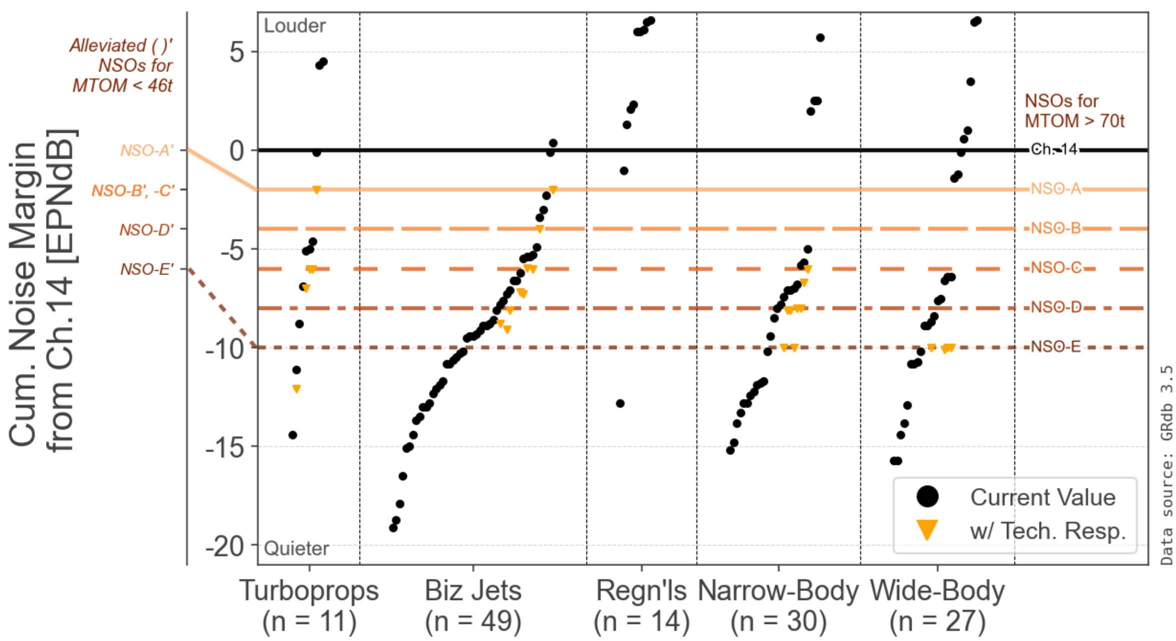


Figure 14: Anonymized cumulative noise margin distribution with maximum technology Responses with focus on the analytical space below Chapter 14

7.2.4 *Technology Responses to CO_2 In Production SOs*: Figure 18 shows the distribution of the CO_2 MVs by aeroplane category in terms of margins to the CAEP/10 NT Limit, including also the margins after the maximum TRs as provided by the OEMs. The CAEP/10 In-Production Limit for CO_2 is also shown for reference[12]. For responses to the CO_2 InP, the changes in CO_2 MV range from 0% to -4.7% with an average of -1.0%.

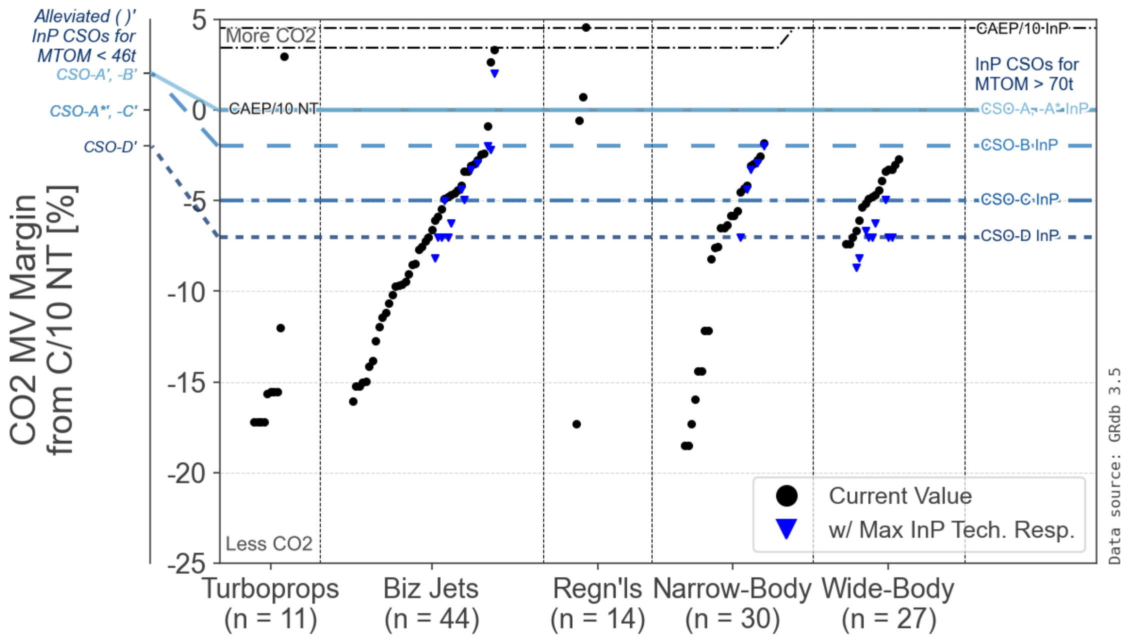


Figure 15: CO_2 In Production (InP): Anonymized CO_2 MV margin distribution with maximum technology responses with focus on the analytical space below the CAEP/10 New Type limit line

7.3 Complementary Technology Responses to Intermediate Stringency Options

7.3.1 As described in Chapter 6, CAEP Members highlighted the utility of investigating the areas between SOs to assist a potential decision at CAEP/13. Only a subset of 47 aeroplanes from the MA GRdb13 required clarifications regarding potential TRs to intermediate SOs.

7.3.2 Out of the subset of 47 aeroplanes for which clarifications were requested, 16 aeroplanes received "extended" TRs to intermediate SOs for CO_2 and/or Noise. Figure 19 shows the maximum TRs to CO_2 NT SOs, including Extended Technology Responses to Intermediate SOs. A total of 12 aeroplanes received "extended" TRs to intermediate CO_2 NT SOs: **7** aeroplanes received TRs to reach **CSO B+, 3** aeroplanes received TRs to reach **CSO D+**, and **2** aeroplanes received TRs to reach **CSO E+.**

[12] The CAEP/10 In-Production Limit for CO_2 is not at a constant % offset from the New-Type Limit, but the offset varies by MTOM.

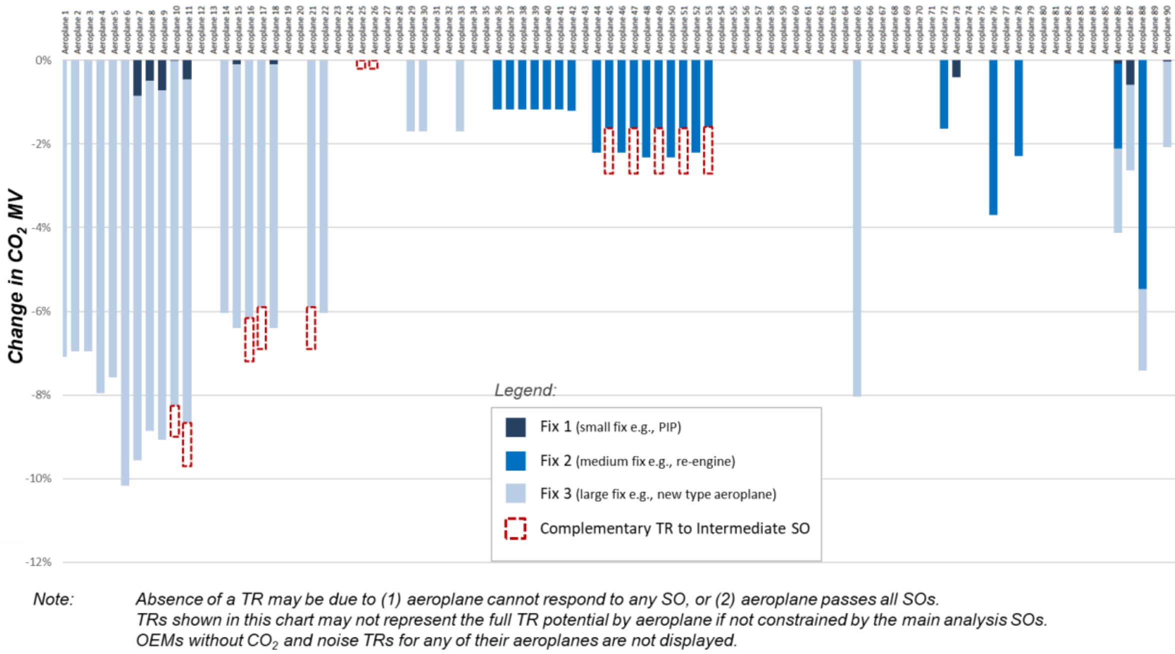


Figure 16: Maximum technology responses to CO_2 New Type (NT) stringency options with Extended Technology Responses to Intermediate Stringency Options

7.3.3 Figure 20 below show the maximum TRs to Noise (NT) SOs, with Extended Technology Responses to Intermediate SOs. A total of **8** Aeroplanes received **"Noise "extended" technology responses, including 4** aeroplanes received TRs to reach **NSO C+, 4** aeroplanes received TRs to reach **NSO D+.**

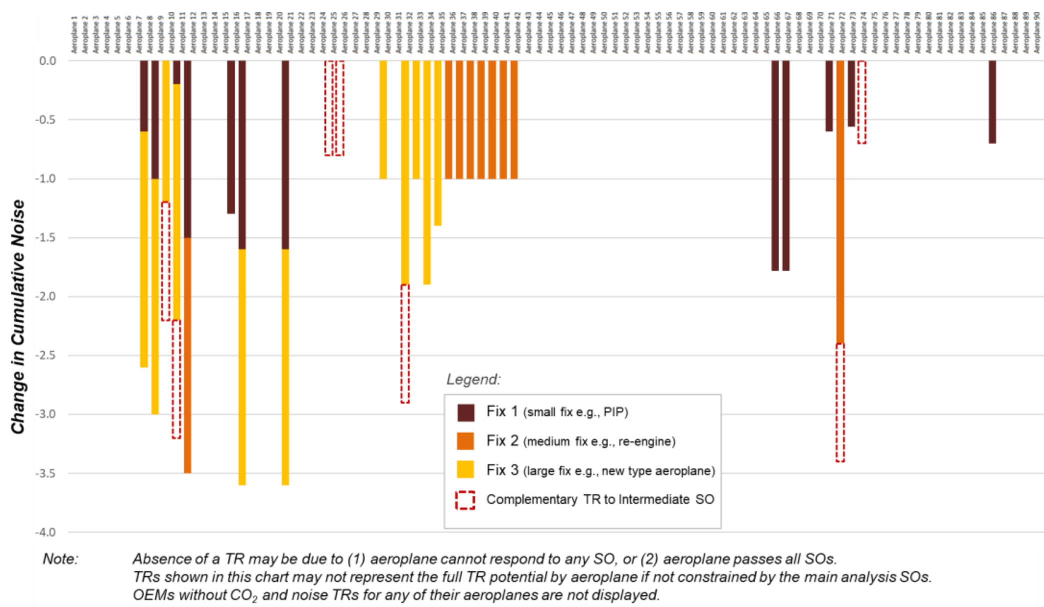


Figure 17: Maximum technology responses to Noise New Type (NT) stringency options

7. MAIN ANALYSIS (TECHNOLOGY) INPUT: GROWTH AND REPLACEMENT DATABASE

8.a	Summary of Assumption(s) *for Main Analysis*	WG1	WG3	MDG-FESG

Structure and Content of the Growth and Replacement Database GRdb13

The CAEP/13 Main Analysis Growth and Replacement database (MA GRdb13) includes:

a) Aeroplane and engine characteristics.

b) ***CO_2 MV*** section that captures the CO_2 MVs

c) ***Noise values*** section that depicts aeroplane mappings to the noise databases

d) ***Technology responses*** for each combination of CO_2 and NSOs and for each aeroplane (GRdb entry) the GRdb provides the status of the aeroplanes (i.e., Pass, Fix, or Fail),

e) ***Change in CO_2 MV*** given a combination of SOs when a Fix was required,

f) ***Change in noise cumulative margins*** given a TR across all combinations of SOs, and

g) ***Complementary and supporting databases*** such as the ICAO Aircraft Engine Exhaust Emissions Databank (EEDB).

7.1 ***CAEP Stringency Analyses:*** To assess the system/fleet wide benefits resulting from a combination of SOs, aeroplane types that are modified (i.e., fixed) to meet SOs need to be propagated through the fleet according to the anticipated fleet growth and replacement forecast horizon. The assessment of CO_2 and Noise benefits as well as costs also require specific information/data for each aeroplane.

7.2 ***CAEP/13 GRdb (GRdb13):*** The GRdb13 documents the information required by modellers regarding each aeroplane and engine type in the analysis, both in the base configuration and -when used in CEA- as defined for each SO. The GRdb13 also includes references to other data sources such as the EEDB, the ICAO noise certification database (NoisedB), and the EASA Noise Database.

8. MAIN ANALYSIS (MODELLING) INPUT: SYSTEM LEVEL MODELLING ASSUMPTIONS

8.1 Analysis Time Horizon

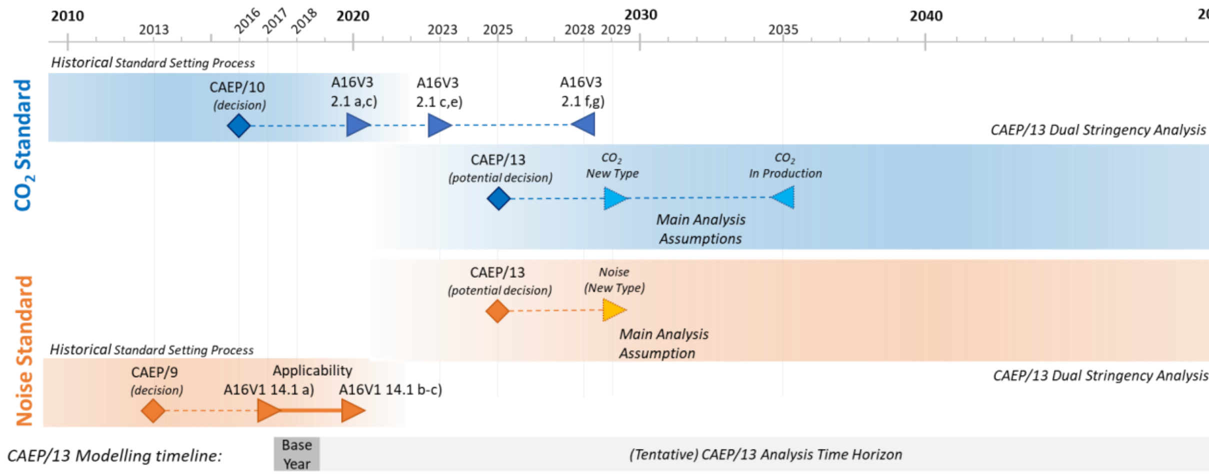
9.a	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG
Analysis Time Horizon A time horizon through 2050 was used for the CAEP/13 Main Analysis.				
Note: As captured in Chapter 10 this leverages the CAEP/13 forecast with a 2018 fleet evolution reference year and outlook through 2050 (with forecast target years in 2028, 2038 and 2050), allowing for a 32-year analysis time horizon.				

8.1.1 The IDS MA uses the CAEP/13 forecast for fleet evolution and emissions/noise modelling. This forecast has a 2018 fleet evolution reference year and outlook to 2050 (with forecast target years in 2028, 2038 and 2050), allowing for a 32-year analysis time horizon. For context, the CAEP/10 CO_2 standard analysis was based on a 2010 fleet evolution reference year and fleet/system level analyses were conducted to 2040 (i.e., a 30-year modelling time horizon). The CAEP/9 Noise Stringency Analysis was also based on a 30-year modelling time horizon with a 2006 fleet evolution reference year and modelling through 2036. A modelling time horizon up to 2050 aligns with FESG forecasts.

8.2 CO_2 and Noise Standards Applicability Dates

9.b	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG
Applicability dates The WG1 and WG3 recommended that the Main Analysis applicability dates for CO_2 NT and Noise was based on a single common year of 2029 (i.e., single and same date for both CO_2 NT and Noise). Regarding the applicability date of the CO_2 InP, it was recommended that 2035 be used. *Note: The 2029 applicability date for CO_2 New Type and Noise aligns with the definition of Technical Feasibility i.e., "[…] any technology expected to be demonstrated to be safe and airworthy proven to TRL8 […] by 2029 […].". For the purpose of the provision of technology response for the CO_2 In Production, and despite a later applicability date i.e., 2035, the same definition of Technical Feasibility i.e., "[…] any technology expected to be demonstrated to be safe and airworthy proven to TRL8 […] by 2029 […]." was used.*				

8.2.1 Figure 21 presents background on historical standard setting process associated with the CO_2 standard (CAEP/10) and the Noise standard (CAEP/9) and initial considerations on potential applicability dates for the CAEP/13 dual stringency analysis.



Annex 16 Volume III, Applicability 2.1:

a) Subsonic jet aeroplanes, including their derived versions, of greater than 5 700 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020, except for those aeroplanes less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 sears or less;
b) Subsonic jet aeroplanes, including their derived versions, of greater than 5 700 kg maximum take-off mass and less than or equal to 60 000 kg maximum take-off mass with a maximum passenger seating capacity of 19 sears or less, for which the application for a type certificate was submitted on or after 1 January 2023;
c) all propeller-driven aeroplanes, including their derived versions, of greater than 8 618 kg maximum take-off mass, for which the application for a type certificate was submitted on or after 1 January 2020;
d) derived versions of non-CO2-certified subsonic jet aeroplanes, including subsequent CO2-certified derived version, of greater than 5 700 kg maximum take-off mass, for which the application for certification of the changes in type design was submitted on or after 1 January 2023,
e) derived versions of non-CO2-certified propeller-driven aeroplanes, including subsequent CO2-certified derived version, of greater than 8 618 kg maximum take-off mass, for which the application for certification of the changes in type design was submitted on or after 1 January 2023,
f) individual non-CO2-certified subsonic jet aeroplanes of greater than 5 700 kg maximum certificated take-off mass, for which a type certificate of airworthiness was first issued on or after 1 January 2028,
g) individual non-CO2-certified propeller-driven aeroplanes of greater than 8 618 kg maximum certificated take-off mass, for which a type certificate of airworthiness was first issued on or after 1 January 2028,

Annex 16 Volume I, Chapter 14 Applicability 14.1:

a) Application for Type Certificate submitted on or after 31 December 2017 (for subsonic jet aeroplane and propeller-driven aeroplanes with maximum certificated take-off mass 55 000 kg and over).
b-c) Application for Type Certificate submitted on or after 31 December 2020 (for subsonic jet aeroplane with maximum certificated take-off mass less than 55 000 kg and propeller-driven aeroplanes with maximum certificated take-off mass over 8 618 kg and less than 55 000 kg).

Figure 18: Background and assumptions towards the CAEP/13 modelling time horizon and applicability dates

8.2.2 The WG1 and WG3 recommended that the MA be based on applicability dates for CO_2 NT and Noise NT of 2029 (i.e., single and same date for both CO_2 NT and Noise NT). A 2035 applicability date of the CO_2 InP was used.

9. MAIN ANALYSIS (MODELLING) INPUT: TRAFFIC FORECASTS

10.a	Summary of Assumption(s) for the Main Analysis	WG1	WG3	MDG-FESG
CAEP Forecast and Reference Year The CAEP/13 traffic demand and fleet forecast with a 2018 fleet evolution reference year was used for the purpose of the Dual Stringency Main Analysis. The Main Analysis modelling used the CAEP/13 Central/Mid traffic forecasts.				

9.1 The modelling approach and implementation of fleet evolution is consistent with prior single stringency analyses. For the Dual Stringency Main Analysis, the CAEP/13 COVID-19 traffic demand and fleet forecast with a 2018 fleet evolution reference year and 32-year forecast horizon was used.[13]

9.2 The final traffic demand forecasts, developed in coordination with ICAO Aviation Data and Analysis Panel (ADAP), and approved by FESG and MDG were presented for the passenger, freighter and business jet markets. An overview of the information in the LTF information paper is presented below.

9.3 The CAEP/13 Long-Term Forecast (LTF) outlook was based on the CAEP/12 COVID-19 traffic demand forecast with a fleet evolution reference year of 2018 and updated to reflect recent changes in economic activity and near-term traffic demand. The approach used for developing the CAEP/12 COVID-19 forecast was leveraged for the development of the updated CAEP/13 passenger and cargo traffic forecast. Therefore, the key differences between the CAEP/12 traffic forecast and the CAEP/13 update are based on changes in the updated economic forecast inputs and changes in the short-term traffic demand. The FESG CAEP/13 business jet forecast utilized a new business jet delivery forecast provided by the International Business Aviation Council (IBAC).

9.4 Figure 22 shows the CAEP/13 global revenue passenger kilometre (RPK) forecast for the mid, high, and low outlook, along with a comparison to the CAEP/12 forecast. Over the 32-year forecast horizon, RPKs are expected to grow by 3.4% per annum (mid), 3.7% (high) and 2.9% (low). The CAEP/12 forecast had 3.6% per annum growth rate.

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[13] This is consistent with MDG/FESG's recommendation to reuse the 2018 reference year for the purpose of CAEP/13 analyses.

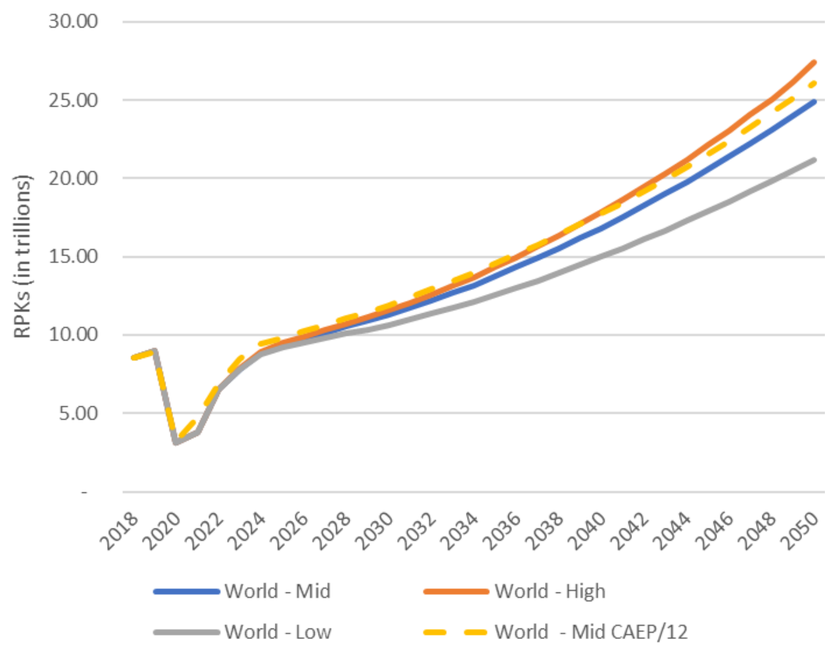

Figure 19: CAEP/13 Global RPK Forecast

9.5 Table 3 shows the 32-year global freight tonne kilometre (FTK) growth rates for the cargo forecast. Over the course of the forecast horizon, global FTKs are expected to increase by 3.1% per annum for the mid outlook. The high outlook was expected to grow by 3.5% per annum and the low by 2.6% per annum.

Table 1: CAEP/13 Cargo LTF FTK Forecast

32-Year CAGRs (2018-2050)	CAPE/13 - Mid	CAEP/13 - High	CAEP/13 - Low	CAPE/12 - Mid
International	3.0%	3.3%	2.6%	3.4%
Domestic	3.6%	4.1%	3.0%	3.5%
Global Total	3.1%	3.5%	2.6%	3.5%

9.6 Table 4 shows the 32-year global operations growth rates for the business jet forecast. Over the course of the forecast horizon, operations are expected to increase by 2.7% per annum (mid). The high outlook was expected to grow by 3.8% per annum and the low by 2.9% per annum.

Table 2: CAEP/13 Business Jet Forecast

	Number of Flights	AAGR v 2018[14]	AAGR v Previous spot year.
2018	2,648,091		
2025	3,431,503	3.8%	3.8%
2028	3,808,734	3.7%	3.5%
2038	5,027,821	3.3%	2.8%
2050	6,200,814	2.7%	1.8%

[14] Average Annual Growth Rate

10. MAIN ANALYSIS (MODELLING) INPUT: FLEET EVOLUTION APPROACHES AND ASSUMPTIONS

10.1 Introduction

10.1.1 The official MDG-FESG fleet evolution models are used to support the running and analysis of the CAEP/13 IDS. These models are the Aircraft Assignment Tool (AAT) and FLEET-Builder[15]. The FESG cost model was updated according to the stringency under consideration and used to cross-check outputs and generate direct operating costs (DOCs).[16]

10.1.2 The fleet evolution models use the FESG long-term traffic demand and generic fleet forecasts, along with other FESG inputs, to generate the composition of the future fleet. Outputs include operations by airframe/engine combination, and aeroplane's year of entry into the fleet. Associated DOCs are also output for stringency analyses. Figure 23 presents an overview of the input information required for fleet evolution.

a) The Common Operations Database (COD) provides the base-year network,[17] including operations by airport pair, Route Group (RG), distance, Seat Class (SC), and aeroplane. It also provides the fleet evolution reference year in-service fleet and the corresponding age, seat, and payload capacity distributions. CAEP/13 analyses use the 2018 COD.

b) The MA GRdb13 contains the details of the aeroplanes available for populating the future fleet. These include current and imminent aeroplanes (e.g., narrow body, wide body, etc.), capacity, and maximum range.

10.1.3 The FESG fleet forecast output provided the fleet evolution forecast targets for each market (passenger, cargo, and business jet) by RG, distance, and SC. Fleet forecasts are derived from the market level FESG traffic demand forecasts.

10.1.4 Aeroplane retirement curves are developed by FESG to define the retirement process for each market and aeroplane (e.g., turbo prop, passenger narrow body, cargo narrow body, etc.).

[15] AAT is managed by EASA and EUROCONTROL; FLEET-Builder is managed by the U.S. Federal Aviation Administration.
[16] FLEET-Builder produces direct operating costs (DOCs) as part of its structure. AAT uses the FESG cost model to generate DOCs.
[17] The network remains fixed during the fleet evolution process.

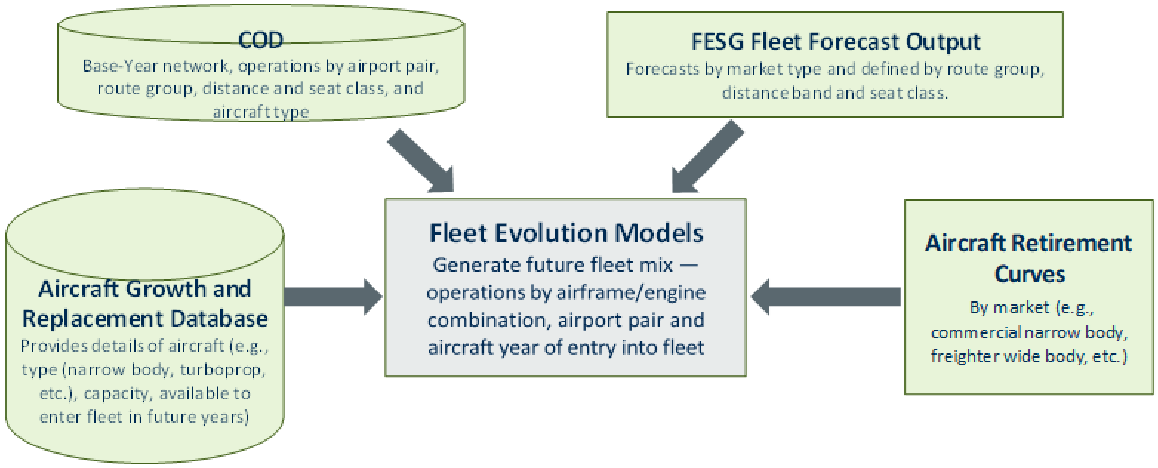

Figure 20: Fleet Evolution Overview

10.1.5 The fleet evolution process begins by calculating the growth and replacement aeroplane requirement. This was done by first retiring the reference year fleet (using the reference year fleet age distribution and associated retirement curves). The growth portion of the fleet was calculated using the traffic demand growth as defined by the FESG fleet forecast; the inputs used for fleet evolution are available seat kilometres (ASKs) for the passenger market, available tonne kilometres (ATKs) for the cargo market and operations for the business jet market. The in-service fleet was provided as a secondary fleet evolution target.

10.1.6 With the growth and replacement fleet requirement defined, the share of each GRdb aeroplane entering the fleet was calculated. For stringency analyses an equal product market share was assumed, which allocates equal market share to each GRdb aeroplane in the same CBin. The stringency analyses include a baseline run and a series of stringency runs (scenarios) that are used to observe the effect of a stringency level on fleet evolution.

10.1.7 After the growth and replacement fleet was deployed, fleet evolution outputs are calculated, including operations by airframe/engine combination, ASKs, etc.

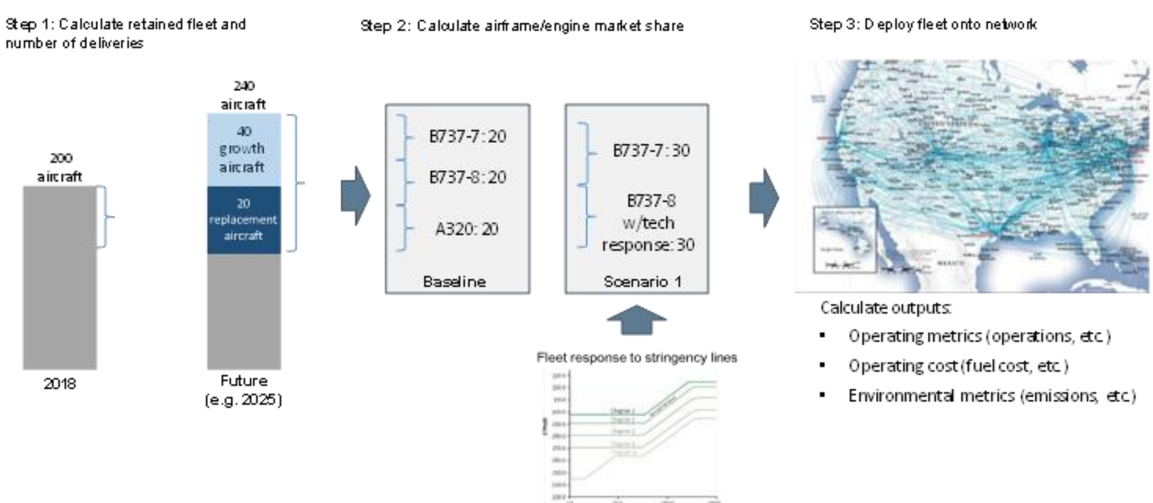

Figure 21: Fleet Evolution Process

10.1.8 For stringency analyses, the fleet evolution output also includes DOCs. These are crew costs, maintenance costs, landing charges, route costs, fuel costs and depreciation and finance costs. Input values for these costs have been developed by the Direct Operating Cost Task Group, and cost outputs are used to calculate cost effectiveness results[18].

10.1.9 The remainder of this section details the inputs required for fleet evolution for the CAEP/13 IDS analysis.

10.2 Forecast and Fleet Evolution Modelling Definitions

10.2.1 For use in the fleet evolution models, the FESG fleet forecasts are defined by RG, distance band and SC.

10.2.2 *Route Group (RG):* These are the 50 ICAO defined RGs that are used in the ICAO LTF.[19] Within these, there are 10 domestic RGs and 40 international RGs.[20]

10.2.3 *Forecast Distance Band (DB):* These define the range distribution of forecast targets and ensures GRdb aeroplanes are assigned to OD pairs according to their range capabilities.[21] They are presented here in nautical miles, which are converted to kilometres (Table 5).

Table 3: Fleet Forecast Distance Bands

Forecast Distance Band[8]	Distance (nm)
DB-1	0-500
DB-2	501-1000
DB-3	1001-1500
DB-4	1501-2000
DB-5	2001-2500
DB-6	2501-3000
DB-7	3001-3500
DB-8	3501-4000
DB-9	4001-4500
DB-10	4501-5000
DB-11	5001-5500
DB-12	5501-6000
DB-13	6001-6500
DB-14	6501-7000
DB-15	7001-7500
DB-16	7501-8000
DB-17	8001-8500
DB-18	>8500

[18] For the final presentation of the cost effectiveness results, the fuel costs are derived from the fuel burn values calculated by the MDG GHG models, taking account of any fuel burn "penalties" associated with technology responses.

[19] Note there are technically 51 ICAO RGs, however RG - Latin America/Caribbean - South West Asia does not have a demand forecast and is not included.

[20] International RGs include intra and international (e.g., Europe - North America is traffic between countries in North America and countries in Europe), with intra representing international travel between separate countries within a RG (e.g., Intra North America is traffic between the U.S. and Canada), whereas North America Domestic is travel within each country.

[21] Whether the longest distance bands are used in the forecast depend upon the O-D pairs contained within the fleet evolution reference year network.

10.2.4 *Competition Bins (CBins):* These define both the broad market types (passenger, cargo, and business jet) and the division of aeroplane sizes/types within a market space.

Table 4: Summary of Definitions of Competition Bins

CBin Definitions						
Cbin Class	Cbin Number	Description	Min Seats	Max Seats	Min Payload (lbs)	Max Payload (lbs)
Passenger	CBin-01	TP__001-019	1	19		
Passenger	CBin-02	TP__020-085	20	85		
Passenger	CBin-03	RJ__020-085	20	85		
Passenger	CBin-04	RJT_086-100	86	100		
Passenger	CBin-05	PNB_101-125	101	125		
Passenger	CBin-06	PNB_126-150	126	150		
Passenger	CBin-07	PNB_151-175	151	175		
Passenger	CBin-08	PNB_176-235	176	235		
Passenger	CBin-09	PWB_236-300	236	300		
Passenger	CBin-10	PWB_301-400	301	400		
Passenger	CBin-11	PWB_401-999	401	999		
Freighter	CBin-12	FrT_001-019k			1,000	19,999
Freighter	CBin-13	FrC_001-019k			1,000	19,999
Freighter	CBin-14	FrC_020-024k			20,000	24,999
Freighter	CBin-15	FrC_025-034k			25,000	34,999
Freighter	CBin-16	FrC_035-039k			35,000	39,999
Freighter	CBin-17	FrC_040-064k			40,000	64,999
Freighter	CBin-18	FrC_065-119k			65,000	119,999
Freighter	CBin-19	FrW_080-144k			80,000	144,999
Freighter	CBin-20	FrW_145-244k			145,000	244,999
Freighter	CBin-21	FrW_245-999k			245,000	1,000,000
Freighter	CBin-22	FrT_040-064k			40,000	64,999
Biz Jet	CBin-23	BJ_1.5-LJ				
Biz Jet	CBin-24	BJ_2.0-LJ				
Biz Jet	CBin-25	BJ_3.0-LJ				
Biz Jet	CBin-26	BJ_3.5-LJ				
Biz Jet	CBin-27	BJ_4.0-LJ				
Biz Jet	CBin-28	BJ_5.0-ME				
Biz Jet	CBin-29	BJ_6.0-LG				
Biz Jet	CBin-30	BJ_7.0-LG				
Biz Jet	CBin-31	BJ_7.5-LG				
Biz Jet	CBin-32	BJ_8.0-CO				
Biz Jet	CBin-33	BJ_8.5-CO				
P2F	CBin-34	FrT_P2F_001-019k			1,000	19,999
P2F	CBin-35	FrC_P2F_001-019k			1,000	19,999
P2F	CBin-36	FrC_P2F_020-024k			20,000	24,999
P2F	CBin-37	FrC_P2F_025-034k			25,000	34,999
P2F	CBin-38	FrC_P2F_035-039k			35,000	39,999
P2F	CBin-39	FrC_P2F_040-064k			40,000	64,999
P2F	CBin-40	FrC_P2F_065-119k			65,000	119,999
P2F	CBin-41	FrW_P2F_145-244k			145,000	244,999
P2F	CBin-42	FrW_P2F_245-999k			245,000	1,000,000

10.3 Forecast Target Years

10.3.1 Fleet forecast inputs are required for the fleet evolution reference year and each forecast target year. For CAEP/13, 2018 was the forecast fleet evolution reference year. Forecast target years are developed in coordination with MDG modelers. As a starting point, the initial target years are: 2019, 2020, 2025, 2028, 2038, 2050 for the passenger mid forecast.

10.4 Main Analysis Baseline

10.4.1 The baseline run for the IDS was defined to allow for a single outlook (in terms of future fleet composition) to be used for all modelling approaches (A1 and M.07 described in section 11.8) and standards (NT and in-production). This allows for analytical consistency when comparing analysis outputs and cost effectiveness results.

10.4.2 The IDS analysis baseline for fleet evolution was defined as:

a) Baseline Aeroplanes: all in-production and project aeroplanes as defined and included in the MA GRdb13.
b) Applicable Standards: CAEP/10 CO_2 InP along with the date of applicability per Annex 16, Volume III was applied for the baseline. Aeroplanes failing are expected to go out of production at the applicability date.
c) Forecast Targets: Baseline and scenario runs have the same (modelling target) years and time horizons.

10.5 Aeroplane Choice Modelling

10.5.1 The fleet evolution process takes into account the requirements for growth and replacement aeroplanes in three steps. First, retirement of fleet evolution reference year (and future year) aeroplanes was calculated based on FESG defined retirement curves by market type (e.g., regional jet, narrow body, wide body etc.). Next, the growth portion of the fleet was calculated based on the traffic and fleet forecast targets for each market. The final step allocates the available growth and replacement (G&R) aeroplanes (defined by the MA GRdb13); for the IDS analysis an equal product market share approach was assumed.

10.5.2 The Stringency Analysis Market Share Approach is defined as an equal product market share that allocates equal market share to each airframe and engine combination at the RG, DB and CBin level. Figure 25 provides a notional example of this market share approach, whereby each airframe/engine combination was treated as a separate and distinct entry in the aeroplane choice set.

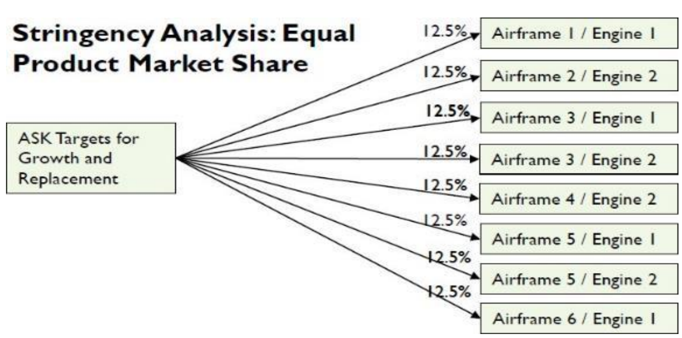

Figure 22: Stringency Analysis Equal Product Market Share Example

10.6 Empty CBins

10.6.1 The fleet evolution modellers established a series of steps and rules for handling situations where there are empty CBin(s), i.e., where no compliant aeroplane is left in a CBin for given SOs, in a stringency run. This occurs when all growth and replacement aeroplanes within a single CBin fail a stringency, precluding the execution of the fleet evolution models.

10.6.2 The guidelines and assumptions for managing empty CBins are presented in Table 7. The requirement for managing empty CBins depends upon the modelling approach used (i.e., A1 or M.07) and the extent of empty markets.

Table 5: Managing Empty CBins

	Guidance/rules for managing empty CBins in Main Analysis.
GRdb Review	Review MA GRdb13 for CBin failures – determine whether these can be filled prior to fleet evolution. Eliminates need to handle empty CBins.
Crossing Markets	Do not allow aeroplanes to move across markets: NB aeroplanes can't fill WB market (and vice versa) -- same with NB/RJ markets.TP/RJs exist in same space (DB variation).
Selecting Adjacent CBins	Only look up – market upgauges to a larger capacity aeroplane over time. Move only 1 CBin.
Selecting Aeroplanes	Shifting aeroplanes use capacity as defined in GRdb – changing seat counts means altering aeroplanes defined in analysis GRdb. Shift all compliant and responding aeroplanes (review capacity/DB capability).

10.7 Niche Markets

10.7.1 The MA GRdb13 include all current in-production and future project aeroplanes for fleet evolution, and also includes aeroplanes with limited (or niche) markets. These niche market aeroplanes are defined as aeroplanes with either certification limits (lacking global certifications) or having limited use or markets.

10.7.2 Due to the very small nature of these markets, it was important to not overstate their relative impact on fleet evolution. In the CAEP/12 SST Exploratory Study, the niche aeroplanes accounted for only 0.04% of total operations in 2050. Therefore, fleet evolution modelling needs to reflect the relative market share of these aeroplanes (in terms of ASKs/ATKs and operations).

10.7.3 To manage niche markets, a representative fleet evolution reference year network was derived from identified niche aeroplanes from the 2018 COD. These niche aeroplanes can then be used to isolate the subset of O-D pairs they operate on. These O-D pairs and identified aeroplanes are used as the basis for constructing a separate niche market fleet evolution dataset. Niche market forecast targets (ASKs, ATKs, operations and in-service fleet) are constrained to the niche fleet evolution reference year network and held constant through the forecast period. This is similar to how the small, less than 20-seat market was handled (CBin-1). In addition, only CBins with identified G&R niche market aeroplanes are used for fleet evolution. Table 8 provides the list of niche market G&R aeroplanes used for the purpose of the MA.

Table 6: CAEP/13 G&R Niche Market Aeroplanes

GR_Airframe	AC_Manufacturer	CBin_GRdb13	Market	Niche Market Aircraft
An-32B-100	Antonov	CBin-02	TP	Yes
An-140-100, flap=10°	Antonov	CBin-02	TP	Yes
Il-114-300	Ilyushin	CBin-02	TP	Yes
An-72-100D	Antonov	CBin-03	RJ	Yes
An-74T-100	Antonov	CBin-03	RJ	Yes
An-74T-200A	Antonov	CBin-03	RJ	Yes
An-74TK-300D	Antonov	CBin-03	RJ	Yes
An-148-100E flap=20°	Antonov	CBin-03	RJ	Yes
An-148-200E flap=20°	Antonov	CBin-03	RJ	Yes
An-158 flap=20°	Antonov	CBin-04	RJ	Yes
Tu-214	Tupolev	CBin-07	NB	Yes
Tu-204SM	Tupolev	CBin-07	NB	Yes
MS-21-310	Irkut	CBin-08	NB	Yes
Tu-154M	Tupolev	CBin-08	NB	Yes
Il-96-300-04	Ilyushin	CBin-09	WB	Yes
Il-96-400M	Ilyushin	CBin-10	WB	Yes

10.8 CAEP Fleet Evolution Modelling Approaches

10.8.1 Historically, CAEP has modelled NT applicability, using an approach that assumes a market driven production cut-off. This was used for the last Noise Standard modelling and the CAEP/10 NT CO_2 Standard and InP Standard setting activities. Under this approach, referred to as ***"Approach A1"*** TRs to a standard are applied on the applicability date of the standard (e.g., 2029 for the CAEP/13 CO_2 & Noise NT standards). This means that aeroplanes that are not compliant with a NT SO are assumed to go out of production at the standard applicability date (2029). This also means that if no aeroplanes in a CBin comply or have a TR (to achieve compliance), compliant aeroplanes in the next larger CBin (or those with a TR) are used (using ECBM guidelines). If none are available, the analysis fails.

10.8.2 During the CAEP/13 cycle, the CAEP has also developed a new fleet evolution modelling approach. Under this modelling approach, referred to as ***"Approach M.07"***, it is assumed that manufacturers will introduce new aeroplanes every 20 years and TRs are applied when those new aeroplanes enter production. This means that aeroplanes included in the analysis will respond to the NT standard at a different time, after the NT applicability date, based on the EIS of each aeroplane (i.e. older aeroplanes will respond sooner, newer aeroplanes later). If no aeroplanes in a CBin have a TR, the CBin reverts to the baseline, with all in-production aeroplanes continuing to be produced to the end of the analysis period.

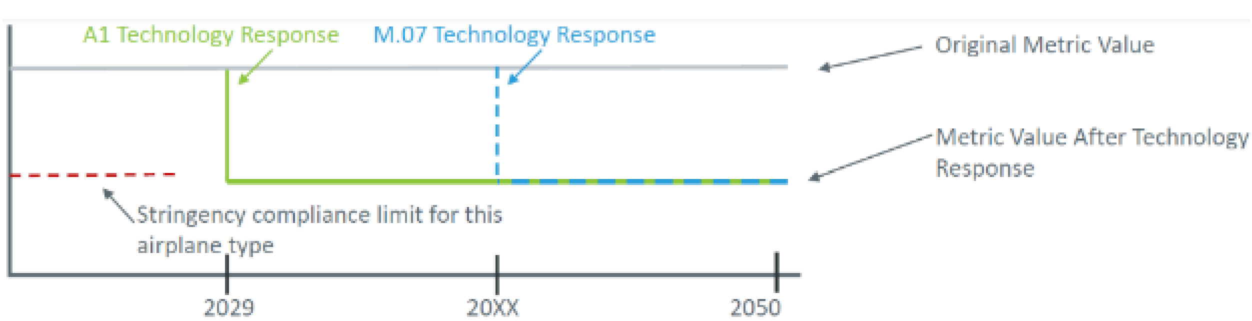

Figure 23: Single Aeroplane Notional Example

10.8.3 Figure 26 shows an illustration of the implementation of the A1 Approach and the M.07 Approach for a single aeroplane notional example. Under the A1 Approach, an aeroplane that does not pass the NT standard on the applicability date of January 1, 2029 would apply a TR (if technically feasible) or go out of production on that date. Under the M.07 approach, aeroplanes are assumed to be replaced every 20 years (from the original EIS of the current aeroplane). An aeroplane that does not pass the NT standard would receive a TR when the new aeroplane enters production (if technically feasible) or go out of production.

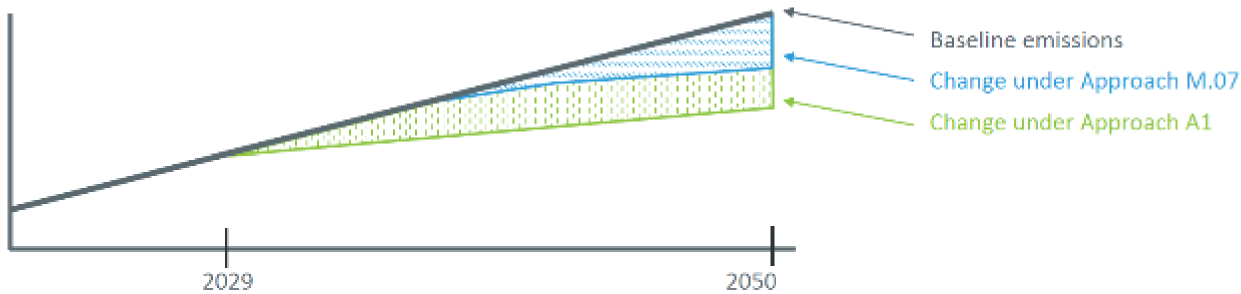

Figure 24: Notional Emissions Change

10.8.4 Figure 27 shows the evolution of CO_2 emissions over time under the Baseline and both the A1 and M.07 approaches. Baseline emissions grow over time as demand increases with constant aeroplane efficiency. Under the A1 approach, benefits start to accrue on the applicability date of the standard and grow over analysis period. Under the M.07 approach, benefits accrue over time as aeroplanes start to respond to the standard over the years after the applicability date.

11. MAIN ANALYSIS (MODELLING) INPUT: SCENARIOS ANALYSED

11.1 Background and Approach towards Down Selection of Scenarios

11.2 The process of building alleviation in SOs as well as the availability of TR information, allowed for an assessment of conditions for downstream analyses (e.g., empty CBins for fleet evolution) and resulted in a set of SOs, including:

a) 7 SOs for CO_2 NT,

b) 5 SOs for Noise (NT), and

c) 6 SOs for CO_2 InP.

11.2.1 This resulted in a reduced set of up to 35 potential combinations of SOs for CO_2 NT and Noise NT (i.e., 7 by 5 matrix) recognizing that the less stringent options (NSO-A and NSO-B) were designed to account for noise performance across the full range of aeroplanes (or full market) and to account for lower carbon technologies with noise trade-offs expected to reach TRL8 beyond 2029 which are not part of the MA.

11.2.2 Given that the MDG-FESG recommended using several modelling approaches for fleet evolution, this required further down selection and allocation of the modelling runs (i.e., scenarios defined as a combination of SOs and modelling approach).

11.2.3 The MDG-FESG recommended general Guidelines for Application of A1 and M.07 methods in Stringency Selection, including:

a) Evaluate a broad analytical space,

b) Use A1 & M.07 where both can be run, accounting for empty CBin management and maintaining sufficient control scenarios for validation of the M.07 method.

c) Use unique M.07 scenarios extending beyond “A1 feasible region”,

d) Use unique A1 scenarios in the “A1 feasible region”

e) Include an independent set of InP scenarios (run using the A1 approach only)

11.2.4 Figure 28 presents the summary of the proposed allocation of the scenarios across combinations of SOs along with the proposed modelling approach to be used.

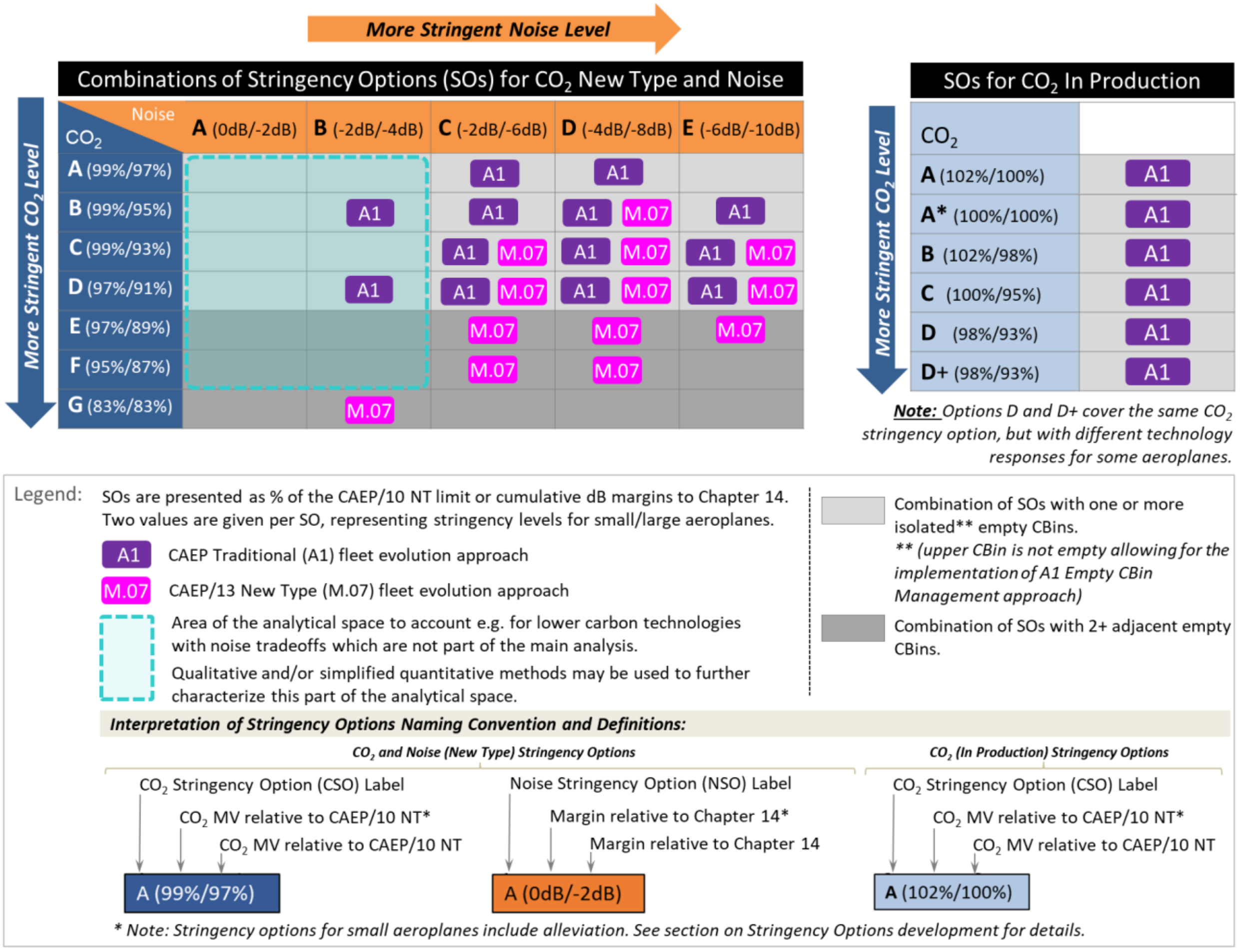

Figure 25: Summary of down selected set of scenarios assessed as part of the CAEP/13 Main Analysis

12. MAIN ANALYSIS (MODELLING) INPUT: COST MODELLING ASSUMPTIONS

12.1 Non-Recurring Costs

13.a	Summary of Assumption(s) *for Main Analyses*	WG1	WG3	MDG-FESG

Non-Recurring Cost Function

For the purpose of the CAEP/13 MA, the Non-Recurring Cost function was defined as:

$$NRC = NRC_{Airframe} + NRC_{Engine} = (1+\delta)NRC_{Airframe}$$

where

$$\mathrm{NRC}_{\mathrm{Airframe}} = \left[\Delta_{\mathrm{f}} + \frac{\Delta_{\mathrm{d}}}{1+\exp\left(-25\left(x_3 - \frac{1+2\beta}{4}\right)\right)} + \frac{\Delta_{\mathrm{n}}}{1+\exp\left(-25\left(x_3 - \frac{3-2\beta}{4}\right)\right)} + A\exp\left(Bx_3\right)\right] S$$

$$S = \left(\frac{m}{m_{\mathrm{ref}}}\right)^{0.5453 + \frac{0.6970 - 0.5453}{1+\exp\left(-25\left(x_3 - \frac{1+2\beta}{4}\right)\right)}}$$

$$x_3 = \begin{cases} \beta x & \text{for small fix} \\ 1/2 + \beta\left(x - 1/2\right) & \text{for derivative} \\ 1 + \beta\left(x-1\right) & \text{for new} \end{cases}$$

$$x = \alpha x_{\mathrm{CO_2}} + \left(1-\alpha\right) x_{\mathrm{Noise}}$$

, and

$$\mathrm{NRC}_{\mathrm{Engine}} = \delta_{\mathrm{Engine}} \mathrm{NRC}_{\mathrm{Airframe}}$$

$$\delta_{\mathrm{Engine}} = \delta_{\mathrm{Program\ Type}} \delta_{\mathrm{Airframe\ Size}}$$

$$\delta_{\mathrm{Program\ Type}} = \begin{cases} 0.0 & \text{for small fixes} \\ 1.0 & \text{for derivatives and all-new aircraft} \end{cases}$$

$$\delta_{\mathrm{Airframe\ Size}} = \begin{cases} 1.25 & \text{for single aisle and smaller aircraft} \\ 0.80 & \text{for twin aisle} \end{cases}$$

The regression coefficients are:

	Recommended Value	Full Precision Value
α	0.777996	0.777996051464575
β	0.333333	0.3333333333333333
Δ_f	0.161608	0.16160762858919497
Δ_d	0.851094	0.8510935012985514
Δ_n	0.152544	0.15254447677684888
A	0.000000762687	0.0000007626867498098863
B	15.6571	15.657117085978618

12.2 Aeroplane Direct Operating Costs

12.2.1 **Introduction**

12.2.1.1 The CAEP/13 work programme called for the development of the direct operating cost (DOC) assumptions to be used for the IDS analysis (as part of the Review of Economic Models task). These costs are used by the Fleet Evolution models to generate airline operating costs for stringency cost effectiveness analysis and for determining other related costs.

12.2.1.2 The starting point for estimating DOCs was to establish their input values in the analysis fleet evolution reference year (i.e., 2018 for the CAEP/13 IDS analysis). There are six direct operating cost areas calculated in the Fleet Evolution models and these are presented below in Table 9.

Table 7: Fleet Evolution Airline Cost Data

Direct Operating Costs
1. Fuel
2. Capital: Depreciation & Finance
3. Crew
4. Maintenance
5. Landing
6. Route

12.2.1.3 MDG and FESG have worked through the development of the airline cost data for all cost elements and details on the CAEP/13 DOCs are presented below.

12.2.1.4 Airline direct operating input cost data are estimated for the fleet evolution reference year, which was 2018 for the CAEP/13 IDS analysis. These fleet evolution reference year input cost values (which represent the distribution of airline costs in 2018) are held constant for the entire analysis, so all future operating costs (calculated using the input cost data) are constant in 2018 U.S. dollars.

12.2.1.5 DOCs are estimated in dimensions consistent with the requirements of the Fleet Evolution models (Table 10).

Table 8: Input Cost Data Dimensions

Input Cost	Fleet Evolution Dimension
Fuel Price	Global aviation fuel price per gallon
Capital Costs	Aeroplane prices, Depreciation Rate (%), Finance Rate (%)
Crew Costs	Cost per block hour (including flight and cabin crew) by CBin
Maintenance Costs	Cost per block hour by CBin
Landing Charges	Cost per landing by CBin and region
Route Charges	Cost per distance flown (km) by CBin and RG

12.2.1.6 The final airline direct operating input cost data was maintained in a DOC Database.

12.3 **Fuel Price**

12.3.1 The fuel price represents the weighted average global price of jet fuel sourced from information published by the International Air Transport Association (IATA) for 2018.[22] This report establishes the 2018 jet fuel price at $1.90 per gallon.

12.3.2 The possibility of increases in future fuel prices due to the introduction and use of alternative fuels (e.g., SAF) were considered. This was done through using information from the U.S. Energy Information Administration (EIA) and the LTAG study.

12.3.3 Figure 29 below shows the U.S. EIA reference case jet fuel price outlook (mid dashed line, 2022 outlook), along with the high and low oil price scenarios (high/low dashed lines). The dots show high/low weighted average price of jet fuel (including SAF) estimated from the CAEP/12 LTAG study for Integrated Scenario (IS) 1.[23]

Figure 26: Accounting for Future Increase in Fuel Prices (2018$)

12.3.4 The growth of jet fuel prices from the EIA reference case, the LTAG scenario, and from the Airbus 2022 forecast[24] were used to estimate an average annual growth rate over thirty years (estimated at 0.4% per annum). The fuel price methodology was refined to reflect expected increases in jet fuel price via increased market penetration of alternative fuels. To estimate both the costs of alternative fuels and conventional fuels, values from LTAG were used to estimate the growth in costs through 2050.[25] The LTAG information incorporate assumptions regarding the mix of alternative fuels and changes in production costs over the forecast horizon.

12.3.5 The mid scenario was developed using assumptions under IS2 in the LTAG report, with all values converted to constant 2018 dollars. A compound annual growth rate (CAGR) from 2018 to 2050

[22] IATA, Economic Performance of the Airline Industry 2019 End-Year Report

[23] Under IS1 and assuming LCAF has the same price as Jet-A, SAF represents approximately 5% of aviation fuel by 2035 and 27% by 2050.

[24] An approximated increase in jet fuel prices was estimated from data presented in the Airbus outlook.

[25] ICAO Environmental Report 2022, Placing costs associated with LTAG Integrated Scenarios in Context, https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art100.pdf

was estimated and the baseline conventional jet fuel price was grown through 2050 using that CAGR. The average of the series (2018 to 2050) was taken to generate a 2018 mid (base) price.

12.3.6 Along with a mid-fuel price, high and low scenarios are also estimated to provide a range of possible future variation in fuel prices.

12.3.7 Table 11 shows the CAEP/13 jet fuel prices for the mid, high and low scenarios.

Table 9: CAEP/13 Jet Fuel Price per Gallon (2018$)

Forecast Scenario	Fuel Price (2018)
Mid (Base)	$3.00
High	$3.40
Low	$2.60

12.3.8 For the purpose of the IDS MA only the Mid (base) fuel price scenario was used. The results in the following Chapters reflect this assumption.

12.4 Capital Costs

12.4.1 Estimating airline capital costs was dependent upon three elements: aeroplane prices (fleet evolution reference year and growth and replacement aeroplanes, aeroplane depreciation rate and finance rate). Annual capital costs are calculated through applying the depreciation rate and finance rate to the value of each aeroplane operating in the fleet for a specific year. As the aeroplane ages its value will diminish (due to depreciation), and the capital cost will decline.

12.4.2 ***Finance Rate:*** The CAEP/13 global finance rate was sourced from the IATA weighted average cost of capital (WACC) for the airline industry. The value for 2018 was set at 7.3%.[26]

12.4.3 ***Depreciation Rate:*** The CAEP/13 depreciation rate was estimated using the aeroplane price information.[27] Using price data for 2018, the change in aeroplane price by age (depreciation) from one year to the next defines the deprecation curve – the depreciation rate closely aligned across markets (Figure 30).

[26] IATA, Economic Performance of the Airline Industry 2019 Mid-Year Report. WACC represents an opportunity cost for investors in the airline industry (i.e., the expected return on investing in assets with similar risk profiles).
[27] These are the same data used for estimating aircraft prices.

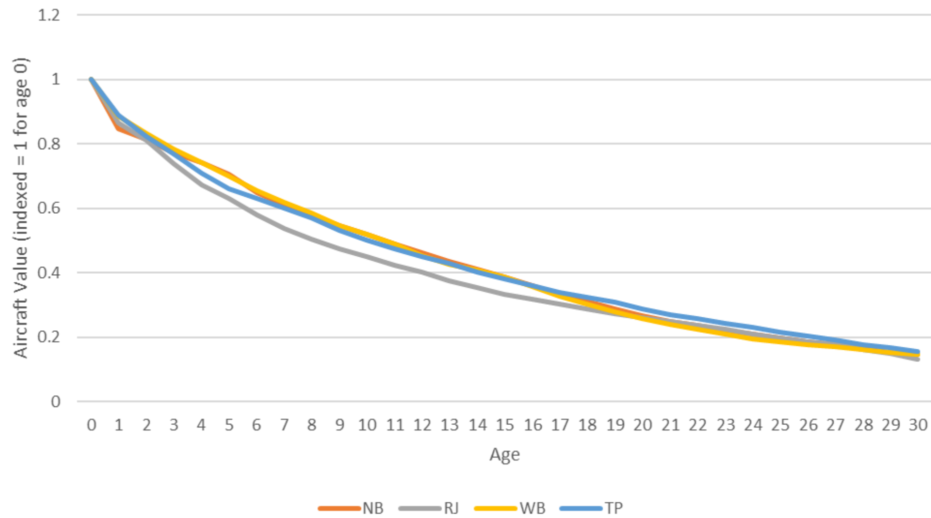

Figure 27: Depreciation Curves by Market

12.4.4 The CAEP/13 depreciation rate was estimated at 6.2%, which was an average across markets. This value was confirmed to be robust by year and relatively stable across time (i.e., a stationary time series).

12.4.5 ***Aeroplane Prices:*** Calculating capital costs requires having an estimated aeroplane price for the analysis GRdb aeroplanes.[28] As with other costs, this are defined in 2018 U.S. dollars. Two approaches were developed and reviewed by the task group. The first of these used a pooled regression approach and the other was based on the CAEP/10 methodology.

12.4.6 ***Regression Approach:*** An econometric model for estimating aeroplane prices was developed using data from 2012-2019 (adjusted to 2018$).[29] The passenger and freighter markets were modelled separately. A specification with MTOM, average seats and market type (e.g., NB, WB, etc.) performed best for the passenger market, while the cargo market used MTOM and number of engines.[30] The model coefficients for the key variables were precisely estimated and captured data variation well. The regression model coefficients can be used to calculate aeroplane prices for GRdb and fleet evolution reference year aeroplane (passenger estimation requires: MTOM, seats, and market. Freighter estimation requires: MTOM and number of engines (2 or 4)).

12.4.7 ***MTOM Approach:*** This approach leverages the CAEP/10 methodology to estimate a series of MTOM factors by market type. Using cross-section aeroplane price data[31] from 2016 (adjusted to 2018$), an MTOM factor was calculated through dividing the price by MTOM. Within the cross-section, the calculation of MTOM factor was done for aeroplanes between 1-5 years old, and a linear fit was applied to these estimated factors to derive a current MTOM factor for a new aeroplane in 2018. This calculation was done for each market type (e.g., NB, WB, RJ, TP, BJ and freighters[32]).[33] The MTOM factors can be used to estimate aeroplane prices based on the MTOM value for each GRdb and fleet evolution reference year

[28] Aircraft prices are assigned to the reference year fleet, but a stringency analysis only considers changes in the GRdb fleet.
[29] These data were sourced from CV aircraft guide and the 2018 COD. Data after 2019 were not included to avoid biasing the estimation with the exogenous effects of the pandemic.
[30] The dataset for the freighter market comprised mainly wide body aircraft.
[31] These data are from the Cirium fleet database. 2016 data was used to avoid incorporating bias related to the pandemic.
[32] Similar to the regression approach dataset, the freighter data comprised WB aircraft only.
[33] The group did review doing this calculation by CBin and determined that market level estimates are more reliable.

aeroplanes. Table 12 shows the agreed upon aeroplane price estimating coefficients and MTOM factors from the two approaches.

Table 10: Aeroplane Price Estimation Coefficients and MTOM Factors

CAEP/13: Passenger Reg Model Coef.		CAEP 13: Freighter Reg Model Coef.		CAEP13: MTOM Factors	
Max MTOM	0.27	Max MTOM	0.59	TP	0.913
Avg. Seats	0.16	four_eng	-36.07	RJ	0.641
RJ Market Ind	1.70	Constant	-35.87	NB	0.556
NB Market Ind	-3.70			WB	0.478
WB Market Ind	4.94			BJ	1.186
Constant	3.51			FR	0.416

12.4.8 ***Estimating Aeroplane Prices:*** It was decided to use both approaches for estimating CAEP/13 aeroplane prices. This leverages all the work done on developing the two methodologies and benefits from the different approaches and datasets. The CAEP/13 estimated aeroplane prices are the average of the price calculated by each approach for each aeroplane in the GRdb (and reference year fleet).

12.4.9 ***Project Aeroplane Adjustment:*** A project aeroplane adjustment value was estimated as part of the aeroplane price work. This factor was applied to the base estimated price for project aeroplanes in the GRdb (e.g., B777x), reflecting the improved operational characteristics. The adjustment values were developed using price information for existing examples of aeroplane transitions from an existing to project version – for example, the E190/E195 to the E190-E2/E195-E2 and the A320 to the A320-NEO. Table 13 shows the project aeroplane adjustment values.

Table 11: CAEP/13 - Project Aeroplane Adjustment

Project Aeroplane Adjustment	
Market	**Adjustment**
TP	5%
RJ	12%
NB	15%
WB	16%

12.4.10 ***Business Jet Prices:*** IBAC provided a table with 2018 prices for a series of business jet aeroplanes. These values were used to inform the prices for business jet aeroplanes in the GRdb and the reference year fleet. In the event there are aeroplanes in the GRdb, or fleet evolution reference year, that do not align with the IBAC data, the business jet MTOM factor was used to estimate the aeroplane price.

12.4.11 ***Aeroplane Price Review:*** An initial set of MA aeroplane prices was estimated based on an available version of the GRdb to estimate aeroplane prices (e.g., MTOMs, seats).[34] These initial price estimates were reviewed for reasonableness. A list of fleet evolution reference year aeroplane prices was generated and reviewed.[35]

[34]This includes niche market aircraft.
[35] The estimated price of reference year aircraft was adjusted to reflect their age.

12.5 Landing Charges

12.5.1 Landing charges are estimated using information provided by ICAO.[36] Data used are the landing charge in U.S. $ per MTOM by region (covering Africa, Asia/Pacific, Europe, Middle East, North America, Central America, South America, and World) – see Table 14.[37]

Table 12: Base 2018 Landing Charge by Region

Year	Fleet Evolution Region	ICAO Region	Landing Charge per MTOM
2018	Africa	AFR	$2.68
2018	Europe	EUR	$6.35
2018	Asia/Pacific	FEP	$2.60
2018	Middle East	MES	$1.67
2018	North America	NAM	$1.95
2018	Latin America/Caribbean	SAM	$1.37
2018	World	World	$3.62

12.5.2 Using an operations-weighted average MTOM by CBin and region (from the 2018 COD), the CAEP/13 landing charge was estimated.[38,39] A comparison of the estimated landing charge against values from several airports across regions showed the estimated value was reasonable.[40]

12.5.3 Input Cost Development Approach

12.5.3.1 The development of the CAEP/13 input cost data was based on methodologies established in CAEP/11. While using these methodologies does not preclude new, or better, approaches being used in the future, it does mean that the CAEP/13 cost approach was consistent with prior stringency analyses. To the extent possible, the development of the cost data was based on publicly available information, acknowledging that some information used for this work (e.g., aeroplane price information) was sourced from proprietary datasets that cannot be shared.

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[36] Landing charge information had previously been sourced from published ICAO reports that are no longer available.
[37] The 2018 ICAO value had been inflated from 2012 based on growth in ASKs, and the 2018 value was adjusted to account for this growth in KMs.
[38] Niche market aircraft were removed from the calculations. Adjustments were made to some aircraft in CBin-2 with extremely high MTOM values based on manual review and available online data.
[39] $\text{Landing Charge}_{\text{CBin, Region}} = \text{Weighted Average(MTOM)}_{\text{CBin, Region}} * \text{Landing charge per MTOM}_{\text{Region}}$
[40] For freighter competition bins with insufficient MTOM data, the equivalent passenger MTOM value was used.

12.6 **Route Charges**

12.6.1 The CAEP/13 methodology uses data provided by ICAO, including enroute charges per RPK and total RPKs for international RGs. The ICAO data were mapped to the dimensions required for fleet evolution and combined with information from the 2018 COD to estimate charges per kilometre by RG and CBin.[41]

12.6.2 The provided ICAO data included information for 17 international RGs, as well as a world value. The 51 RGs used for fleet evolution were mapped to these set of available RGs.[42] A per kilometre charge by RG and CBin was calculated for all RGs using a single approach. Using this approach, alignment checks with available data were performed for the largest RGs and the approach was further refined. Finally, the dataset was refined to fill in missing information.[43]

12.6.3 Total enroute charges by RG were estimated using the enroute charges per RPK and total RPKs. This was then used to calculate the base charge per kilometre by RG, using total kilometres flown by RG from the 2018 COD.

12.6.4 Research regarding available route charge information by country under CAEP/11 and CAEP/13 showed that the most common approach for calculating a per kilometre charge incorporates a weight factor. In order to apply this weight factor by RG and CBin an operations- weighted average MTOM value (in tonnes) by CBin and RG was estimated using the 2018 COD. The per kilometre charge was then estimated using the below equation which incorporates the weight factor.

$$RC_{ij} = Base\ Charge\ per\ KM_i \times \sqrt{\frac{WA\ MTOM_{ij}}{x}}$$

where i = RG and j = CBin and x = 50.

12.6.5 The CBin and RG level results were compared against available information for the largest RGs. Alignment was checked in the order of magnitude of the charges as well as the expected difference in charges between markets (e.g., NB to WB). The Intra Europe RG results are reasonably well aligned with costs calculated using available online information (Table 15). This was to be expected, as EUROCONTROL information indicates that the weight factor approach used above was used for route charges in this RG.

[41] Previous approach for estimating route charges per kilometre by RG and competition bin (e.g., CAEP/11) used ICAO circulars which are no longer available.

[42] The same approach was used in CAEP/11.

[43] All international RGs were mapped to the 17 RGs available in the ICAO data. Domestic RGs were treated separately and mapped to the world RG and RPK information for the world RG was estimated using the 2018 COD. The treatment of the China/Mongolia Domestic and North American RGs is discussed in the following sections.

Table 13: Passenger Market, Per Kilometre Route Charge Comparison: Intra Europe

CBin	Estimated Route Charge CAEP/13	Comparison: EUROCONTROL
1	$0.21	$0.18
2	$0.44	$0.38
3	$0.52	$0.45
4	$0.58	$0.50
5	$0.64	$0.54
6	$0.74	$0.63
7	$0.76	$0.65
8	$0.77	$0.66
9	$1.17	$1.00
10	$1.30	$1.11
11	$1.69	$1.45

12.6.6 China/Mongolia Domestic route charges were compared to available information and were found to be in reasonable alignment in smaller CBins. However, adjustments in the wide body and narrow body markets were made to reflect the structure of charges found in research regarding China's route charges. Adjustments were made to CBins -6 through -11 (as well as analogous freighter CBins) to reflect relative expected differences between the CBins.[44]

12.6.7 Review of alignment of charges for the North America Domestic RG with available information regarding route charges in Canada and the United States resulted in changes to the methodology for North America Domestic and Intra North America RGs.[45] Instead of applying the factor (x=50) in the above equation, a factor of 1 was applied in calculation of route charges for the North America Domestic and Intra North America RGs. When compared to the expected route charges based on US and Canadian available documentation, adjustments were made to WB market values to reflect relative expected differences between the NB and WB markets in the North America Domestic RG.[46]

12.6.8 Fleet Evolution models require that every combination of RG and CBin has a route charge. Not all RG and CBin combinations have operations in the COD (or in the forecast), so missing information was filled with an operations-weighted average MTOM and route charge by CBin, where the average was taken across all RGs. For conversion freighter CBins -13 through -18, -22, and -43, relevant passenger values were used at the RG level. Finally, the data were reviewed by RG for logical progression of charges over CBins as they increase in size.[47]

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[44] Research showed that China's route charges are applied on a per kilometre basis without a weight factor (instead using a weight-based charge for a range of weights) for aircraft under 200 tonnes, and a weight factor is used for larger aircraft. This results in expected route charges based on online research which are not well represented by a weight factor when comparing results in the NB and WB markets. Adjustments were made to reflect the growth rate within the NB market and between the NB and WB markets which would be expected based on online research.

[45] These two North American RGs were combined in calculation of kilometres flown in the 2018 COD to estimate a per kilometre charge (when combined with ICAO total route charge data for North American flights).

[46] The United States, which makes up the vast majority of North America Domestic operations uses a flat distance based charged with no weight factor for all flights. This results in expected route charges based on online research which are not well represented by a weight factor when comparing results in the NB and WB markets. Adjustments were made to reflect the growth rate between the NB and WB markets which would be expected based on online research and assuming that 92% of operations in the North America Domestic RG are in the United States (based on the 2018 COD).

[47] For large illogical values in CBin-3 and -4 found in some RGs, the average per kilometre route charge value was used.

12.7 Crew and Maintenance Costs

12.7.1 Crew and maintenance costs are estimated by block hour and CBin. The methodology for developing these costs uses a regression analysis approach, incorporating aeroplane MTOMs (among other control variables) to generate predicted crew and maintenance cost values for passenger and freight aeroplanes based on historical information. This approach has the advantage of being able to estimate cost values for CBins where raw data was not available by using the estimated model coefficients. It also allows for smoothing out volatility and inconsistencies in the underlying base cost data. Initial estimations of crew and maintenance costs used the CAEP/11 methodology as a starting point. Adjustments were then made in data sources and methodology to reflect crew costs more accurately for both pilots and flight attendants.

12.7.2 Information from the U.S. Bureau of Transportation Statistics (BTS) on U.S. airline operating costs was used as the basis for estimating passenger and freighter crew and maintenance costs. The data covered 2003 to 2019 and were adjusted so costs were in constant 2018 dollars. BTS publishes airline financial data in Form 41 that were merged with the BTS T-100 dataset containing information on the number of seats and block hours flown for an aeroplane. This process allows for the cost information to be weighted by total block hours, which are the units used in Fleet Evolution modelling. Data on MTOMs and aeroplane production status were also included, in addition to all cost data being converted into real 2018 dollars using the CPI. [48]

12.7.3 Form 41 Schedule P-5.1 provides crew and maintenance cost per year for large and medium regional carrier aeroplanes, while Schedule P-5.2 presents the same data for large U.S. carrier aeroplanes. Each dataset contains expenses reported by airlines by aeroplane type, aeroplane configuration (passenger or freight), and carrier. The Schedule P-5.1 and P-5.2 datasets, however, only have good coverage of pilot costs and not for flight attendant costs. In order to estimate total pilot and flight attendant costs, the sources for analysis were updated to also include Form 41 Schedule P-6 data, which provides operating expenses for carriers that includes pilot and flight attendant salaries. The Schedule P-6 data was reported at the carrier level.

12.7.4 Schedule P6 data were censored below the 5th and above the 75th percentile to remove significant outliers. The final dataset included crew costs per block hour, average seats, and year at the carrier level.[49] Passenger crew costs for CBins 2 to 11 (i.e., CBins where flight attendant crew costs are expected) were estimated as a function of year indicators and average seats per aeroplane, using a log-log specification.[50]

12.7.5 Form 41 Schedule P-5.1 and P-5.2 data were used in estimation of maintenance costs freighter crew costs, and passenger crew costs for CBin-1 and business jet CBins. The Schedule P-5.1 and P-5.2 data were censored above the 95th percentile and below the 5th percentile of crew and maintenance costs per block hour and missing or illogical values of crew costs were removed. The final dataset included crew costs per block hour, seats, year, and MTOMs at the aeroplane level.[51] Passenger crew costs were estimated as a function of year indicators (2003 to 2019) and the MTOM of the aeroplane, using a log-log specification. Freighter crew costs were estimated separately as a function of year indicators and MTOM, using a log-log specification. Freighter crew costs were estimated separately as a function of year indicators and MTOM, using a log-log specification. Average predicted values for passenger and freighter crew costs per block hour by CBin are shown in Table 16 and Table 17, respectively.

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[48] MTOM data was sourced from the 2018 COD.

[49] For the estimation of costs per block hour using P-6 data, block hours were sourced from the T-100 dataset.

[50] Average number of seats was sourced from the T-100 dataset and aggregated to the carrier level.

[51] Total block hours for P-5.1 and P-5.2 data were estimated using a proportional adjustment based on the ratio of block hours to flight hours in the T-100 data applied to the P-5.1 and P-5.2 flight hour values. This estimate of block hours was used to estimate costs per block hour.

Table 14: Passenger Crew Costs per Block Hour by Competition Bin

Competition Bin	Sources	Seat Range	Average Predicted Value (2018 $)
CBin-1	P-5.1, P-5.2, T-100	1-19 (TP)	250
CBin-2	P-6, T-100	20-85 (TP)	499
CBin-3	P-6, T-100	20-85 (RJ)	501
CBin-4	P-6, T-100	86-100	735
CBin-5	P-6, T-100	101-125	844
CBin-6	P-6, T-100	126-150	1,010
CBin-7	P-6, T-100	151-175	1,183
CBin-8	P-6, T-100	176-235	1,487
CBin-9	P-6, T-100	236-300	1,747
CBin-10	P-6, T-100	301-400	2,068
CBin-11	P-6, T-100	401-1000	2,550*
CBin-23 to CBin-33	P-5.1, P-5.2, T-100	Business Jets	402

*Notes: *Imputed based on estimated average seat count elasticity and seat capacity differences between CBin-10 and CBin-11*

Table 15. Freighter Crew Costs per Block Hour by Competition Bin

Competition Bin	Sources	Equivalent Seat Range	Average Predicted Value (2018 $)
CBin-12	P-5.1, P-5.2, T-100	20-85 (TP)	550
CBin-13	P-5.1, P-5.2, T-100	20-85 (RJ)	666^
CBin-14	P-5.1, P-5.2, T-100	86-100	781
CBin-15	P-5.1, P-5.2, T-100	101-125	814
CBin-16	P-5.1, P-5.2, T-100	126-150	940
CBin-17	P-5.1, P-5.2, T-100	151-175	980*
CBin-18	P-5.1, P-5.2, T-100	176-235	1,020
CBin-19	P-5.1, P-5.2, T-100	236-300	1,174
CBin-20	P-5.1, P-5.2, T-100	301-400	1,345
CBin-21	P-5.1, P-5.2, T-100	401-1000	1,456

Notes: ^data not available, average taken between adjacent seat classes
** Estimated value inconsistent with size, average taken between adjacent seat classes*

12.7.6 Maintenance costs were estimated as a function of year indicators (2003 to 2019), aeroplane configuration (passenger or freighter), MTOMs and production status. Similar to the crew cost approach, an Ordinary Lease Square (OLS) regression, specified in log-log form, was estimated. A single in-production value was estimated for both freighter and passenger aeroplanes. The average predicted values for maintenance costs per block hour of in-production aeroplanes by CBin are presented in Table 18.

Table 16: Maintenance Costs per Block Hour of In-Production Aeroplanes by Competition Bin

Equivalent Competition Bin	Sources	Equivalent Seat Range	Average Predicted Value (2018 $)
CBin-1	P-5.1, P-5.2, T-100	1-19 (TP)	305
CBin-2	P-5.1, P-5.2, T-100	20-85 (TP)	506
CBin-3	P-5.1, P-5.2, T-100	20-85 (RJ)	451
CBin-4	P-5.1, P-5.2, T-100	86-100	479
CBin-5	P-5.1, P-5.2, T-100	101-125	539
CBin-6	P-5.1, P-5.2, T-100	126-150	540
CBin-7	P-5.1, P-5.2, T-100	151-175	718
CBin-8	P-5.1, P-5.2, T-100	176-235	729
CBin-9	P-5.1, P-5.2, T-100	236-300	929
CBin-10	P-5.1, P-5.2, T-100	301-400	1,083
CBin-11	P-5.1, P-5.2, T-100	401-1000	1,262*
CBin-23 to CBin-33	P-5.1, P-5.2, T-100	Business Jets	481

*Notes: *Data not available, value linearly extrapolated*

12.7.7 Calibration

12.7.7.1 The estimated direct operating cost input data discussed above was used in the Fleet Evolution models to generate a global estimate of these costs for the 2018 fleet evolution reference year. These estimated global values can be compared against 2018 (ICAO) information on the global value and distribution of these costs (if available). The estimated inputs cost values can be adjusted if necessary to align the global total with published sources.

12.7.8 CAEP/13 Discount Rates (default assumption and input to sensitivity analysis)

12.7.8.1 The MDG-FESG generally presents stringency analysis costs results that are discounted to a reference year. This helps observing (and comparing) the net present value (NPV) of discounted stringency related costs incurred in future years. The reference year for calculating the NPV should be common across all analyses and sensitivities for the stringency under consideration (e.g., the year in which costs from a proposed standard may begin to be incurred). For CAEP/10 analyses, 2016 was selected as the NPV reference year as it was the standard announcement year and presumably the point in time when related costs would begin to be incurred.

12.7.8.2 Following a review and deliberations within MDG-FESG for the purposes of the CAEP/13 Dual Stringency Analyses, the results are presented using a 0% discount rate. The NPV reference year for the CAEP/13 dual stringency analysis was set to 2025 (i.e., date of the CAEP/13 meeting and expected decision on the dual standard). A sensitivity analysis was also conducted using 3%, 7% and 9% discount rates.

13. MAIN ANALYSIS (TECHNOLOGY) RESULTS (NT): PASS & FIX RATES OF AEROPLANES IN THE GROWTH AND REPLACEMENT DATABASE

Note: All the statistics reported in this Chapter summarize the information about the set of aeroplanes assumed to be available for fleet evolution, which is used as input to the modelling of changes in CO_2 emissions (including NOx trade-offs), noise and costs. These statistics are the result of a set of assumptions, as described in the Chapters above, which were made solely for the purpose of analysing aeroplane noise and CO_2 stringencies in this study.

13.1 Pass & Fix rates of Aeroplanes in the Growth and Replacement Database

13.1.1 The following table shows the percent pass & fix rates of the aeroplanes available for fleet evolution (i.e., in-production and project aeroplanes with TR improvements, as described in Chapter 7) with respect to the noise and CSOs for NTs:

92 Entries - Pass & Fix Combined					
CSO/NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)	92%	92%	92%	78%	64%
B (99%/95%)	82%	82%	82%	76%	64%
C (99%/93%)	72%	72%	72%	67%	58%
D (97%/91%)	63%	63%	63%	60%	52%
E (97%/89%)	61%	61%	61%	58%	50%
F (95%/87%)	54%	54%	54%	51%	46%
G (83%/83%)	12%	12%	12%	11%	10%

92 Entries - Pass & Fix Noise					
CSO/NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)	95%	93%	93%	79%	64%
B (99%/95%)	95%	93%	91%	79%	64%
C (99%/93%)	95%	93%	91%	78%	63%
D (97%/91%)	95%	93%	91%	78%	63%
E (97%/89%)	95%	93%	91%	77%	61%
F (95%/87%)	95%	93%	90%	75%	61%
G (83%/83%)	95%	92%	89%	72%	57%

92 Entries - Pass & Fix CO2					
CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)	96%	96%	96%	92%	90%
B (99%/95%)	85%	85%	85%	85%	83%
C (99%/93%)	75%	75%	75%	75%	73%
D (97%/91%)	65%	65%	65%	65%	63%
E (97%/89%)	63%	63%	63%	63%	61%
F (95%/87%)	57%	57%	57%	55%	55%
G (83%/83%)	12%	12%	12%	12%	12%

Legend:

Scenario modelled using…
- …the A1 fleet evolution approach
- …the M.07 fleet evolution app.
- …the A1 and M.07 approaches

Figure 28: Percentage of aeroplanes that pass the stringency options after technology responses (i.e., Pass & Fix rates)

13.1.2 These pass & fix rates are not distributed equally across aeroplane categories, as can be seen in the following tables, which uses the aeroplane categories in the MA GRdb13 to group the data for the combined SOs (note: "regional aircraft' in the table below denotes the combination of turboprops and regional jets):

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
Pass & Fix Combined - Regional Aircraft (11 out of 92)					
A (99%/97%)	64%	64%	64%	55%	45%
B (99%/95%)	64%	64%	64%	55%	45%
C (99%/93%)	64%	64%	64%	55%	45%
D (97%/91%)	64%	64%	64%	55%	45%
E (97%/89%)	64%	64%	64%	55%	45%
F (95%/87%)	64%	64%	64%	55%	45%
G (83%/83%)	64%	64%	64%	55%	45%

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
Pass & Fix Combined - Narrow Bodies (25 out of 92)					
A (99%/97%)	96%	96%	96%	76%	60%
B (99%/95%)	80%	80%	80%	76%	60%
C (99%/93%)	68%	68%	68%	68%	60%
D (97%/91%)	68%	68%	68%	68%	60%
E (97%/89%)	68%	68%	68%	68%	60%
F (95%/87%)	52%	52%	52%	52%	52%
G (83%/83%)	8%	8%	8%	8%	8%

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
Pass & Fix Combined - Wide Bodies (15 out of 92)					
A (99%/97%)	93%	93%	93%	87%	73%
B (99%/95%)	80%	80%	80%	80%	73%
C (99%/93%)	53%	53%	53%	53%	47%
D (97%/91%)	27%	27%	27%	27%	27%
E (97%/89%)	13%	13%	13%	13%	13%
F (95%/87%)	7%	7%	7%	7%	7%
G (83%/83%)	0%	0%	0%	0%	0%

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
92 Entries - Pass & Fix Combined - Light BJ (12 out of 92)					
A (99%/97%)	100%	100%	100%	92%	92%
B (99%/95%)	100%	100%	100%	92%	92%
C (99%/93%)	100%	100%	100%	92%	92%
D (97%/91%)	100%	100%	100%	92%	92%
E (97%/89%)	100%	100%	100%	92%	92%
F (95%/87%)	100%	100%	100%	92%	92%
G (83%/83%)	8%	8%	8%	8%	8%

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
92 Entries - Pass & Fix Combined - Medium and Large BJ (16 / 92)					
A (99%/97%)	94%	94%	94%	82%	59%
B (99%/95%)	94%	94%	94%	82%	59%
C (99%/93%)	94%	94%	94%	82%	59%
D (97%/91%)	88%	88%	88%	82%	59%
E (97%/89%)	88%	88%	88%	82%	59%
F (95%/87%)	88%	88%	88%	82%	59%
G (83%/83%)	6%	6%	6%	6%	6%

CSO\NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
92 Entries - Pass & Fix Combined - Corporate BJ (12 out of 92)					
A (99%/97%)	100%	100%	100%	75%	58%
B (99%/95%)	67%	67%	67%	67%	58%
C (99%/93%)	50%	50%	50%	50%	42%
D (97%/91%)	25%	25%	25%	25%	25%
E (97%/89%)	25%	25%	25%	25%	25%
F (95%/87%)	17%	17%	17%	17%	17%
G (83%/83%)	0%	0%	0%	0%	0%

Legend:

Scenario modelled using…
- …the A1 fleet evolution approach
- …the M.07 fleet evolution app.
- …the A1 and M.07 approaches

Figure 29: Percentage of aeroplanes that pass the stringency options after technology responses (i.e., Pass & Fix rates) across categories of aeroplanes

13.1.3 To facilitate the cost effectiveness analyses, the MA GRdb13 further groups aeroplanes into CBins defined in Section 11.2.4 above). The following tables show the number of CBins that fail the combined SOs as well as noise and NT CO_2 options.

Fail Combined	A	B	C	D	E
A	1	1	1	1	1
B	1	1	1	1	1
C	1	1	1	1	1
D	2	2	2	2	2
E	4	4	4	4	4
F	5	5	5	5	5
G	18	18	18	18	18

Fail noise	A	B	C	D	E
A	1	1	1	1	1
B	1	1	1	1	1
C	1	1	1	1	1
D	1	1	1	1	1
E	1	1	1	2	2
F	1	1	1	2	2
G	1	1	1	3	3

Fail CO_2	A	B	C	D	E
A	1	1	1	1	1
B	1	1	1	1	1
C	1	1	1	1	1
D	2	2	2	2	2
E	4	4	4	4	4
F	5	5	5	5	5
G	18	18	18	18	18

A1
A1 & M.07
M.07

Figure 30: Number of CBins[52] that fail the combined stringency options as well as noise and NT CO_2 options

13.1.4 The data shows that failure of CBins, i.e., lack of aeroplanes assumed for fleet evolution modelling, is mostly driven by the NT CO_2 SOs. Furthermore, apart from the scenarios that include CSO G, only CBins from the regional jet and widebody categories fail SOs. CBin-3 (smaller regional jets) in the GRdb does not have aeroplanes that can meet any of the combined new-type CO_2 and NSOs. Within the widebody category, CBin-9 (smaller widebodies) fails starting from scenario D\A, CBins 20 and 21 (widebody freighters) fail from scenario E\A and CBin-33 (widebody corporate jets) fails from scenario F\A. No CBins from any other category fail through scenario F\E. 18 CBins (all but five CBins) fail from scenario G\A.

13.1.5 Unlike for the InP SOs, existing aeroplane types failing any NT SOs would not be prevented from being produced beyond the applicability date of these NT stringencies. The same applies for future derived versions of existing aeroplane types, as was explained in section 3.2.

[52] Out of 33 CBins modelled as part of the CAEP/13 Main Analysis.

14. MAIN ANALYSIS (MODELLING) RESULTS (NT): FLEET EVOLUTION

14.1 Introduction

14.1.1 The fleet evolution modelling started with the baseline fleet evolution run. In this baseline run the in-production and project aeroplanes enter the fleet as if there were no CAEP/13 CO_2 and/or Noise standards. The baseline was developed using two CAEP-approved fleet evolution tools: AAT developed by European/EASA modellers and Fleet Builder (FB) developed by experts from the United States.

14.1.2 After running the baseline, the two fleet evolution tools were set-up to process the scenario runs. Each scenario run requires the identification of aeroplane level TRs to the integrated CO_2/Noise SOs as identified in the MA GRdb13 (v3.5), with a 2029 NT standard applicability date.[53, 54]

14.1.3 There are two types of fleet evolution approaches implemented for the CAEP/13 IDS:

a) A1 approach i.e., CAEP traditional fleet evolution approach with Empty CBin Management (ECBM), and
b) M.07 approach i.e., CAEP/13 NT approach.

14.1.4 These approaches are described in Section 11.8. Along with the NT standard under consideration (using A1 and M.07 approaches), there are six InP runs using A1 that required fleet evolution runs.

14.1.5 The MDG-FESG agreed that FB would be used to provide inputs to all noise, emissions (i.e., CO_2 and NOx) and cost models for the MA, and that AAT would be used to conduct a validation and verification cross-check of FB results for approximately half of the MA scenarios, including the MA scenarios where both A1 and M.07 were run.

14.1.6 The following sections present the comparison of the fleet evolution results computed using the two tools. Outputs are presented by market and CBin for each model and run type. Fleet evolution results for the full set of analysis scenarios run by FB are also discussed.

14.2 Fleet Evolution Validation Comparison

14.2.1 **New Type (NT) A1 Approach:** Under the A1 approach, aeroplanes that fail the standard go out of production (OoP) at the implementation date i.e., 1 January 2029, and are no longer available for fleet evolution. This OoP response may result in a change in the average capacity of aeroplanes that enter the fleet in a given CBin. W hen all aeroplanes in a CBin fail at a stringency level, Empty Competition Bin Management (ECBM) was used to meet demand (i.e., ASKs) by using aeroplanes from an adjacent CBin. If this was not possible, then the scenario run fails and cannot be modelled using the A1 approach. The ECBM assumption will change average capacity of aeroplanes that enter the fleet in a given CBin. Table 19 presents the Fleet-Builder and AAT operations comparison by CBin for approach.

14.2.2 Overall, the CAEP approved fleet evolution models (i.e., AAT and FB) were found to be in good agreement, with the same direction and similar magnitude of operational changes in passenger market CBins relative to the baseline for all NT A1 comparison scenarios. Differences in CBin-3 were reviewed

[53] Defined as January 1, 2029.
[54] InP runs have an implementation date of January 1, 2035.

and were determined to be a result of differences in the fleet evolution base year. The impact of ECBM on fleet evolution and capacity changes can be observed in CBin-9 when moving from CSO C to CSO D. The cargo and business markets do not exhibit changes in operations as there are no responses leading to capacity and operations changes in the cargo market. For CAEP modelling purposes, business jets all have the same capacity (i.e., number of seats). As a result, there was no change in capacity and operations even if aeroplanes fail.

Table 17. New Type A1 approach comparison scenarios 2050 change in operations from the baseline by CBin for FB and AAT

SO	A1 B/C		A1 B/D		A1 C/C		A1 C/D		A1 C/E		A1 D/C		A1 D/D		A1 D/E	
CBIN	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	2.1%	1.8%	0.0%	0.0%	2.1%	1.8%	5.3%	4.6%	0.0%	0.0%	2.1%	1.8%	5.3%	4.6%
3	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%	-14.2%	-13.5%
4	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%	-4.5%	-4.4%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
7	0.0%	0.0%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
8	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.5%	-0.3%	-0.3%	-0.5%	-0.5%	-0.5%	-0.5%	-0.3%	-0.3%
9	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-0.6%	-24.7%	-24.8%	-24.7%	-24.8%	-24.7%	-24.8%
10	0.1%	0.1%	0.1%	0.1%	-1.9%	-1.9%	-1.9%	-1.9%	-0.8%	-0.8%	-5.1%	-5.1%	-5.1%	-5.1%	-5.1%	-5.1%
11	0.0%	0.0%	0.0%	0.0%	2.5%	2.4%	2.5%	2.4%	2.5%	2.4%	2.5%	2.4%	2.5%	2.4%	2.5%	2.4%

14.2.3 **New Type M.07 Approach:** Under the M.07 approach, the same TRs apply for the same scenario as with NT A1, but the enforcement of the standard happens at the introduction date of an identified PNGA. Since a PNGA may enter into service (EIS) several years after the applicability date (2029), this lowers the magnitude of any operational changes from an aeroplane failing the standard (i.e., fewer years to affect fleet evolution and the composition of the fleet).

14.2.4 Aeroplanes that fail the standard go out of production at the PNGA EIS year and are no longer available for fleet evolution. This OoP response may result in a change in the average capacity of aeroplanes that enter the fleet in a given CBin. If all aeroplanes fail within a CBin, the entire set of baseline aeroplanes remain available for fleet evolution over the entire forecast period. As a result, there are no differences with the baseline.[55] Table 20 shows the CBin level change in operations for M.07 comparison scenarios for AAT and Fleet-Builder.

14.2.5 Overall, the models are in excellent agreement with similar operational changes in passenger market CBins relative to the baseline between the two models for all NT M.07 comparison scenarios. The cargo and business jet markets have no changes in operations due to no responses leading to a change in capacity in the cargo market and all aeroplanes in the business jet market having the same seating capacity.

[55] By reverting to the baseline, the M.07 approach avoids needing to use the ECBM assumption used in Approach A1.

Table 18. NT M.07 approach comparison scenarios 2050 change in operations from the baseline by CBin for FB and AAT

SO	M07 B/D		M07 C/C		M07 C/D		M07 C/E		M07 D/C		M07 D/D		M07 D/E		M07 F/D	
CBIN	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB	AAT	FB
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.8%	0.7%	0.0%	0.0%	0.8%	0.7%	2.1%	1.7%	0.0%	0.0%	0.8%	0.7%	2.0%	1.7%	0.8%	0.7%
3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	-1.4%	-1.3%	-1.4%	-1.3%	-1.4%	-1.3%	-1.4%	-1.3%	-1.4%	-1.3%	-1.4%	-1.3%	-1.3%	-1.3%	-1.4%	-1.3%
5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%
6	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
7	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
8	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.7%	-0.7%	-0.7%	-0.7%	-0.6%	-0.6%	-0.6%	-0.6%
9	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10	0.0%	0.0%	-1.3%	-1.3%	-1.3%	-1.3%	-0.9%	-0.9%	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%	-3.4%	-2.7%	-2.7%
11	0.0%	0.0%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	5.1%	5.0%

14.2.6 **InP Approach A1:** Under approach A1, aeroplanes that fail the standard go out of production at the standard implementation date (2035) and are no longer available for fleet evolution. This response can change the average capacity of available growth and replacement aeroplanes, and operations within a CBin. Table 21 shows the CBin level change in operations for InP A1 comparison scenario InP C for AAT and FB.

14.2.7 The models were found to be in good alignment with similar operational changes by CBin in the passenger market relative to the baseline. The cargo and business jet markets have no change in operations due to no responses in the cargo market that would lead to a capacity change and all aeroplanes in the business jet market have the same seating capacity. Fleet evolution results for all InP scenarios can be found in Chapter 20.

Table 19. InP A1 approach InP (SO C) scenario 2050 change in operations from the baseline across CBins for the FB and AAT fleet evolution tools

SO	InP-C	
CBIN	AAT	FB
1	0.0%	0.0%
2	0.0%	0.0%
3	0.0%	0.0%
4	-4.2%	-4.0%
5	0.0%	0.0%
6	0.6%	0.6%
7	0.0%	0.0%
8	-0.6%	-0.6%
9	-0.5%	-0.5%
10	1.4%	1.4%
11	0.0%	0.0%

14.3 Fleet Evolution NT Scenario Results

14.3.1 This section contains fleet evolution results for the full set of 32 analysis scenarios for the IDS. These results were all produced using Fleet-Builder and show the percent change in operations relative to the baseline for each scenario.[56.]

14.3.2 **NT Approach A1 – Fleet Wide Results:** Considering the full set of NT SOs modelled using the A1 approach, the overall stringency-related shift in operations was relatively small up through scenario C\E. For scenario D\B, the operations shift increases; this was due to ECBM, which occurs at CSO

[56] As noted earlier, a change in operations results from a shift in average capacity within a CBin due to aircraft failing a scenario.

D in the wide body (WB) market in CBin-9. There are no changes in operations relative to the baseline in the cargo or business jet markets.

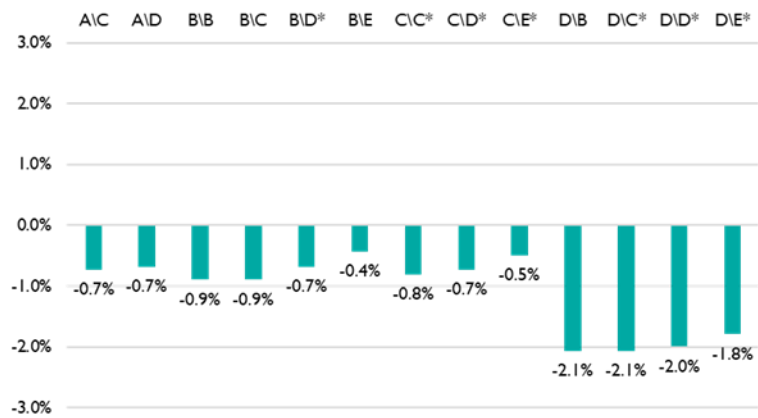

Figure 31: Fleet wide differences in operations NT A1 scenario compared to the baseline (Fleet Builder tool) [57]

14.3.3 *NT Approach A1 – Results by Markets:* Stringency related changes in operations by market are shown in Figure 35.

14.3.4 Considering the Turbo Prop market (CBin-2), scenarios B\B, D\B, A\C, B\C, C\C, and D\C have no change in operations, as all aeroplanes either pass or have a fix response. For NSO D scenarios, one aeroplane fails, reducing average capacity, leading to an increase in operations. Likewise, for NSO E scenarios, two aeroplanes fail leading to a decrease in average capacity and an increase in operations.[58]

[57] Stringency options marked with a * were also run for M.07.

[58] For Noise SO D scenarios, the average capacity of new deliveries decreases to 57, and for Noise SO E scenarios, the average capacity decreases to 54, compared to 60 in the baseline.

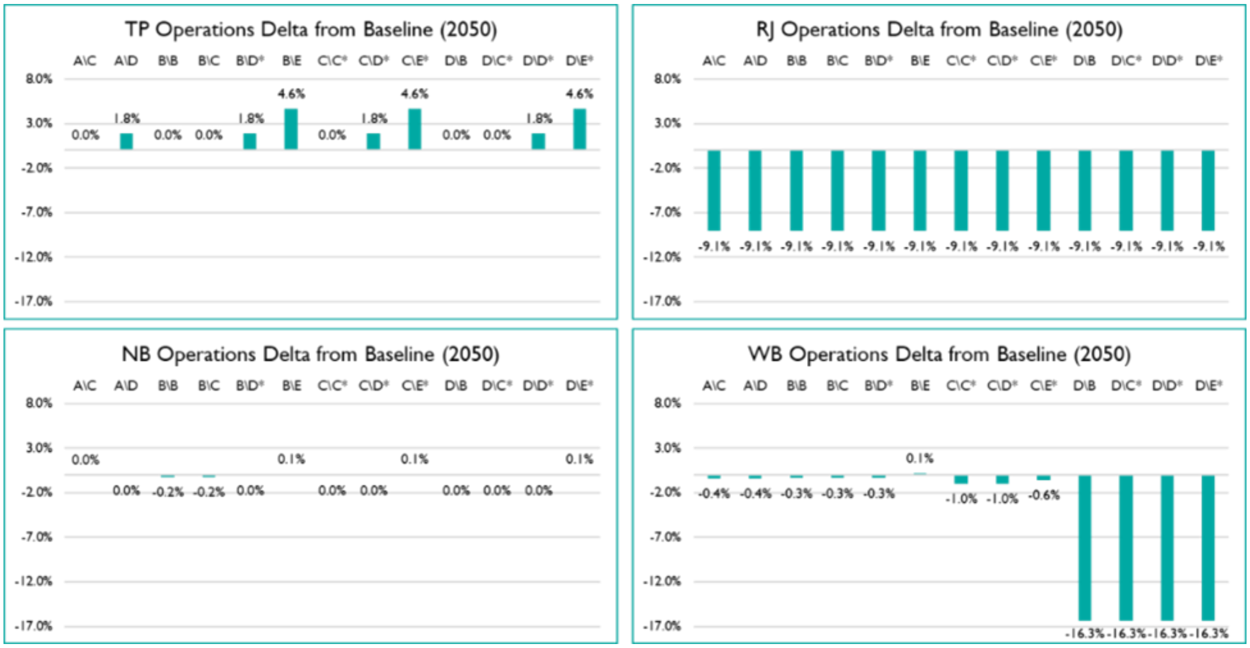

Figure 32: Operations Delta to Baseline by Market and NT A1 Scenario (FB)[59]

14.3.5 In the RJ market (CBin-3 and CBin-4), the same decrease in operations was observed across all scenarios. CBin-3 has a decrease in operations due to ECBM (moving a larger aeroplane from CBin-4 into CBin-3, increasing average capacity); CBin-4 also sees a decline in operations as a result of one aeroplane failing, resulting in an increase in average capacity.[60]

14.3.6 Overall, the stringency related operational changes in the Narrow Body Market (CBin-5 through CBin-8) are relatively small. Starting with scenario A\C, no narrow body aeroplanes fail, so there is no change in operations (note that there are no stringency-related operational changes in CBin-5 under any scenario).

14.3.7 For scenarios A\D, B\D, C\C, C\D, D\B, D\C, and D\D, increases in operations in CBin-6 and CBin-7 are offset by a decrease in CBin-8 resulting in a less than 0.1% decrease in operations in 2050.[61,62]

14.3.8 The 0.2% decrease in 2050 operations in scenarios B\B and B\C, result from an increase in operations in CBin-6 and a decrease in CBin-8 (no change in CBin-7).

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[59] Stringency options marked with a * were also run for NT M.07.

[60] This reduces increases the average capacity of new deliveries in CBin 4 to 96, compared to 92 in the baseline.

[61] This change is shown as 0.0% in Figure 28 due to rounding.

[62] CBin 6 shows an increase in operations of 0.7% in all scenarios other than A\C (for scenarios, A\D, B\B, B\C, and B\D, one aircraft fails, decreasing capacity to 138, compared to 140 in the baseline, and for scenarios B\E, C\C, C\D, C\E, D\B, D\C, D\D, and D\E, three aircraft fail, decreasing capacity to 139). CBin 7 shows no change in operations in B\B and B\C, as all aircraft receive a pass response, and an increase in operations of 0.8% in scenario A\D, B\D, B\E, C\C, C\D, C\E, D\B, D\D, and D\E. However, these operations increase in CBins 6 and 7 are offset in scenarios A\D, B\B, B\C, B\D, C\C, C\D, D\C, and D\D by a 0.5% decrease in 2050 operations in CBin 8 and in B\E, C\E, D\E by a 0.3% decrease in 2050 operations in CBin 8.

14.3.9 For the Noise E SOs (i.e., scenarios B\E, C\E, and D\E), a slight increase in 2050 operations (0.1%) is seen in the NB market. This is caused by a different set of aeroplanes failing at NSO E relative to NSO D in CBin-8.[63]

14.3.10 In the Wide Body (WB) market, operational changes vary across the scenarios. For the CSOs D (i.e., scenarios D\B, D\C, D\D, and D\E), there is a large change in operations, which is primarily due to ECBM in CBin-9 resulting in a 24.8% decrease in operations in 2050 (the largest CBin in the WB market).[64]

14.3.11 At NSO E, there is a moderation in the decrease in operations, which is due to differences in the set of aeroplanes in CBin-10 that fail at NSO E relative to NSO D.[65]

14.3.12 *NT Approach M.07 – Fleet wide results*: Considering the full set of NT M.07 scenarios, the fleet evolution results show decreases in operations in all, except for scenario G\B, which has a small increase in operations (Figure 36). The magnitude of changes in operations is generally smaller than in approach A1, which is as expected due to the staggered nature of TRs (fails) under approach M.07.[66]

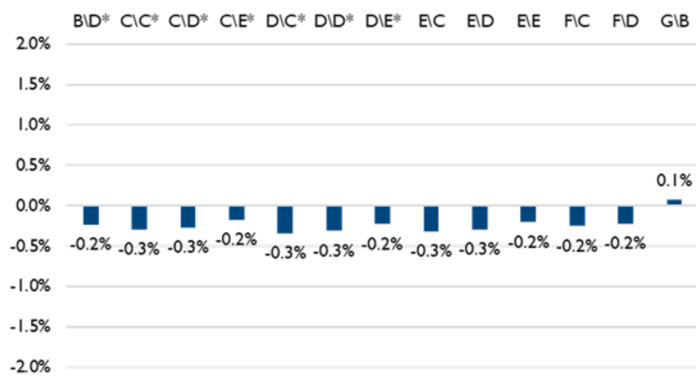

Figure 33: Total operations compared to the baseline across NT M.07 Scenario (Fleet Builder tool)[67]

14.3.13 The staggered nature of TRs under M.07 may lead to a shift in the magnitude and/or direction of operations changes due to a response during the forecast. This depends upon the timing of the PNGA dates of aeroplanes which fail at a particular stringency level. For reporting purposes, differences in

[63] For NSO D (i.e., A\D, B\D, C\D, and D\D) scenarios, the average capacity of new deliveries in CBin 8 increases to 200, as three aircraft fail, and for NSO E (i.e., B\E, C\E, and D\E) scenarios, the average capacity increases to 199, as five aircraft fail, compared to a capacity of 198.6 in the baseline. Scenarios B\B, B\C, C\C, and D\C show the same capacity change as NSO D responses in this CBin.

[64] For stringencies A\C, A\D, B\B, B\C, B\D, B\E, C\C, C\D, C\E there is a 0.6% decrease in operations in CBin 9.

[65] For scenario B\B, B\C and B\D, the average capacity of new deliveries in CBin 10 decreases very slightly as one aircraft fails (resulting in a 0.1% increase in operations), while under B\E, the average capacity decreases to 340 as a second, large, aircraft fails (resulting in a 1.4% increase in operations). For scenario C\C and C\D, the average capacity of new deliveries in CBin-10 increases to 352 as two aircraft fail (resulting in a 1.9% decrease in operations), while under C\E, the average capacity increases by a smaller amount to 348 as a third, large, aircraft fails, compared to capacity of 345 in the baseline (resulting in a 0.8% decrease in operations). For CSO D scenarios (i.e., D\B, D\C, D\D and D\E), a decrease in operations of 5.1% is seen as four aircraft fail, increasing average capacity to 365.

[66] There are no changes in operations relative to the baseline in the turbo prop market of aeroplanes with less than 19 seats, TP Freighter, WB Freighter, Business Jet, or Freighter Conversion markets.

[67] Stringency options marked with a * were also run for NT A1.

seat capacity and operations are discussed in terms of the change in 2050 PNGA years are mentioned for context.[68]

14.3.14 *<u>NT Approach M.07 – Results by Markets</u>*: Stringency related changes in operations by market are shown in Figure 37 below.

14.3.15 In the Turbo Prop (TP) market (CBin-2), for scenarios C\C, D\C, E\C, and F\C and G\B, there is no change in operations as all aeroplanes receive a pass or fix response. For NSO D scenarios (i.e. B\D, C\D, D\D, E\D and F\D), one aeroplane fails in 2043, and for NSO E (i.e., scenarios C\E, D\E, and E\E), two aeroplanes fail in 2043.[69] The magnitude of the change in operations is smaller under M.07 than under the comparable stringencies run using A1, due to the later implementation date of the stringency under M.07 at the year of EIS of the PNGA.

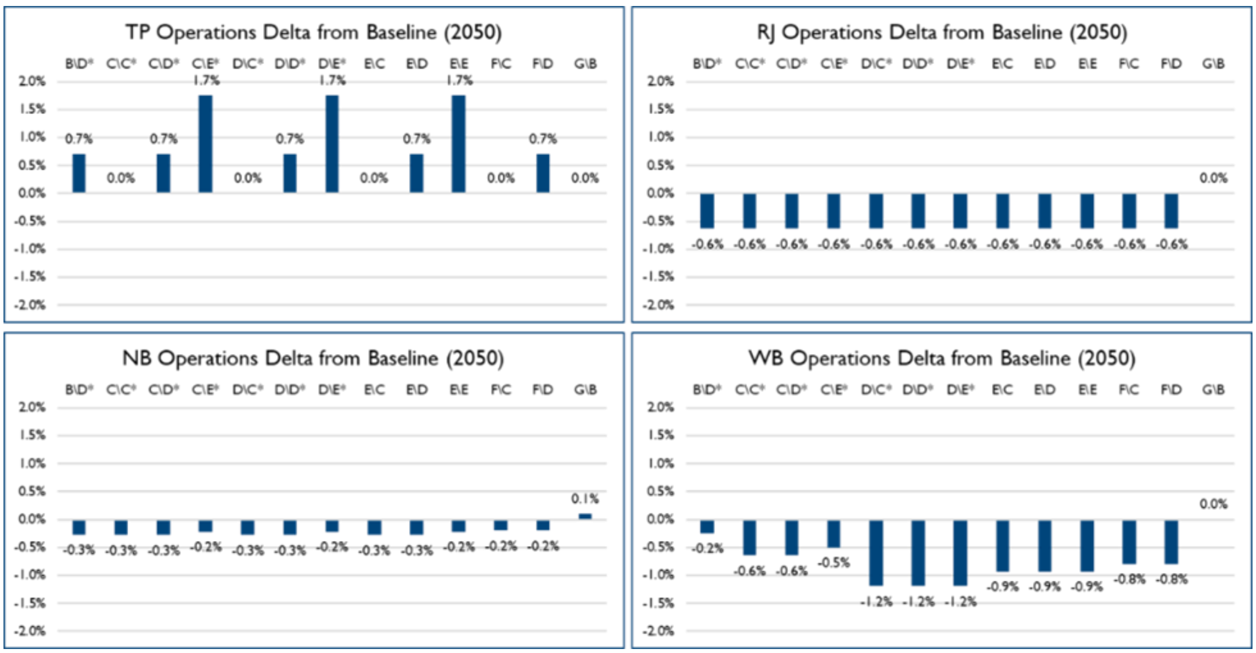

Figure 34: Changes in operations compared to the baseline by market for NT M.07 scenarios (Fleet Builder tool)[70]

14.3.16 In the RJ market (CBins 3 and 4), there is a 0.6% decrease in 2050 operations for all stringency scenarios other than G\B. This is due to differences in operations in CBin-4, as one aeroplane fails in 2047.[71] CBin-3 lacks available GRdb aeroplanes for all scenarios (due to fails), therefore, there are no operational changes as the baseline configuration is maintained. As expected, the magnitude of the change in operations is smaller under M.07 than under A1, due to later stringency responses at the PNGA year (in this case 2047 in CBin-4), along with no ECBM under M.07 in CBin-3.

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[68] For example, in CBin 10, average seats of GRdb aircraft in the baseline are 345. For scenario C/E, three aircraft fail. Due to the PNGA dates of aircraft that fail the stringency, average seats of new deliveries of GRdb aircraft are 351 in 2038, as one aircraft fails at this level in 2046, and 348 in 2046 onward, where two additional aircraft fail the stringency in 2046. For simplicity, the 348 value is reported in this document as it reflects the average seat capacity value in 2050.

[69] For Noise SO D scenarios, the average capacity of new deliveries decreases to 57, and for Noise SO E scenarios, the average capacity decreases to 54, compared to 60 in the baseline.

[70] Stringency options marked with a * were also run for NT A1.

[71] In CBin 4 for scenarios B\D, C\C, C\D, C\E, D\C, D\D, D\E, E\C, E\D, E\E, F\C, and F\D, one aircraft fails in 2047, increasing average capacity to 96, compared to 92 in the baseline, and decreasing operations in CBin 4 by 1.3% in 2050.

14.3.17 In the Narrow Body (NB) market there are small changes in operations across all scenarios. For stringencies also run using approach A1, the magnitude of the change in operations is larger under M.07. This result is driven by aeroplane responses in CBin-8, where the change in average seats is staggered based on the PNGA date (under A1, without the staggered implementation dates, the seat capacity shift is of a constant magnitude); this dynamic shifts the average seat capacity in CBin-8 further away from the baseline (and relative to A1), as initial aeroplane failures occur in 2037 and 2038 creating a wider gap in operations in M.07 than in A1, and the subsequent failure of a larger aeroplane in 2044, shifting seat capacity back to towards the baseline.

14.3.18 There are small operational changes in CBin-6 with increases relative to the baseline occurring in all scenarios except G/B, and in CBin-5, where operational changes are seen in scenario F\C and F\D.[72] Small operational changes are seen in CBin-7, where operational increases relative to the baseline occur in all scenarios.[73] In CBin-8 an increase in seat capacity results in a 0.7% decrease in 2050 operations in scenarios B\D, C\C, C\D, D\C, D\D, E\C, and E\D, and a 0.6% decrease in 2050 operations in scenarios C\E, D\E, E\E, F\C, F\D. All aeroplanes in CBin-8 fail under G\B, resulting in no difference in operations compared to the baseline.[74]

14.3.19 In the Wide Body Market, the largest differences in operations relative to the baseline are under scenarios D\C, D\D and D\E, driven by a 3.4% decrease in 2050 operations in CBin-10. All wide body aeroplanes fail for scenario G\B, resulting in no change in operations under the M.07 approach.

14.3.20 Variation in the WB market is primarily driven by CBin-10. In CBin-10, a less than 0.1% increase in operations is seen in 2050 for scenario B\D, a 1.3% decrease in 2050 operations is seen in C\C and C\D, and a 0.9% decrease in operations is seen in scenario C\E, with larger decrease in operations under scenarios D\C, D\D, and D\E (3.4% decrease), and for scenarios E\C, E\D, E\E, F\C, and F\D (2.7% decrease).[75]

14.3.21 In CBin-9, small decreases in 2050 operations are seen in scenarios B\D, C\C, C\D, and C\E and no change is seen in CBin-9 for CSO D and higher, as there is no ECBM under M.07 and all aeroplanes fail in this CBin.[76] In CBin-11, there is no change in operations for scenario B\D, scenarios C\C, C\D, C\E, D\C, D\D, D\E, E\C, E\D, and E\E have a 1.9% increase in 2050 operations, and scenarios F\C, F\D have a 5.0% increase in 2050 operations.[77] For stringencies also run under NT A1, the magnitude of the change in operations in aggregate for the WB market is smaller under M.07 than under A1, as expected, due to the later implementation date of the stringency and the reversion to baseline under M.07 in CBin-9.[78]

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[72] In CBin 5 for scenarios B\D, C\C, C\D, C\E, D\C, D\D, D\E, E\C, E\D, and E\E, all aircraft pass, and there is no change in operations, and for scenario G\B, all aircraft fail, and there is no change in operations. For scenarios F\C and F\D, two aircraft fail in 2036, decreasing capacity to 108.7, compared to 109.2 in the baseline. In CBin 6 for scenario B\D, one aircraft fails in 2043, decreasing capacity to 138. For scenarios C\C, C\D, C\E, D\C, D\D, D\E, E\C, E\D, E\E, F\C, and F\D, two aircraft fail in 2037, and a third aircraft fails in 2043, decreasing capacity to 139, compared to 140 in the baseline.

[73] For all scenarios, one CBin-7 aircraft fails in 2042, decreasing capacity to 165, and increasing operations by 0.4% in 2050.

[74] In CBin 8 for scenarios B\D, C\C, C\D, D\C, D\D, E\C, and E\D, three aircraft fail (one in 2037, one in 2038, and one in 2044), increasing capacity to 200. For scenarios C\E, D\E, E\E, F\C, and F\D, five aircraft fail (the same set of aircraft as under B\D, and two additional aircraft which fail in 2044), increasing capacity to 199, compared to 198.6 in the baseline.

[75] In CBin 10, for scenario B\D, one aircraft fails in 2046, resulting in small decrease in capacity. For scenarios C\C and C\D, one aircraft fails in 2038, and a second aircraft fails in 2046, increasing average seat capacity to 352. For scenario C\E, one aircraft fails in 2038, and two additional aircraft fail in 2046, increasing average capacity to 348. For scenarios D\C, D\D, and D\E, two aircraft fail in 2038 and two aircraft fail in 2046, increasing average capacity to 365. For scenarios E\C, E\D, E\E, F\C, and F\D, one aircraft fails in 2037, two aircraft fail in 2038 and two aircraft fail in 2046, increasing average capacity to 360.

[76] In CBin 9, for scenario B\D, one aircraft fails in 2040, increasing capacity to 267, and under C\C, C\D, and C\E, two aircraft fail in 2038, and a third fails in 2040, also increasing average capacity to 267, compared to 265 in the baseline.

[77] In CBin-11, for scenarios C\C, C\D, C\E, D\C, D\D, D\E, E\C, E\D, and E\E, one aircraft fails the stringency in 2038, decreasing seat capacity to 421. For scenarios F\C and F\D, one aircraft fails in 2034, and one aircraft fails in 2038, decreasing seat capacity to 401, compared to 434 in the baseline.

[78] However, under scenario C\E, the magnitude of the change for M.07 in CBin-10 is greater than the change under A1.

14.4 Fleet Evolution Results: Summary

14.4.1 Overall, the two CAEP approved fleet evolution models show excellent agreement for the selected verification and validation (V&V) scenarios, and the sources of the small differences between the models are well understood. These V&V runs allow for a comparison of the analysis space where both approach A1 and approach M.07 are being utilized, and the models are aligned in terms of the changes in operations relative the baseline for each of these scenarios. An InP run was also run for comparison purposes, and the models again show good agreement.

14.4.2 For the entire set of scenario runs, the Fleet-Builder output is consistent with the responses in the GRdb leading to operational changes, and the variation between approach A1 and approach M.07 is consistent with their underlying assumptions.[80]

[80] The CAEP/13 niche market has been set-up using Fleet-Builder. This market represents 0.03% of total operations in 2050; since there are no responses/passes in the niche market, it was assumed to have a zero delta to the baseline and is not being included in the environmental modelling.

15. MAIN ANALYSIS (MODELLING) RESULTS (NT): CO_2 EMISSIONS (INCLUDING NOx TRADE-OFFS) RESULTS

15.1 Introduction

15.1.1 Using the results of the fleet evolution modelling as summarized and reported in the section above, CO_2 emissions (including NOx trade-offs) were estimated for each of the 26 scenarios for a NT standard, incorporating both CO_2 and Noise TRs. See Figure 28 for details on the set of scenarios analysed.

15.2 Modelling Input and Scenarios

15.2.1 For the purpose of CO_2 emissions (including NOx trade-offs) modelling, TRs for each SO were derived from the MA GRdb13 (v3.5). Fuel burn, and NOx adjustments were provided by OEMs.

15.2.2 The following default MDG GHG modelling assumptions were used:

a) standard day sea level airport with 8 knots headwind during take-off,

b) all engines used for taxi,

c) full power take-off, and

d) 60 percent relative humidity.

15.2.3 The CAEP WG2 provided horizontal and vertical flight inefficiency factors. This same factors from the CAEP/12 Long Term Aspirational Goal (LTAG) Task Group analysis were used and applied to full flight fuel burn and full flight NOx.

15.2.4 In addition, the latest SAE AIR 8035 recommendation were applied to the taxi fuel burn. This recommendation reduces by 20% the fuel flow from Engine Emissions Data bank that is used for calculating taxi fuel burn. Only taxi fuel burn is reduced, and the taxi mode emissions indices (EI) are unaffected.

15.3 Interpretation of CO_2 Emissions Results

15.3.1 The full flight fuel burn and NOx results from the Aviation Environmental Design Tool (AEDT), IMPACT and FAST models were compared for the above scenarios and for the analysis years 2038 and 2050. The consensus results used to report results of the IDS analyses are based on the AEDT tool.

15.3.2 All three models align well in terms of stringency rank ordering for fuel burn. AEDT and IMPACT have the same fuel burn rank ordering for 11 out of 13 A1 scenarios for both 2038 and 2050. AEDT and IMPACT have the same fuel burn rank ordering for 11 out of 13 M.07 scenarios for both 2038 and 2050.

15.3.3 For NT M.07 scenarios fuel burn benefit, CSO F has the largest benefit, followed by scenario CSO(s) E, D, C and B. CSO G, having the highest CSO assessed has the lowest benefit as at this scenario most of the CBin(s) do not receive TRs and revert to baseline. For the scenarios in which both A1 and M.07 approaches were used, changes in fuel burn under M.07 approach are between one half to one quarter of the changes in fuel burn from A1 approach.

15.3.4 As expected, the 2038 NT M.07 results have the lowest benefit (very close to the baseline). Most of the aeroplanes have their PNGA based entry date after 2038.

Consensus New Type (NT) Applicability: 2050 Fuelburn Change in Mt Relative to Baseline of 644.2 Mt

CO_2 \ Noise	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-6.29	-3.51	
B (99%/95%)		-10.01	-10.01	-10.90 / -5.06	-10.88
C (99%/93%)			-15.22 / -7.26	-15.22 / -7.28	-16.40 / -7.24
D (97%/91%)		-40.34	-40.34 / -8.52	-40.27 / -8.51	-37.86 / -7.24
E (97%/89%)			-11.58	-11.57	-10.32
F (95%/87%)			-14.60	-14.59	
G (83%/83%)		-4.32			

Figure 35: Change in fuel burn relative to baseline in 2050 (in Mt Fuel) for New Type (NT) scenarios

Consensus New Type (NT) Applicability: 2050 Percent Fuelburn Change Relative to Baseline 644.2 Mt

CO_2 \ Noise	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-1.0%	-0.5%	
B (99%/95%)		-1.6%	-1.6%	-1.7% / -0.8%	-1.7%
C (99%/93%)			-2.4% / -1.1%	-2.4% / -1.1%	-2.5% / -1.1%
D (97%/91%)		-6.3%	-6.3% / -1.3%	-6.3% / -1.3%	-5.9% / -1.1%
E (97%/89%)			-1.8%	-1.8%	-1.6%
F (95%/87%)			-2.3%	-2.3%	
G (83%/83%)		-0.7%			

Figure 36: Change in fuel burn relative to baseline in 2050 (in Percent) for New Type (NT) scenarios

15.4 NOx Results Comparisons

15.4.1 The NOx results derived from the AEDT, IMPACT and FAST models were compared. The AEDT results align well with both IMPACT and FAST for the baseline. AEDT and IMPACT results align well for the scenarios as well.

15.4.2 As expected, there are larger differences (for scenarios other than the baseline) between AEDT/IMPACT and FAST. FAST currently uses the DLR method for NOx which has known deficiencies in modelling lean burn engines. Lean burn engines become more prominent in scenarios in a few CBins. This is the primary reason for larger differences. The FAST modellers are planning to implement the latest BFFM2 methodology with lean burn corrections later in the CAEP/13 cycle.

15.4.3 The NOx results derived from the AEDT model were chosen as the MDG-FESG consensus results. All charts depicting NOx results below are based on results from the AEDT model.

15.5 **Interpretation of NOx Results**

15.5.1 As part of the provision of TRs to NT scenarios and InP SOs, OEMs provided NOx TRs that had either a small NOx increase, or no NOx change with CO_2 emissions reduction. Overall, a small to medium NOx increase would be expected when moving across the CSOs.

15.5.2 However, this behaviour is only observed with scenarios containing CSO B (i.e., B\B, B\C, B\D, and B\E). In all other scenarios there are too many fleet changes that mask the TRs related trade-off.

15.5.3 In the case of scenarios containing CSO C (i.e., C\C, C\D, and C\E) the fleet change effect results in large NOx reduction. This behaviour is driven primarily by a single OEM lean burn project aeroplane/engine that is receiving a significant NOx reduction as part of the TR (compared to the existing in production engine). This particular aeroplane/engine dominates CBin-10 in which higher NOx rich burn engines are replaced by this lower NOx lean burn engine. The MDG modellers verified this behavior directly with the OEM.

15.5.4 For scenarios containing CSO D (i.e., D\B, D\C, D\D, and D\E) the fleet change effects result in the opposite behavior to CSO C with a large NOx increase. Under the A1 approach, this is due to all lower NOx lean burn engines in CBin-9 getting replaced (due to ECBM assumptions) by higher NOx rich burn engines. A similar increase in NOx is seen under the M.07 approach, as failing aeroplanes with lean burn engines get replaced by fixed aeroplanes with rich burn engines in CBin-10. For M.07, the increase in NOx is smaller in magnitude because of the delayed application of fixes in M.07 compared to the A1 approach.

Consensus New Type (NT) Applicability: 2050 NOx Change in Kt Relative to Baseline of 11,609 Kt

Noise / CO_2	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-210.5	-102.8	
B (99%/95%)		180.5	180.5	3.0 -13.3	126.9
C (99%/93%)			-650.8 -488.7	-649.1 -488.3	-487.2 -428.7
D (97%/91%)		540.0	540.0 194.1	541.2 194.3	541.8 198.2
E (97%/89%)			-61.8	-61.7	-57.7
F (95%/87%)			-37.9	-37.9	
G (83%/83%)		-84.3			

Figure 37: Change in NOx relative to the baseline in 2050 (in kt NOx) for New Type (NT) scenarios

Consensus New Type (NT) Applicability: 2050 Percent NOx Change Relative to Baseline of 11,609 Kt					
Noise / CO_2	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-1.8%	-0.9%	
B (99%/95%)		1.6%	1.6%	0.0% -0.1%	1.1%
C (99%/93%)			-5.6% -4.2%	-5.6% -4.2%	-4.2% -3.7%
D (97%/91%)		4.7%	4.7% 1.7%	4.7% 1.7%	4.7% 1.7%
E (97%/89%)			-0.5%	-0.5%	-0.5%
F (95%/87%)			-0.3%	-0.3%	
G (83%/83%)		-0.7%			

Figure 38: Change in NOx relative to the baseline in 2050 (in Percent) for New Type (NT) scenarios

15.6 Estimations for Set of Low Noise Stringency Options (i.e., NSO A and B)

15.6.1 The WG1 and WG3 recommended to explore an area of the analytical space (i.e., matrix of NT SOs) to account for noise performance across the full range of aeroplanes (or full market) and to account for lower carbon technologies with noise trade-offs expected to reach TRL8 beyond the agreed TFD timeline (2029) which are not part of the MA. This area of the matrix covers low NSOs (NSO A and NSO B) and the full range CSOs (i.e., CSO A to CSO G). The MDG-FESG modelled results for 2 scenarios (i.e., B\B and D\B) using the A1 approach. In 2050, the fuel burn reduction from the baseline for these scenarios B\B and D\B are approximately 1.5% and 6% respectively.

15.6.2 Qualitative and/or simplified quantitative methods were used to further characterize this part of the analytical space.

16. MAIN ANALYSIS (MODELLING) RESULTS (NT): NOISE RESULTS

16.1 Introduction

16.1.1 Using the results of the fleet evolution modelling as summarized and reported in section 4.3, noise impacts were estimated for each of the 26 scenarios for a NT standard, incorporating both CO_2 and Noise TRs. See Figure 28 for details on set of scenarios analysed.

16.2 Modelling Input and Scenarios

16.2.1 TRs for the SO(s) and noise certification levels including project aeroplanes were obtained from the MA GRdb13 (v3.5).

16.2.2 The MDG-FESG recommended that noise assessments for the dual stringency MA rely on 103 airports (including 75 from AEDT, 27 from STAPES, and 1 from ANCON) out of 318 (from CAEP/12 Noise Airports Master).

16.2.3 Noise results are always presented for all aeroplanes covering both fleet evolution reference year and Growth and Replacement (G&R) fleet.

16.2.4 The following default MDG Noise modelling assumptions were used:

a) standard day sea level airport with 8 knots headwind during take-off, and

b) SAE-AIR-1845 atmosphere.

16.3 Interpretation of Noise Results

16.3.1 All (combination of AEDT, STAPES and ANCON) airports 2050 DNL 55 noise results for contour area change and population exposed change relative to baseline are shown below:

New Type (NT): 2050 Noise Contour Area Change in Sq Km Relative to Baseline (13964) DNL 55 dB

CO_2 \ Noise	**A** (0dB/-2dB)	**B** (-2dB/-4dB)	**C** (-2dB/-6dB)	**D** (-4dB/-8dB)	**E** (-6dB/-10dB)
A (99%/97%)			-458	-1003	
B (99%/95%)		-538	-533	-1002 -435	-1549
C (99%/93%)			-829 -372	-1139 -528	-1667 -812
D (97%/91%)		-1063	-1075 -286	-1382 -469	-1989 -743
E (97%/89%)			-408	-550	-793
F (95%/87%)			-482	-581	
G (83%/83%)		-60			

Figure 39: DNL 55 noise contour area change relative to the baseline in 2050 (AEDT, STAPES, ANCON Combined)

New Type (NT): 2050 Population Exposed Change Relative to Baseline (31,522,484) DNL 55 dB					
Noise / CO_2	**A** (0dB/-2dB)	**B** (-2dB/-4dB)	**C** (-2dB/-6dB)	**D** (-4dB/-8dB)	**E** (-6dB/-10dB)
A (99%/97%)			-822,009	-1,737,534	
B (99%/95%)		-712,210	-693,260	-1,734,279 / -708,209	-3,043,487
C (99%/93%)			-1,288,472 / -508,393	-2,011,998 / -887,867	-3,299,252 / -1,587,001
D (97%/91%)		-1,614,754	-1,645,140 / -313,934	-2,377,861 / -747,992	-3,849,431 / -1,453,056
E (97%/89%)			-539,921	-906,155	-1,613,114
F (95%/87%)			-751,009	-1,010,495	
G (83%/83%)		-92,294			

Figure 40: DNL 55 <u>population exposed</u> change relative to baseline in 2050 (AEDT, STAPES, ANCON Combined)

New Type (NT): 2050 Noise Contour Area Percent Change Relative to Baseline (13964) DNL 55 dB					
Noise / CO_2	**A** (0dB/-2dB)	**B** (-2dB/-4dB)	**C** (-2dB/-6dB)	**D** (-4dB/-8dB)	**E** (-6dB/-10dB)
A (99%/97%)			-3.3%	-7.2%	
B (99%/95%)		-3.9%	-3.9%	-7.2% / -3.2%	-11.1%
C (99%/93%)			-6.0% / -2.7%	-8.2% / -3.8%	-12.0% / -5.9%
D (97%/91%)		-7.7%	-7.8% / -2.1%	-9.9% / -3.4%	-14.3% / -5.4%
E (97%/89%)			-3.0%	-4.0%	-5.7%
F (95%/87%)			-3.5%	-4.2%	
G (83%/83%)		-0.5%			

Figure 41: DNL 55 <u>noise contour area</u> percent change relative to baseline in 2050 (AEDT, STAPES, ANCON Combined)

New Type (NT): 2050 Noise Population Exposed Percent Change Relative to Baseline (31,522,484) DNL 55 dB

CO_2 \ Noise	**A** (0dB/-2dB)	**B** (-2dB/-4dB)	**C** (-2dB/-6dB)	**D** (-4dB/-8dB)	**E** (-6dB/-10dB)
A (99%/97%)			-2.7%	-5.6%	
B (99%/95%)		-2.3%	-2.2%	-5.6% -2.3%	-9.7%
C (99%/93%)			-4.1% -1.7%	-6.4% -2.9%	-10.5% -5.1%
D (97%/91%)		-5.2%	-5.3% -1.0%	-7.6% -2.4%	-12.3% -4.7%
E (97%/89%)			-1.8%	-2.9%	-5.2%
F (95%/87%)			-2.4%	-3.3%	
G (83%/83%)		-0.3%			

Figure 42: DNL 55 <u>population exposed</u> percent change relative to baseline in 2050 (AEDT, STAPES, ANCON Combined)

16.3.2 For DNL55 dB and for all the A1 modelling approach scenarios, results for all airports show the expected behaviour with scenario D\E having the highest noise benefit, followed by scenarios C\E, B\E, etc. The largest benefit is around 14% reduction in contour area and around 12% reduction in population exposed for scenario D\E and the smallest benefit is around 3% reduction in contour area for scenario A\C and around 2% reduction in population exposed relative to the baseline for scenario B\C.

16.3.3 For DNL55 dB and for all the M.07 modelling approach scenarios, there are minor variations, with scenario C\E having the highest benefit followed by scenario D\E. Also, M.07 has the lowest benefit for 2038 and again as anticipated as most of the new aeroplanes have PNGA date only after 2038. The largest benefit is around 6% reduction in contour area for the scenario D\E and around 5% reduction in population exposed for scenario C\E and smallest benefit is around 0.5% reduction in contour area and 0.3% reduction in population exposed relative to the baseline for the scenario G\B.

16.3.4 For DNL60 dB and for all the A1 modelling approach scenarios, results for all airports show the expected behaviour with D\E having the highest noise benefit, followed by C\E, B\E, etc. The largest benefit is around 12% reduction in contour area and around 11% reduction in population exposed for the scenario D\E and the smallest benefit is around 2% reduction in contour area and 0.1% increase in population exposed relative to the baseline for the scenario B\B.

16.3.5 For DNL60 dB and for all the M.07 modelling approach scenarios, there are minor variations, with scenario C\E having the highest benefit followed by scenario D\E. The largest benefit is around 5% reduction in contour area and population exposed for the scenario C\E and smallest benefit is 0.5% reduction in contour area and 0.3% increase in population exposed relative to the baseline for scenario D\C.

16.3.6 For DNL65 dB and for all the A1 modelling approach scenarios, results for all airports show the expected behaviour with scenario C\E having the highest noise benefit, followed by scenarios D\E, B\E etc. The largest benefit is around 11% reduction in contour area and 9% reduction in population exposed for the scenario C\E and the smallest benefit is around 0.5% reduction in contour area and around 3% increase in population exposed relative to the baseline for the scenario B\C.

16.3.7 For DNL65 dB and for all the M.07 modelling approach scenarios, the behaviour is different with many scenarios having increase in noise relative to baseline, with scenario C\E having the highest benefit followed by scenario E\E. The largest benefit is around 4% reduction in contour area and population exposed for the scenario C\E and smallest benefit is 1% increase in contour area and 2% increase in population exposed relative to the baseline for the scenario D\C.

16.4 Estimations for Set of Low Noise Stringency Options (i.e. NSO A and B)

16.4.1 The WG1 and WG3 recommended to explore an area of the analytical space (i.e., matrix of NT SOs) to account for noise performance across the full range of aeroplanes (or full market) and to account for lower carbon technologies with noise trade-offs expected to reach TRL8 beyond the agreed TFD timeline (2029) which are not part of the MA.

16.4.2 The MDG modelled two scenarios B\B and D\B using the A1 approach. In 2050, modelling results show in terms of contour area reduction, 4% and 8% respectively and population exposed reduction 2% and 5% respectively relative to the baseline.

16.4.3 Qualitative and/or simplified quantitative methods were used to further characterize this part of the analytical space.

17. MAIN ANALYSIS (MODELLING) RESULTS (NT): COST RESULTS

17.1 Integrated Dual Stringency Cost Assessment

17.1.1 The unique nature of the IDS presents challenges for reporting results due to the inclusion of TRs for two environmental metrics: noise and CO_2 emissions. For each NT stringency scenario, the responses are integrated (i.e., noise and CO_2 emissions change relative to the baseline) as well as the associated fleet evolution and cost changes i.e., DOCs and NRCs.

17.1.2 Recognizing these challenges, the MDG-FESG have explored several possible approaches for presenting both cost results and for combined cost and environmental results.

17.1.3 To build a clear narrative for the IDS cost results, a single series of legacy tables and graphs are presented in this section.

17.1.4 The IDS cost results are described in terms of TRs for each scenario and associated changes in costs relative to the baseline. Specially, the results focus on changes in the available GRdb aeroplanes for fleet evolution by CBin in a scenario due to a TR (i.e., pass/fix/fail), which alter the composition of the GRdb fleet, and associated costs, relative to the baseline.

17.1.5 Aeroplanes failing a scenario may lead to a change in the average capacity and price of available GRdb aeroplanes:

a) ***Changes in average capacity*** in a scenario run result in a change in operations, and operational related costs (i.e., other DOCs and fuel cost) relative to the baseline.

b) ***Changes in average aeroplane price*** in a scenario run lead to a change in capital costs relative to the baseline.

17.1.6 Along with fleet mix changes, the number of aeroplanes with a fix response for a scenario influence the change in noise and CO_2 emissions.

17.1.7 For each scenario, the change (relative to the baseline) in fuel costs, capital costs and Other DOCs (i.e., crew, maintenance, route, and landing costs) are discussed and presented. NRCs, which are associated with a fix response, are also included.

17.1.8 Results are presented by CSO level which allows for observing the shift in cost changes from one CSO to the next, and the marginal changes within a CSO level from increases in the NSO level.

17.1.9 Under the NT standard, cost results are presented separately for each of the fleet evolution approaches (A1 and M.07).

17.1.10 The following sections present a presents a high-level summary of all cost results, followed by the NT A1 total cost narrative, the NT M.07 narrative, and the InP narrative.

17.2 Cost Results Summary

17.2.1 Overall, the CAEP/13 IDS NT standard cost results show a reduction in total costs across all scenarios run (except for scenario A\D using the A1 approach). The change in total costs is from operations related changes to other DOCs (from aeroplane mix capacity changes), capital cost changes (from aeroplane mix price changes), fuel burn changes (from fleet mix changes and TRs) and NRCs.

17.2.2 For Approach A1, as the CSO stringency level increases (holding NSO level constant) there is a larger reduction in costs (Figure 46). Within each CSO stringency level, increases in the NSO level tend to have minimal effect on total costs, until the highest NSO (i.e., NSO E) is reached. This trend is consistent with the underlying nature of the data in the GRdb, whereby the number of responding aeroplanes (fixes and fails) increases at each new CSO stringency.

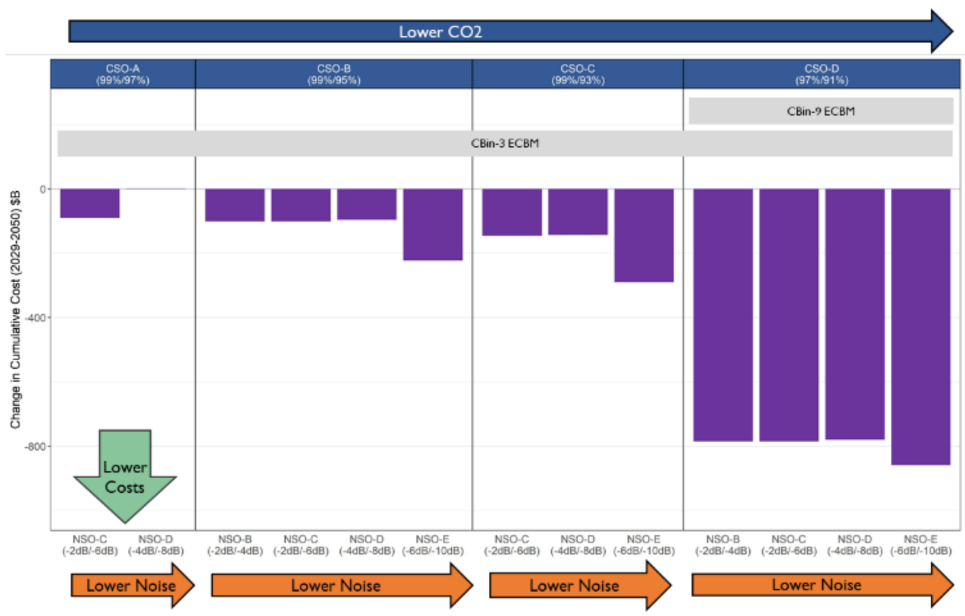

Figure 43: Total costs associated with NT scenarios modelled using the A1 approach[81] (Change in cumulative (2029-2050) costs relative to the baseline)

17.2.3 While approach M.07 results show a reduction in total costs across the scenarios run, the overall trend is less pronounced compared with A1, and the magnitude of cost reductions is smaller (Figure 47). This is due to TRs occurring after the applicability date, which reduces the time TRs and fleet mix changes affect costs. For the highest scenario run (as fails increase) the total cost reduction declines as more of the market reverts to the baseline.

17.2.4 The total cost results shown for A1 and M.07 present the results from the perspective of each CSO stringency, highlighting changes in costs between CSOs (and within CSO by NSO).

17.2.5 The largest reduction in total costs is observed at CSO D under A1 and at CSO F under M.07. Considering where there is overlap between A1 and M.07 runs, and avoiding analysis related market distortions (i.e., empty CBin management in CBin-9 in CSO-D under A1 and multiple CBin reversions to the baseline in M.07), the largest decline in total costs is observed in CSO C/NSO E.

[81] There is a small increase in total costs at A1 A/D of approximately $1B.

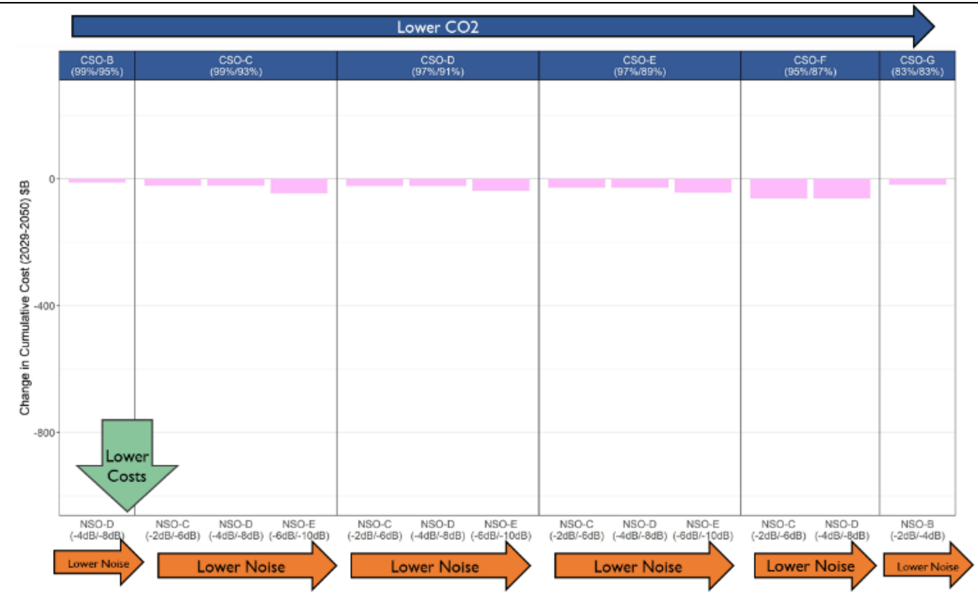

Figure 44: Total costs associated with NT scenarios modelled using the M.07 approach (Change in Cumulative (2029-2050) Costs Relative to Baseline)

17.3 New Type Standard: Approach A1

17.3.1 The initial step for detailing the change in total costs under the A1 approach for the NT standard is reviewing responses of the fleet available for growth and replacement under each scenario. A key assumption for the A1 approach is the use of empty CBin management (ECBM)[82] for certain scenarios and CBins. Specifically, ECBM is required in CBin-3 and CBin-19 across all A1 NT scenarios (i.e., starting at CSO A). ECBM is also needed in CBin-9 at CSO-D.[83]

17.3.2 A1 Growth and Replacement Fleet Responses

17.3.2.1 Table 22 presents the NT growth and replacement aeroplane TRs for all aeroplanes and markets (passenger, freighter and business jet) defined in the final MA GRdb and for each scenario under consideration.

[82] ECBM is applied when all aircraft in a CBin fail at a stringency level. When this happens aircraft from an adjacent CBin (limited to the next higher one without crossing markets – i.e., WB aircraft can't be used to fill NB CBins), can be moved to the empty CBin to meet the ASK demand. If this is not possible, then the scenario run fails and cannot be modelled using the A1 approach.
[83] ECBM is required for the baseline scenario in CBin 19.

Table 20. NT growth and replacement aeroplane technology responses[84,85]

Approach Run	NT A1				Both NT A1 & M.07	NT A1	Both NT A1 & M.07			NT A1	Both NT A1 & M.07			NT M.07					
Response	CSO A		B				C			D				E			F		G
	NSO C	D	B	C	D	E	C	D	E	B	C	D	E	C	D	E	C	D	B
Pass	77	68	57	57	53	39	48	46	34	39	39	38	28	39	38	28	36	35	6
Fix	15	11	25	25	24	27	25	23	26	26	26	24	27	23	21	24	20	18	9
Fail	4	17	14	14	19	30	23	27	36	31	31	34	41	34	37	44	40	43	81
Pass	80%	71%	59%	59%	55%	41%	50%	48%	35%	41%	41%	40%	29%	41%	40%	29%	38%	36%	6%
Fix	16%	11%	26%	26%	25%	28%	26%	24%	27%	27%	27%	25%	28%	24%	22%	25%	21%	19%	9%
Fail	4%	18%	15%	15%	20%	31%	24%	28%	38%	32%	32%	35%	43%	35%	39%	46%	42%	45%	84%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

17.3.2.2 **CSO A:** Majority of aeroplanes available for growth and replacement pass the CO_2 and Noise levels, with an increase in failures going from NSO C to NSO D. Shifting from NSO C to D under CSO A also causes one of the two ECBM aeroplanes to require a fix.

17.3.2.3 **CSO B:** Majority of aeroplanes still pass while increasing the NSO levels up to NSO E when the pass rate drops to 41% and the failure rate increases to 31%. The response rates between NSO B and C are identical, with a slight change at NSO D when 5 additional aeroplanes fail. The increase in failures at NSO E mainly affect the narrowbody market, with 4 additional failures, while the widebody market has 1 additional failure, and the rest occurring in the business jet market.

17.3.2.4 **CSO C**: Responses see an increase in the number of fixes and failures relative to the CSO B level, with at least 50% of aeroplanes either requiring a fix or failing the stringency. Similar to NSO C and D levels at CSO B, the number of aeroplanes failing increases slightly from 23 at scenario C\C to 27 at NSO D. Again, there is a noticeable increase in failures at the NSO E level, increasing by 9 additional aeroplanes, with 3 additional aeroplanes receiving a fix compared against NSO D.

17.3.2.5 **CSO D**: There are significant fleet mix changes, with the largest change occurring in CBin-9, which requires ECBM. Fix and failure rates between NSO B and C are exact, with a slight increase in the number of failures at NSO D. Similar to other NSO E levels within a CSO, there is also a noticeable increase in fixes and failures at this CSO combination. All told, only 28 aeroplanes now pass under scenario D\E, while 27 require a fix, 41 fail, and 4 aeroplanes are required for ECBM.

17.3.3 A1 Total Operational Changes to the Baseline

17.3.3.1 Table 23 presents 2050 operational changes relative to baseline for each SOs under an A1 approach. Changes in operations are tied to changes to the fleet mix and average capacity from aeroplanes failing certain scenarios.[86] Moreover, capacity changes directly affect costs relative to the baseline, for example, a reduction in total operations decreases block hours, which in turn decreases crew, maintenance, landing, and route costs. An effect on capital costs could also be expected, depending on changes in average aeroplane price. Fuel costs change based on fleet mix and operational changes (due to fails) and from TRs (fixes).

[84] For A1 scenarios, all aircraft in CBin 3 fail in all scenarios and aircraft from CBin 4 are used to meet demand, and all aircraft in CBin 9 fail for CSO D scenarios and aircraft from CBin-10 are used to meet demand.

[85] Counts exclude Niche market aircraft, aircraft which fail the MA Baseline and aircraft with a last made date prior to 2028.

[86] Changes in operations only occur in the passenger market; there are no changes in operations in the cargo or business jet markets.

Table 21. Operational change (in millions operations i.e., flights) to the baseline under A1 approach (in 2050)

	CSO A		B				C			D			
	NSO C	D	B	C	D	E	C	D	E	B	C	D	E
2050 % Change	-0.7%	-0.7%	-0.9%	-0.9%	-0.7%	-0.4%	-0.8%	-0.7%	-0.5%	-2.1%	-2.1%	-2.0%	-1.8%
2050 Ops Change (millions)	-0.73	-0.68	-0.89	-0.89	-0.68	-0.43	-0.80	-0.73	-0.49	-2.06	-2.06	-1.99	-1.78

17.3.3.2 **CSO A:** The decrease in operations is consistent between the two NSOs (C and D) options at 0.73 and 0.68 million (-0.7%); even though an additional 12 aeroplanes fail at NSO D the effect on capacity is marginal.

17.3.3.3 **CSO B:** Operations are unchanged between NSO B and NSO C, decreasing by 0.89 million. This decrease in operations shrinks as the NSO level increases to NSO D and NSO E, with the change moderating to 0.68 and 0.43 million operations, respectively.

17.3.3.4 **CSO C:** Operational changes follow a similar pattern to CSO B, whereby the largest decrease in operations occurs at NSO C at -0.80 million of operations, before tightening up as the NSO level increases from NSO D to NSO E.

17.3.3.5 **CSO D**: Operational effects see a dramatic change due to ECBM in CBin-9 causing significant increases in capacity (as demand in CBin-9 is met with CBin-10 aeroplanes). Shifting CBin-10 aeroplanes to CBin-9 causes an overall decrease of -24.8% in CBin-9 operations. Total change in operations for all CBins is held constant between NSO B and NSO C before changing slightly at NSO D and NSO E.[87]

17.3.4 NT A1 Total Cost Results

17.3.4.1 Total cost results for all A1 scenarios combinations under consideration are presented in Figure 48. The MDG-FESG observed that:

- Total cost reductions generally increase as the CSO stringency levels increase (holding NSO fixed).
- NSO level E sees a large response in capital costs that is consistent across the three CSO levels due to responses (failures) in both the widebody and narrowbody markets.
- CSO level D has the largest reduction in total costs, ranging from -$780 to -$858 billion, with minimal differences between NSOs B through D and a slightly larger decrease in costs at NSO E. This response is driven largely by the requirement for ECBM in CBin-9. Without ECBM, the largest reduction in total costs is under scenario C\E.
- Following the pattern of fixes, NRC costs increase from CSO A to CSO B (as fixes move from around 15% to more than 20% of the GRdb fleet). From CSO B onward NRC costs are relatively stable, same as the percent of aeroplanes being fixed. NRCs are a relatively small proportion of total costs for all NT scenarios using the A1 approach.[88]
-

[87] Additional decreases in operations occurs in CBin 10 across all NSO operations at CSO D, while increases in operations at CBin 2 at NSO D (1.8%) and NSO E (4.6%) cause the slight reduction in the overall decrease.
[88] For the same scenarios run using both A1 and M.07, the NRC cost is identical (when using a 0% discount rate).

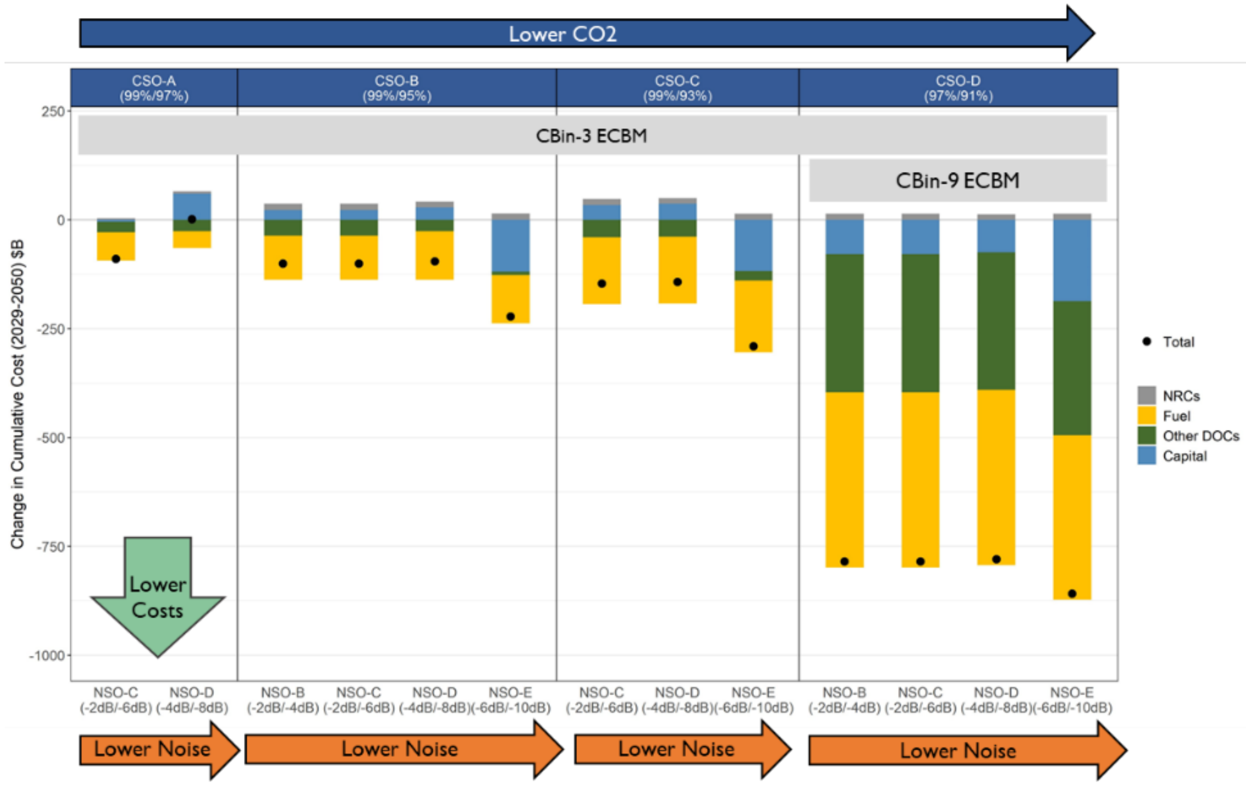

Figure 45: NT A1: Breakdown of costs and net costs (Change in cumulative (2029-2050) costs relative to the baseline)

17.3.4.2 **CSO A:** There is a significant difference in total costs between NSO C and NSO D driven mainly by an increase in capital costs and NRCs at the NSO D level, while other DOCs and fuel burn are both slightly lower relative to NSO C. The result is total costs of -$90 billion at CSO A/NSO C and total costs of $1 billion at NSO D. This shift in total costs is being driven by changes to the fleet mix and some operational effects.

17.3.4.3 **CSO B:** total cost results are consistent between NSO levels B, C, and D, with NSO B and C at -$101 billion and NSO D at -$95 billion. Overall, the slight increase in capital costs and NRCs at NSO D are outweighed by decreases in Other-DOCs and fuel costs. The NSO E level sees a significant drop in capital costs, as noted above, driving down total costs to -$223 billion.

17.3.4.4 **CSO C:** NSO C and D have similar total costs of -$146 and -$143 billion, respectively. Costs decrease relative to CSO A and B are due to larger fuel cost and other-DOC reductions, while capital costs increase marginally. Total costs are reduced by -$290 billion at NSO E, due to the same capital cost reductions noted above (all other costs change only slightly).

17.3.4.5 **CSO D:** The presence of ECBM in CBin-9, requiring larger aeroplanes from CBin-10 to meet CBin-9 demand, creates the marked downward shift in total costs relative to CSO C. The resulting fleet mix and operational changes impact the cost results at all NSO levels for CSO D.

17.3.4.6 Cost results for CSO D and NSO B and NSO C are nearly identical at -$785 billion, with significant reductions in other-DOCs, capital and fuel costs and only marginally higher NRCs relative to the other CSO levels (all significant reduction in costs occur at CBin-9 due to ECBM). Total costs reductions are marginally smaller under scenario D\D at -$780 billion due to slightly lower capital cost reductions. Finally, scenario D\E has the largest decrease in total costs being driven entirely by decreases in capital costs.

- There is a slight increase in capital costs for business jets at NSO D that cuts into the overall decrease in capital costs.

- As noted for other NSO E responses, CBin-8 going from positive to negative capital costs occurs at CSO D.

17.4 New Type Standard: Approach M.07

17.4.1 The total cost results and narrative for NT M.07 differ from NT A1 results in several fundamental ways due to differences in analysis assumptions. The two assumptions most critical to M.07, and which drive the largest difference, are the PNGA EIS dates, and the treatment of CBin level market failures when no aeroplane within a CBin pass or can respond to the given scenario level (i.e., all aeroplanes in a CBin fail at a CSO/NSO integrated level).

17.4.2 Under the A1 approach, all aeroplanes respond at the implementation date (2029). For M.07, aeroplanes respond at their PNGA date of EIS, which can span the entire analysis period (which generally tends to be several years after the implementation date – with the first GRdb aeroplane responding in 2030 and the last responding 2049), directly impacts cost results through shortening the period during which a fleet mix change ("Fix" or "Fail") may occur. In cases where no aeroplane within a CBin can respond (i.e., all GRdb aeroplanes in a CBin fail), the M.07 approach reverts to the baseline GRdb fleet mix (i.e., there is no change in operations or costs relative to the baseline). This allows for modelling more stringent scenarios, with the caveat that large portions of the market may not respond, remaining unchanged from the baseline. The ECBM assumption used in the A1 approach is not used under M.07.

17.4.3 M.07 Growth and Replacement Fleet Responses

17.4.3.1 Table 24 presents the M.07 TRs from the growth and replacement fleet across the scenarios analysed. The M.07 analysis space overlaps with A1, and the assumption of reverting to baseline allows for more stringent scenarios to be examined (i.e., as multiple CBins fail at higher scenarios it is no longer possible to run A1).

Table 22. NT growth and replacement aeroplane technology responses

Approach Run	NT A1				Both NT A1 & M.07	NT A1	Both NT A1 & M.07			NT A1	Both NT A1 & M.07			NT M.07					
Response	CSO A		B				C			D				E			F		G
	NSO C	D	B	C	D	E	C	D	E	B	C	D	E	C	D	E	C	D	B
Pass	77	68	57	57	53	39	48	46	34	39	39	38	28	39	38	28	36	35	6
Fix	15	11	25	25	24	27	25	23	26	26	26	24	27	23	21	24	20	18	9
Fail	4	17	14	14	19	30	23	27	36	31	31	34	41	34	37	44	40	43	81
Pass	80%	71%	59%	59%	55%	41%	50%	48%	35%	41%	41%	40%	29%	41%	40%	29%	38%	36%	6%
Fix	16%	11%	26%	26%	25%	28%	26%	24%	27%	27%	27%	25%	28%	24%	22%	25%	21%	19%	9%
Fail	4%	18%	15%	15%	20%	31%	24%	28%	38%	32%	32%	35%	43%	35%	39%	46%	42%	45%	84%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

17.4.3.2 **CSO B**: For scenario B\D, the TRs are equivalent to A1, with 55% of the fleet passing, 25% receiving a fix and 20% failing.

17.4.3.3 **CSO C:** TRs mirror those under responses under A1.

17.4.3.4 **CSO D:** Mirrors A1 response.

17.4.3.5 **CSO E:** Responses for CSO E show an increase in the failure rate relative to CSO D as the NSO level increases, with 46% of the fleet failing at NSO E.

17.4.3.6 **CSO F:** The failure rate increases further at CSO F, with 42% and 45% of the fleet failing at NSO C and D, respectively.

17.4.3.7 **CSO G:** At CSO G\NSO B, most of the market has failed, with only 6% passing, 9% receiving a fix and 84% failing.

17.4.4 M.07 Total Operational Changes to the Baseline

17.4.4.1 Operational changes relative to the baseline under M.07 are smaller than A1, which is expected given the PNGA responses occurring over time after the applicability date and the subsequent shortened period for fleet mix changes (due to failures) to have an effect. Moreover, reverting CBins to the baseline when no TRs means the relative change in operations between CSOs is much tighter. Table 25 presents the 2050 operational changes to the baseline for all scenarios analysed.

Table 23. Change in operation (in millions of operations in 2050) compared to the baseline under the M.07 approach

	CSO B	C			D			E			F		G
	NSO D	C	D	E	C	D	E	C	D	E	C	D	B
2050 % Change	-0.2%	-0.3%	-0.3%	-0.2%	-0.3%	-0.3%	-0.2%	-0.3%	-0.3%	-0.2%	-0.2%	-0.2%	0.1%
2050 Ops Change (millions)	-0.23	-0.29	-0.27	-0.17	-0.34	-0.31	-0.23	-0.32	-0.29	-0.20	-0.25	-0.22	0.07

17.4.4.2 **CSO B:** For scenario B\D, 2050 operations decrease by 0.23 million of operations against the baseline as the resulting fleet mix changes due to failures increases capacity slightly overall.

17.4.4.3 **CSO levels C, D, E, F and G:** These all see a similar pattern for operational changes across the relative NSO level. Overall, scenario D\C has the largest decrease in total operations at 0.34 million of operations and scenario C\E has the smallest at 0.17 million of operations. Operational changes for scenario G\B see a reverse, with operations increasing slightly by 0.07 million of operations, as most of the market reverts to the baseline fleet mix.

17.4.5 NT M.07 Total Cost Results

17.4.5.1 Total cumulative cost results for M.07 are presented in Figure 49 for all scenarios analysed. The general pattern of cost results across scenarios is somewhat less clear, compared with A1, and the greatest cost reduction occurs under scenario F\C. Note that total costs are substantially lower (by a factor of 10 in some cases) compared with A1 for the comparable scenarios (runs using both A1 and M.07 approaches). This is from the combination of effects discussed in the previous sections, mainly the PNGA entry into dates resulting in shortened time span for fleet mix changes, and reversion to the baseline when all aeroplanes in a CBin fail avoids the fleet evolution changes caused by ECBM).

17.4.5.2 The MDG-FESG observed that NRC costs are relatively stable from CSO B to CSO E, reflecting a stable number of fixes. At CSO F, NRC costs increase due to a higher level of fix required, even as the number aeroplanes responding with a fix declines. At CSO G, NRC costs decline as the number of responding aeroplanes remaining in the fleet declines noticeably.

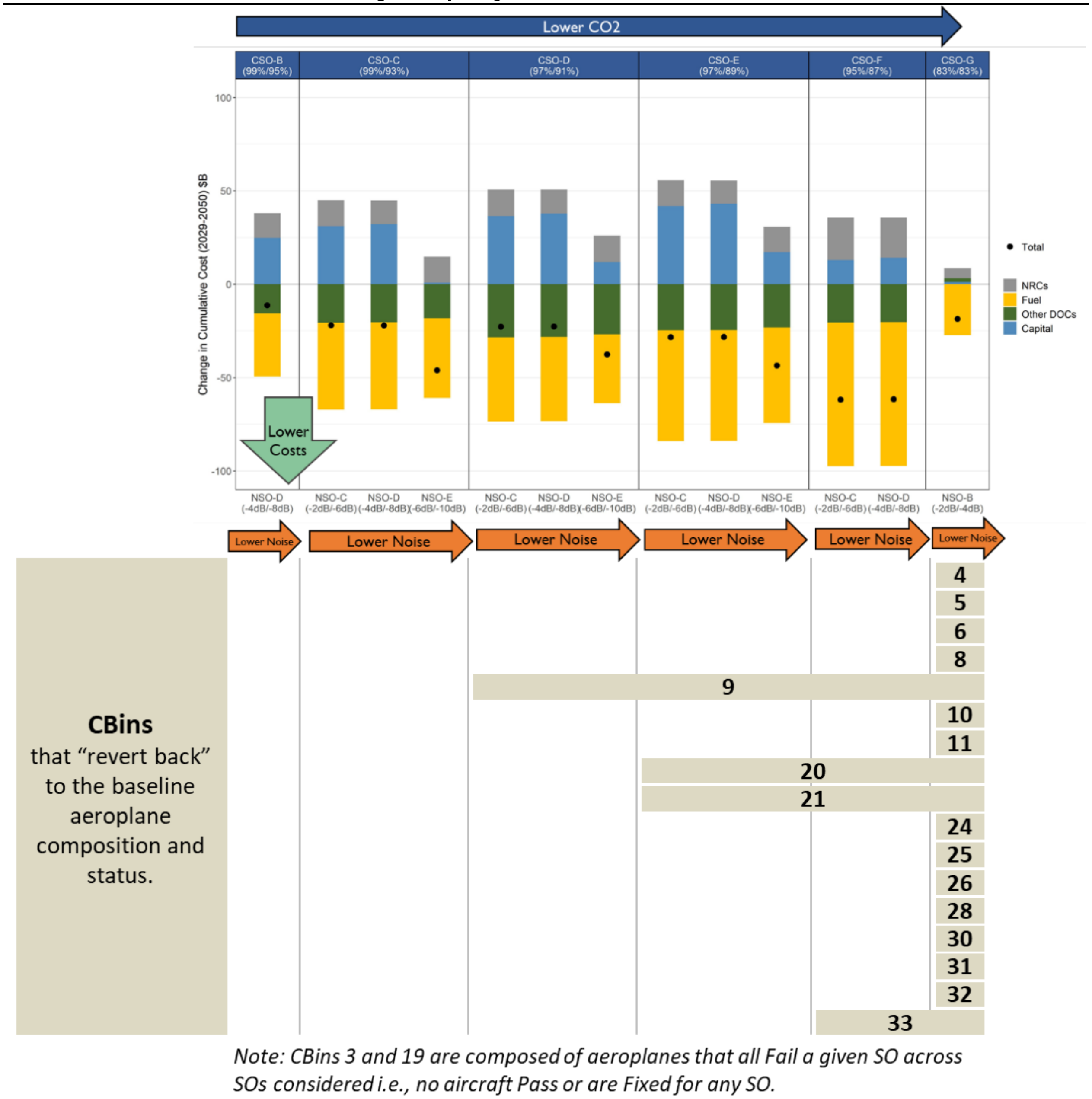

Figure 46: NT M.07 - Breakdown of costs and net costs (Change in cumulative (2029-2050) costs relative to the baseline)[89]

17.4.5.3 **CSO B:** At NSO D, total costs decrease by $11 billion relative to the baseline, with decreases in other-DOCs and fuel outweighing cost increases in capital and NRCs.

17.4.5.4 **CSO C:** results for scenario C\ C and C\D are slightly lower relative to B\D, with decreases in fuel costs offsetting capital cost increases. When NSO levels are increased to NSO E, total costs decrease

notably due to very little change in capital costs (relative to the baseline) and only slight decreases in cost savings in other-DOCs and fuel costs relative to NSO C and NSO D.

[89] Total capital costs for M.07 CSO C/NSO E are nonzero - approximately $1B.

17.4.5.5 **CSO D:** Total cost results for scenario D\C and D\D also see an increase in capital costs, however, very little change in fuel cost savings relative to CSO C is seen at the same noise levels. Slight decreases in other-DOCs helps balance out the change (increase) in costs, with total costs nearly equalling scenario C\C and C\D. At NSO E, again capital costs increase by less relative to the other NSO levels, decreasing total costs.

17.4.5.6 **CSO E:** Capital cost increases are balanced out by fuel cost decreases, resulting in slightly more total cost reductions relative to the lower CSO levels at NSO level C and D. Again, the capital cost increase is reduced at NSO E, resulting in an increase in total cost reductions of $44 billion.

17.4.5.7 **CSO F:** Total cost results at NSO C and D have nearly identical reductions at -$62 billion. Capital costs are relatively small, while fuel cost decreases are the largest among all M.07 SOs. Other-DOCs reductions are slightly lower and similar to CSO level C, and NRCs are the highest among all M.07 SOs, increasing by around $22 billion.

17.4.5.8 **CSO G:** At NSO B most aeroplanes have failed and the vast majority of CBins have reverted to the baseline. Increases in capital costs, other-DOCs and NRCs are marginal, with fuel costs decreases resulting in a total cost reduction of $19 billion.

18. MAIN ANALYSIS (MODELLING) RESULTS (NT): SUMMARY OF INTEGRATED RESULTS

18.1 Summary

18.1.1 While historically the CAEP has focused on CO_2 or Noise Stringency Analyses independently and conducted during different CAEP cycles, the CAEP/13 dual stringency analyses bring new challenges in integrating and communicating results.

18.1.2 Recognizing these challenges, the MDG-FESG explored several possible approaches for presenting combined cost and environmental results. Formats have been used to inform the presentation of the combined cost and environmental results.[90] Results in this paper are presented using a 0% discount rate.

18.1.2.1 The CAEP/13 IDS analysis results are presented as the change relative to the baseline for total cumulative costs, total cumulative CO_2 and total cumulative noise (55 dB population and area avoided).[91] For each scenario run using the fleet evolution modelling approach A1 or M.07, results show the cumulative change from 2029 through 2050 relative to the baseline.

18.1.3 New Type Standard: Approach A1

18.1.3.1 Figure 50 shows the change in CO_2 emissions on the vertical axis, the change in noise (55 dB population avoided) on the horizontal axis. The size of each bubble is proportional to cumulative costs through 2050. The labels of each dot in Figure 50 identify the scenario i.e., combination of CO_2 Noise SOs (e.g., A\C) and reports on the cumulative costs.

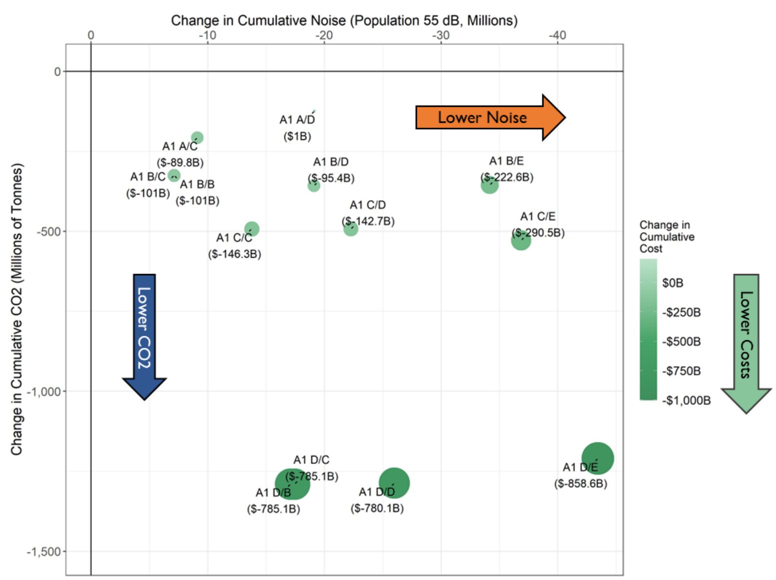

Figure 47: New Type A1 Approach: Change in cumulative CO2 (in Millions of tonnes), 55dB population (in Millions) and costs (in $ Billions)

18.1.3.2 **CO_2 Response:** Overall, the combined results for the A1 approach show a general trend of larger reduction in cumulative CO_2 as the CSO scenarios move from A through D (i.e., with increasing CO_2 stringencies). This is due to increasing magnitudes of TRs, with more aeroplanes either requiring a fix or

[90] MDG-FESG agreed that it was not feasible to develop a cost effectiveness ratio for the IDS analysis, due to the presence of the two environmental metrics that cannot be combined.

[91] Cumulative results are summed from 2029 through 2050.

failing as the increasing CSO. On average, the percent of aeroplanes passing without a TR (i.e., “Pass” only) at each CSO level (across all NSOs within each CSO) declines from 76%, 54%, 44% and 38% for CSO A, B, C and D respectively.[92]

18.1.3.2.1 There are cases where the reduction in CO_2 emissions is essentially unchanged across different NSO levels (given the same CSO) e.g., between scenario B\B and B\C, and D\B and D\C. Given that TRs are similar across NSOs for a given CSO, there is no change in CO_2 emissions reductions as well as for noise and costs.

18.1.3.2.2 Moving across each CSO (i.e., CSO B to CSO C) and holding NSO constant also shows a general trend of an increasing reduction in CO_2 emissions. For example, following the sequences of CSOs A, B, C and D, while holding NSO D constant shows a declining trend for CO_2 emissions. This is consistent with a decline in the percent of aeroplanes passing at each CSO level i.e., for scenarios A\D to B\D the percent of passing aeroplanes declines from 71% to 55%, and for B\D to C\D the percent of passing aeroplanes declines from 55% to 48%, and from C\D to D\D the percent of passing aeroplanes declines from 48% to 40%.

18.1.3.3 The sharp downward shift in CO_2 reduction at CSO D is due to Empty CBin Management (ECBM)[93] as a modelling assumption. Under the A1 approach, all aeroplanes in CBin-9 (i.e., small wide body market 236-300 seats) fail at CSO D. The use of the ECBM methodology where the demand from CBin-9 is met by using aeroplanes from the above CBin-10 reduces the number of operations and associated fuel burn (i.e., larger aeroplanes are used to serve the same demand) and thereby resulting in the step change observed at CSO D.

18.1.3.4 **Noise Response:** Overall, the A1 results also shows a general trend in the magnitude of population (and area) avoided (at 55dB) moving across the NSOs (by CSO). With the exception of the cases identified above, where the scenario combination has the same TRs, increasing NSOs, holding CSOs constant, leads to a greater reduction in 55dB population (area) avoided.

18.1.3.5 Holding the NSOs constant and moving across the CSOs, there is a general reduction in noise outcomes as the CSOs increases. Moving from CSO A to B under NSO D shows no change in noise outcomes (population or area avoided); although the number of passing aeroplanes declines going to CSO B/NSO D, there is a negligible change in noise between these scenarios, in part due to a very slightly smaller decline in operations overall. At NSO C, moving from CSO A to CSO B shows an improvement in the noise outcome for area avoided (55dB) and moderation for population (55dB).

18.1.3.6 As noted above, noise outcomes improve markedly at NSO E as a result of reaching the highest NSO stringency level.

18.1.3.7 **Cost Results:** The overall trend in changes to total cumulative cost broadly mirrors the changes in CO_2 emissions. The average total reduction in costs increases moving from CSO A through CSO D. Across NSOs, within each CSO, cost reductions may remain unchanged (e.g., from scenario B\B to B\C), due to the lack of change in the TR mix, or decline in magnitude (e.g., from scenario B\C to B\D), due to the mix of aeroplanes with TRs shifting to a larger number of aeroplanes failing instead of being fixed (and a lower reduction in operations and related costs). The sharp shift in costs at CSO D is related to ECBM being used in CBin-9 (noted earlier); this has the effect of reducing operations, other DOCs and capital costs.

[92] On average, the percent of aeroplanes passing with a technology response (i.e., “Pass” and/or “Fix”) at each CSO level declines from 84%, 77%, 68% and 60% for CSO A, B, C and D respectively.

[93] See paragraph 11.6 for details.

18.1.3.8 Figure 51 presents the values for cumulative changes relative to the baseline for costs, CO_2 and noise (population and area avoided at 55dB), with larger reductions in a metric shown by a darker colouring.

18.1.3.9 Overall, the largest reduction in total cumulative costs is achieved at CSO D and also along NSO E i.e., combined the largest reduction is at scenario D\E. For CO_2, the largest reductions occur at CSO D, while the combined largest reduction is at scenario D\C and D\B (scenario D\D is very similar in CO_2 reduction magnitude). Considering noise, the largest reductions in population and area avoided are found at the NSO E (across all CSOs), with the largest reduction being at scenario D\E.

NT A1 Cost Results, Cumulative (2029-2050)

Change in Cost (Billions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-$89.8	$1.0	
B (99%/95%)		-$101.0	-$101.0	-$95.4	-$222.6
C (99%/93%)			-$146.3	-$142.7	-$290.5
D (97%/91%)		-$785.1	-$785.1	-$780.1	-$858.6
E (97%/89%)	Outside of A1 Analytical Space				
F (95%/87%)					
G (83%/83%)					

NT A1 Environmental Results, Cumulative (2029-2050)

Change in Tonnes CO2 (Millions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-207.2	-124.4	
B (99%/95%)		-325.7	-325.7	-357.4	-354.8
C (99%/93%)			-492.6	-492.6	-528.1
D (97%/91%)		-1289.7	-1289.7	-1287.1	-1210.0
E (97%/89%)	Outside of A1 Analytical Space				
F (95%/87%)					
G (83%/83%)					

NT A1 Environmental Results, Cumulative (2029-2050)

Change in 55 dB Population (Millions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-9.1	-19.1	
B (99%/95%)		-7.1	-7.1	-19.1	-34.2
C (99%/93%)			-13.8	-22.3	-36.9
D (97%/91%)		-17.1	-17.4	-26.0	-43.4
E (97%/89%)	Outside of A1 Analytical Space				
F (95%/87%)					
G (83%/83%)					

NT A1 Environmental Results, Cumulative (2029-2050)

Change in 55 dB Area (Thousands)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)			-5.0	-10.5	
B (99%/95%)		-5.3	-5.3	-10.5	-16.3
C (99%/93%)			-8.6	-11.9	-17.5
D (97%/91%)		-10.8	-10.9	-14.2	-20.8
E (97%/89%)	Outside of A1 Analytical Space				
F (95%/87%)					
G (83%/83%)					

Figure 48: Cost and environmental cumulative results to New Type scenarios modelled using the fleet evolution approach A1

18.1.4 New Type Standard: Fleet Evolution Modelling Approach M.07

18.1.4.1 Figure 52 presents the change relative to the baseline for total cumulative costs, total cumulative CO_2 and total cumulative noise (55 dB population and area avoided) for the fleet evolution modelling approach M.07 (see Chapter 14 for details on the fleet evolution modelling approaches). The change in CO_2 on the vertical axis, the change in noise (population avoided) on the horizontal axis and the change in total cost is represented by the size of the bubble. When reviewing M.07 results it is important to note that the analytical space is not the same as the analytical space for the A1 approach (i.e., the M.07 modelling approach allows the assessment of scenarios for which the A1 approach cannot be used due to its ECBM assumptions). It is also worth noting that due to responses occurring later in the analysis under M.07, the magnitude of environmental results under M.07 are expected to be lower than under A1 (for scenarios where both approaches are used).

18.1.4.2 **CO_2 Response:** Trends in the change in total cumulative CO_2 emissions under M.07 are harder to discern when moving across CSOs. For instance, the reduction in CO_2 at CSO D is below the reduction in CO_2 at CSO C, and at the highest CSO run, CSO G, the reduction in CO_2 is lower than at CSO B. This happens as a result of the M.07 assumption used when no aeroplanes in a CBin can be fixed to meet the SO and the CBin reverts back to the baseline 2029 set of aeroplanes for fleet evolution. This means there is no environmental benefits from this CBin (unlike A1 where the CBin becomes empty and ECBM is used to meet demand). At CSO D (where CBin 9 reverts to the baseline) and CSO G (where most CBins have reverted to the baseline) this results in a diminished reduction of CO_2 relative to the prior stringency. [94] At CSO E and CSO F the increasing level of TRs leads to greater reductions in CO_2, even in the presence of some CBins reverting to the baseline. [95]

18.1.4.3 Except for the decline at CSO D and at CSO G, moving across each CSO, and holding NSO constant generally shows an increase in CO_2 reduction.

18.1.4.4 Within each CSO, moving across NSOs, shows little variation in CO_2 reduction, although at NSO E there is a moderation in CO_2 reduction. This is due to minimal changes in operations, where at NSO E there is a slightly smaller decrease in operations relative to the baseline.

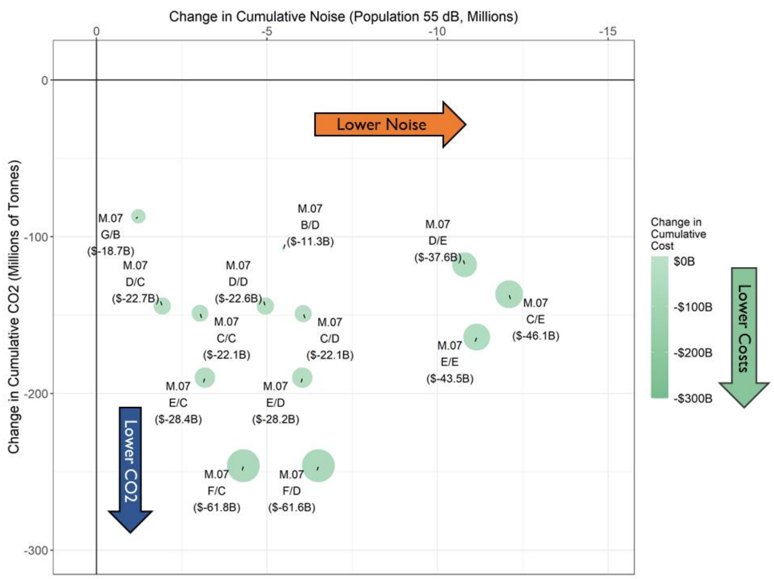

Figure 49: New Type M.07 Approach: Change in Cumulative CO_2 (in Millions of Tonnes)**, 55dB Population** (in Millions) **and Costs** (in $ Billions)

18.1.4.5 **Noise Response:** Considering CSO levels, moving across the NSOs (CSO constant) exhibits greater reductions in 55 dB area and population at each NSO (consistent with more stringent noise options). It should be noted that for scenario G\B the noise reduction is the lowest among M.07 scenarios analysed, reflecting the fact that most CBins have reverted to the baseline. Holding the NSO fixed and increasing CSO generally improves the noise outcomes, except for CSO D.

18.1.4.6 **Cost Response:** Changes in total cumulative costs tend to mirror the change in CO_2, with the variation at NSO E from the effect of TRs on the fleet and associated capital cost changes.

18.1.4.7 Figure 53 presents the M.07 values for cumulative changes relative to the baseline for costs, CO_2 and noise (population and area avoided at 55dB), with larger reductions in a metric shown by a darker colouring.

[94] Under the M.07 approach, CBin-3 reverts to the baseline in all scenarios.

[95] Cumulative results are summed from 2029 through 2050 for environmental measures. Cumulative costs are calculated from 2029 through 2050 for capital costs, fuel costs, and other DOCs. NRCs are calculated over 4 years prior to stringency implementation, which for the M.07 approach is considered to be the earliest PNGA date of a member in the aircraft family.

18.1.4.8 Overall, the largest reduction in total cumulative costs are at CSO F and along NSO E with the combined largest reduction at scenario F\C. For CO_2 emissions, the largest reductions again occur at CSO F, while the combined largest reduction is for scenario F\C and F\D. For noise, the largest reductions in population and area avoided are found at NSO E, with the largest reduction being at scenario C\E.

NT M.07 Cost Results, Cumulative (2029-2050) — Change in Cost (Billions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)					
B (99%/95%)				-$11.3	
C (99%/93%)			-$22.1	-$22.1	-$46.1
D (97%/91%)			-$22.7	-$22.6	-$37.6
E (97%/89%)			-$28.4	-$28.2	-$43.5
F (95%/87%)			-$61.8	-$61.6	
G (83%/83%)		-$18.7			

NT M.07 Environmental Results, Cumulative (2029-2050) — Change in Tonnes CO2 (Millions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)					
B (99%/95%)				-107.8	
C (99%/93%)			-148.8	-149.0	-136.7
D (97%/91%)			-144.2	-144.2	-117.8
E (97%/89%)			-189.9	-190.0	-163.9
F (95%/87%)			-246.2	-246.2	
G (83%/83%)		-86.9			

NT M.07 Environmental Results, Cumulative (2029-2050) — Change in 55 dB Population (Millions)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)					
B (99%/95%)				-5.5	
C (99%/93%)			-3.0	-6.1	-12.1
D (97%/91%)			-1.9	-4.9	-10.8
E (97%/89%)			-3.2	-6.0	-11.1
F (95%/87%)			-4.3	-6.5	
G (83%/83%)		-1.2			

NT M.07 Environmental Results, Cumulative (2029-2050) — Change in 55 dB Area (Thousands)

CSO \ NSO	A (0dB/-2dB)	B (-2dB/-4dB)	C (-2dB/-6dB)	D (-4dB/-8dB)	E (-6dB/-10dB)
A (99%/97%)					
B (99%/95%)				-2.4	
C (99%/93%)			-1.3	-2.7	-5.4
D (97%/91%)			-0.9	-2.2	-4.8
E (97%/89%)			-1.4	-2.7	-4.9
F (95%/87%)			-1.9	-2.9	
G (83%/83%)		-0.5			

Figure 50: New Type M.07: Cost and Environmental Cumulative Results

18.1.5 Ranking of Integrated Dual Stringency Results for New Type Stringency Options

18.1.5.1 Figure 54 shows the NT approach scenario ranking results by modelling approach (at a 0% discount rate). Ranks are shown for total cumulative costs, CO_2, 55dB Population, and 55 dB Area for the A1 and M.07 NT approaches.

18.1.5.2 <u>Rankings for fleet evolution modelling approach A1</u>

a) For reduction in **total cumulative cost**, the lowest net cost under A1 is achieved with scenario D\E, followed by D\C, tied with D\B, then D\D. Considering that the results in CSO D are influenced by the presence of ECBM in CBin 9, the scenarios with the next lowest net costs are scenarios C\E and B\E.

b) The largest **total cumulative CO_2 emissions reductions** are achieved for scenarios D\C and D\B (tied), followed by scenarios D\D and D\E. Beyond the CSO D exhibiting impacts from ECBM in CBin-9, the largest total cumulative CO_2 emissions reductions are achieved at CSO C (for NSOs E, followed by D and C, tied).

c) The largest **total cumulative noise reductions** (measured in population and area avoided) are achieved at NSO E (with CSO D is first, CSO C is second and CSO B third). Beyond the CSO D exhibiting impacts from ECBM in CBin-9, the largest total cumulative noise reductions are achieved with scenario C\E.

d) **Discount Rates:** the A1 results rankings for cost, CO_2 emissions or noise (population and area avoided) are generally stable when using the alternative discount rates (3%, 7% and 9%), with some limited variation for scenarios with lower rankings (lower declines in each metric). Scenarios with higher rankings (e.g., 1 through 5) are unchanged across the discount rates.

18.1.5.3 Rankings of results under fleet evolution modelling approach M.07

(a) The largest **total cumulative cost reductions** under M.07 are achieved with scenario F\C**,** followed by scenarios F\D and C\E.

(b) The largest reductions in **total cumulative CO_2**, are achieved with scenario F\C and F\D (tied), followed by scenarios E\D and E\C.

(c) The scenarios exhibiting the lowest total **cumulative noise** are C\E, E\E and D\E.

(d) **Discount Rates:** For M.07 results, there is variation in rankings for cost, which occurs across scenarios; this is due to the staggered nature of the costs under M.07 (i.e., TRs begin several years after the implementation date). This temporal variation leads to an effect on the discounted magnitude from discount rates, with NRCs, which lead fleet related cost changes also becoming more important at higher discount rates. CO_2 and noise tend to be more stable across the discounts rates, and in particular for the ones with better rankings (e.g., ranking 1 through 5).

CSO	NSO	A1 – Cumulative (2029-2050)				M.07 – Cumulative (2029-2050)			
		Cost Rank (Change in Total Costs, $B)	CO2 Rank (Change in CO2, Millions of Tonnes)	55 dB Noise Rank (Change in 55 dB Population, Millions)	55 dB Noise Rank (Change in 55 dB Area, Thousands)	Cost Rank (Change in Total Costs, $B)	CO2 Rank (Change in CO2, Millions of Tonnes)	55 dB Noise Rank (Change in 55 dB Population, Millions)	55 dB Noise Rank (Change in 55 dB Area, Thousands)
A (99%/97%)	C (-2dB/-6dB)	12 (-89.8)	12 (-207.2)	11 (-9.1)	13 (-5.0)	Not Run			
	D (-4dB/-8dB)	13 (1.0)	13 (-124.4)	6 (-19.1)	8 (-10.5)				
B (99%/95%)	B (-2dB/-4dB)	9 (-101.0)	10 (-325.7)	12 (-7.1)	11 (-5.3)				
	C (-2dB/-6dB)	9 (-101.0)	10 (-325.7)	12 (-7.1)	11 (-5.3)				
	D (-4dB/-8dB)	11 (-95.4)	8 (-357.4)	6 (-19.1)	8 (-10.5)	13 (-11.3)	12 (-107.8)	7 (-5.5)	7 (-2.4)
	E (-6dB/-10dB)	6 (-222.6)	9 (-354.8)	3 (-34.2)	3 (-16.3)	Not Run			
C (99%/93%)	C (-2dB/-6dB)	7 (-146.3)	6 (-492.6)	10 (-13.8)	10 (-8.6)	10 (-22.1)	7 (-148.8)	11 (-3.0)	11 (-1.3)
	D (-4dB/-8dB)	8 (-142.7)	6 (-492.6)	5 (-22.3)	5 (-11.9)	10 (-22.1)	6 (-149.0)	5 (-6.1)	5 (-2.7)
	E (-6dB/-10dB)	5 (-290.5)	5 (-528.1)	2 (-36.9)	2 (-17.5)	3 (-46.1)	10 (-136.7)	1 (-12.1)	1 (-5.4)
D (97%/91%)	B (-2dB/-4dB)	2 (-785.1)	1 (-1289.7)	9 (-17.1)	7 (-10.8)	Not Run			
	C (-2dB/-6dB)	2 (-785.1)	1 (-1289.7)	8 (-17.4)	6 (-10.9)	8 (-22.7)	8 (-144.2)	12 (-1.9)	12 (-0.9)
	D (-4dB/-8dB)	4 (-780.1)	3 (-1287.1)	4 (-26.0)	4 (-14.2)	9 (-22.6)	8 (-144.2)	8 (-4.9)	8 (-2.2)
	E (-6dB/-10dB)	1 (-858.6)	4 (-1210.0)	1 (-43.4)	1 (-20.8)	5 (-37.6)	11 (-117.8)	3 (-10.8)	3 (-4.8)
E (97%/89%)	C (-2dB/-6dB)	Outside of A1 Analytical Space				6 (-28.4)	4 (-189.9)	10 (-3.2)	10 (-1.4)
	D (-4dB/-8dB)					7 (-28.2)	3 (-190.0)	6 (-6.0)	5 (-2.7)
	E (-6dB/-10dB)					4 (-43.5)	5 (-163.9)	2 (-11.1)	2 (-4.9)
F (95%/87%)	C (-2dB/-6dB)					1 (-61.8)	1 (-246.2)	9 (-4.3)	9 (-1.9)
	D (-4dB/-8dB)					2 (-61.6)	1 (-246.2)	4 (-6.5)	4 (-2.9)
G (83%/83%)	B (-2dB/-4dB)					12 (-18.7)	13 (-86.9)	13 (-1.2)	13 (-0.5)

Figure 51: NT approach A1 and M.07 - Scenario ranking for cumulative cost and environmental results

18.2 The intention of the discount ranking tables is to show whether applying discount rates affects scenario rankings and so absolute values are not presented.

CSO	NSO	A1 – Cumulative (2029-2050)								M.07 – Cumulative (2029-2050)							
		Cost Rank				CO2 Rank				Cost Rank				CO2 Rank			
Discount Rate		0%	3%	7%	9%	0%	3%	7%	9%	0%	3%	7%	9%	0%	3%	7%	9%
A (99%/97%)	C (-2dB/-6dB)	12	11	9	9	12	12	12	12	Not Run							
	D (-4dB/-8dB)	13	13	13	13	13	13	13	13								
B (99%/95%)	B (-2dB/-4dB)	9	9	10	10	10	10	10	10								
	C (-2dB/-6dB)	9	9	10	10	10	10	10	10								
	D (-4dB/-8dB)	11	12	12	12	8	8	8	8	13	13	13	13	12	12	12	12
	E (-6dB/-10dB)	6	6	6	6	9	9	9	9	Not Run							
C (99%/93%)	C (-2dB/-6dB)	7	7	7	7	6	6	6	6	10	10	10	9	7	7	7	6
	D (-4dB/-8dB)	8	8	8	7	6	6	6	6	10	9	8	8	6	6	6	6
	E (-6dB/-10dB)	5	5	5	5	5	5	5	5	3	3	2	2	10	10	10	10
D (97%/91%)	B (-2dB/-4dB)	2	2	2	2	1	1	1	1	Not Run							
	C (-2dB/-6dB)	2	2	2	2	1	1	1	1	8	12	12	12	8	8	8	8
	D (-4dB/-8dB)	4	4	4	4	3	3	3	3	9	11	11	9	8	8	8	8
	E (-6dB/-10dB)	1	1	1	1	4	4	4	4	5	5	6	6	11	11	11	11
E (97%/89%)	C (-2dB/-6dB)	Outside of A1 Analytical Space								6	7	9	9	4	3	3	3
	D (-4dB/-8dB)									7	6	7	7	3	3	3	3
	E (-6dB/-10dB)									4	4	4	4	5	5	5	5
F (95%/87%)	C (-2dB/-6dB)									1	2	3	5	1	1	1	1
	D (-4dB/-8dB)									2	1	1	3	1	1	1	1
G (83%/83%)	B (-2dB/-4dB)									12	8	5	1	13	13	13	13

Figure 52: Scenario Rank by Discount Rate by NT Approach for Cumulative Cost and CO_2 Emissions

CSO	NSO	A1 – Cumulative (2029-2050)								M.07 – Cumulative (2029-2050)							
		Noise 55dB Population Rank				Noise 55dB Area Rank				Noise 55dB Population Rank				Noise 55dB Area Rank			
Discount Rate		0%	3%	7%	9%	0%	3%	7%	9%	0%	3%	7%	9%	0%	3%	7%	9%
A (99%/97%)	C (-2dB/-6dB)	11	11	11	11	13	13	11	11	Not Run							
	D (-4dB/-8dB)	6	6	6	6	8	8	8	6								
B (99%/95%)	B (-2dB/-4dB)	12	13	13	13	11	11	11	11								
	C (-2dB/-6dB)	13	12	12	12	11	11	11	11								
	D (-4dB/-8dB)	7	7	7	7	8	9	8	6	7	7	7	6	7	7	5	5
	E (-6dB/-10dB)	3	3	3	3	3	3	3	3	Not Run							
C (99%/93%)	C (-2dB/-6dB)	10	10	10	10	10	10	10	10	11	11	10	10	11	10	10	10
	D (-4dB/-8dB)	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5
	E (-6dB/-10dB)	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1
D (97%/91%)	B (-2dB/-4dB)	9	9	9	9	7	7	6	6	Not Run							
	C (-2dB/-6dB)	8	8	8	8	6	6	6	6	12	12	12	12	12	12	12	12
	D (-4dB/-8dB)	4	4	4	4	4	4	4	4	8	8	8	8	8	8	8	8
	E (-6dB/-10dB)	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	2
E (97%/89%)	C (-2dB/-6dB)	Outside of A1 Analytical Space								10	10	10	10	10	10	10	10
	D (-4dB/-8dB)									6	5	5	6	5	5	5	5
	E (-6dB/-10dB)									2	2	2	2	2	2	2	2
F (95%/87%)	C (-2dB/-6dB)									9	9	9	9	9	9	9	8
	D (-4dB/-8dB)									4	4	4	4	4	4	4	4
G (83%/83%)	B (-2dB/-4dB)									13	13	13	13	13	13	13	12

Figure 53: Scenario Rank by Discount Rate by NT Approach for Noise Results

18.3 Considerations on Interpolation for Intermediate Stringency Options

18.3.1 Introduction

18.3.1.1 The CAEP/13 IDS analysis is based on the analytical space as defined and agreed at the SG 2 in 2023. This includes a total of 26 scenarios for NT CO_2 and Noise standards, and six scenarios for an In-Production (InP) standard (CO_2 TRs only).

18.3.1.2 Following direction from CAEP Members, MDG/FESG developed, and implemented, an interpolation approach for estimating cost (and environmental) results in the spaces in between the modelled scenarios (NT standard only), and provided a narrative to assist discussions at CAEP/13.

18.3.2 Interpolation Approach

18.3.2.1 The first step in developing the interpolation results requires defining the possible working space for these estimations. Two adjacent scenarios are required for interpolation within a CSO or NSO, while interpolating results between both a CSO and NSO requires four adjacent scenarios (see Figure 57 for an A1 interpolation example). As noted previously, interpolation is only done for the NT standard and separately for both modelling approaches (i.e., A1 and M.07 interpolation is conducted separately). Interpolated scenarios for CSO, NSO, or both are denoted using "+" (e.g., for A1, CSO-B+ is interpolated between CSO-B and CSO-C, NSO-C+ is interpolated between NSO-C and NSO-D, and B+/C+ is interpolated between the four scenarios B/C, C/C, B/D, and C/D).

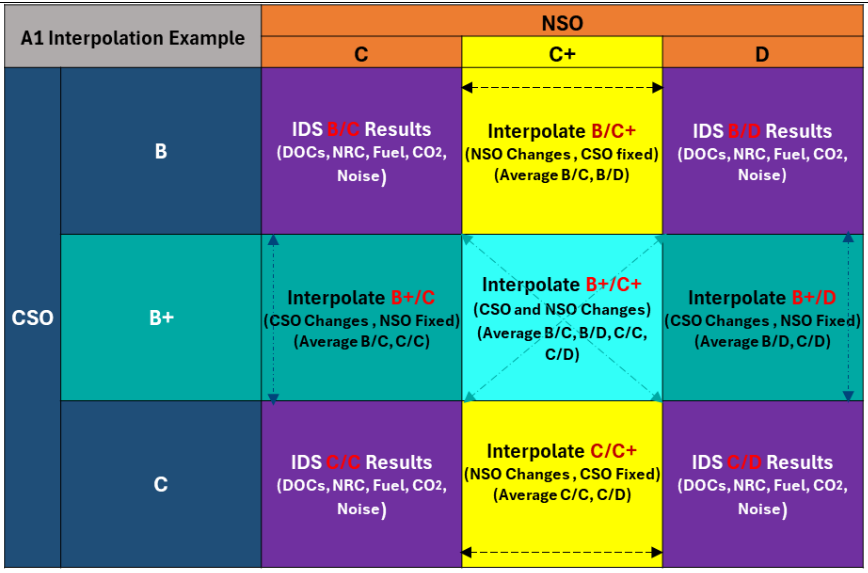

Figure 54: Interpolation Approach from Results based on A1 Approach

18.3.2.2 A linear interpolation is used to approximate the midpoint between scenarios, and is done for each analysis element (e.g., DOCs, NRCs, Fuel Costs, CO_2, Noise[96]) at the aggregate level using cumulative results.[97] Only modelled data from the MA is used for interpolation; no additional data or information (e.g., TRs) is used in the interpolation process.

18.3.2.3 For spaces shown with a red outline in each figure, additional narrative is provided in the following sections for the A1 and M.07 approaches, respectively, as those spaces show where interpolation results are substantially influenced by modelling assumptions (e.g., A1 results with empty CBin management (ECBM) changes between scenarios or M.07 reverting to baseline).The A1 interpolation working space is shown in Figure 54, and the M.07 working space is shown in Figure 58.

18.3.2.4 The A1 interpolation space, shown in Figure 57, includes 22 total interpolation spaces as follows:

- Eight CSO interpolation spaces, which are between two CSOs at a fixed NSO level (e.g., A+/C, B+/D)
- Nine NSO interpolation spaces, which are between two NSOs at a fixed CSO level (e.g., A/C+, B/B+)
- Five combined CSO and NSO spaces (e.g., B+/C+, C+/D+).

18.3.2.5 The red outlined area at CSO-C+ and CSO-D denotes significant ECBM impacts under A1 assumptions with increasing CSO levels.

[96] Noise interpolation is conducted for 55dB Area and 55dB Population separately.
[97] Interpolation is only conducted for primary results.

Figure 55: Interpolation Space for A1 Approach

18.3.2.6 The M.07 interpolation space, shown in Figure 59, includes 21 total interpolation spaces as follows:

- Nine CSO interpolation spaces, which are between two CSOs at a fixed NSO level (e.g., B+/D, C+/E)
- Seven NSO interpolation spaces, which are between two NSOs at a fixed CSO level (e.g., C/C+, D/D+)
- Five combined CSO and NSO spaces (e.g., C+/C+, D+/D+).

18.3.2.7 The red outlined area at CSO-C+, CSO-D, CSO-D+, CSO-E, CSO-E+, CSO-F and CSO-G denotes where CBins begin shifting back to the baseline under M.07 assumptions with increasing CSO levels.

CSO		NSO	A	A+	B	B+	C	C+	D	D+	E
		Small a/c	0 dB	-1 dB	-2 dB	-2 dB	-2 dB	-3 dB	-4 dB	-5 dB	-6 dB
		Large a/c	-2 dB	-3 dB	-4 dB	-5 dB	-6 dB	-7 dB	-8 dB	-9 dB	-10 dB
Small a/c	Large a/c										
99%	97%	A									
99%	96%	A+									
99%	95%	B							M.07		
99%	94%	B+							M.07 CO_2 Int. Space		
99%	93%	C					M.07	M.07 Noise Int. Space	M.07	M.07 Noise Int. Space	M.07
98%	92%	C+					M.07 CO_2 Int. Space	Combined Int	M.07 CO_2 Int. Space	Combined Int	M.07 CO_2 Int. Space
97%	91%	D					M.07	M.07 Noise Int. Space	M.07	M.07 Noise Int. Space	M.07
97%	90%	D+					M.07 CO_2 Int. Space	Combined Int	M.07 CO_2 Int. Space	Combined Int	M.07 CO_2 Int. Space
97%	89%	E					M.07	M.07 Noise Int. Space	M.07	M.07 Noise Int. Space	M.07
96%	88%	E+					M.07 CO_2 Int. Space	Combined Int	M.07 CO_2 Int. Space		
95%	87%	F					M.07	M.07 Noise Int. Space	M.07		
83%	83%	G			M.07						

Figure 56: Interpolation Space for M.07 Approach

18.3.3 Interpolation Results Interpretation Overview

18.3.3.1 Interpolated results using linear interpolation for cost and environmental results were assessed. While interpolation results do not incorporate extended TR data, the OEM-provided extended TR data can be used for additional context regarding where the linear interpolation approach may be a reasonable approximation of results for in-between unmodeled scenarios.

18.3.3.1.1 Given the additional TR information, Figure 60 below provides a guide showing where in the IDS analysis matrix linear interpolation is deemed to be a reasonable representation of expected cost and environmental results for the in-between unmodeled areas. Modelled results are shown in purple for NT A1 and pink for M.07 (overlap in A1 and M.07 analysis space is shown using split shading) and represent the outcome of the MA runs.

18.3.3.1.2 Any scenario within the red box is impacted by modelling assumptions—under approach A1 this is from ECBM assumptions or under approach M.07 from reversion to baseline assumptions.

18.3.3.1.3 Linear interpolation was examined within the context of the extended TR data in order to determine whether the interpolated results are likely representative of the outcome in the intermediate interpolation scenarios considered. The interpolation scenarios are shaded green, yellow, or orange in terms of confidence in results based on a review of implied fleet mixes (from the extended TR data), and whether they would result in unmodeled interpolation scenarios. As noted above, no additional modelling was conducted.

- Green spaces (i.e., CSO B\NSO B+ and CSO D\NSO B+) indicate where it is reasonable to ***consider linear interpolation***.

- Yellow spaces (e.g., CSO B\NSO D+, CSO A+\NSO D, and CSO D\NSO C+), indicate where ***linear interpolation should be considered with caution***, as linear interpolation is likely not representative of implied fleet evolution impacts from extended TR data.

- Orange spaces (e.g., CSO A\NSO C+, CSO C+\NSO C, and CSO D+\NSO E) indicate where ***linear interpolation should be considered with extreme caution***, as there is insufficient information from extended TR data to determine reasonableness of linear interpolation.

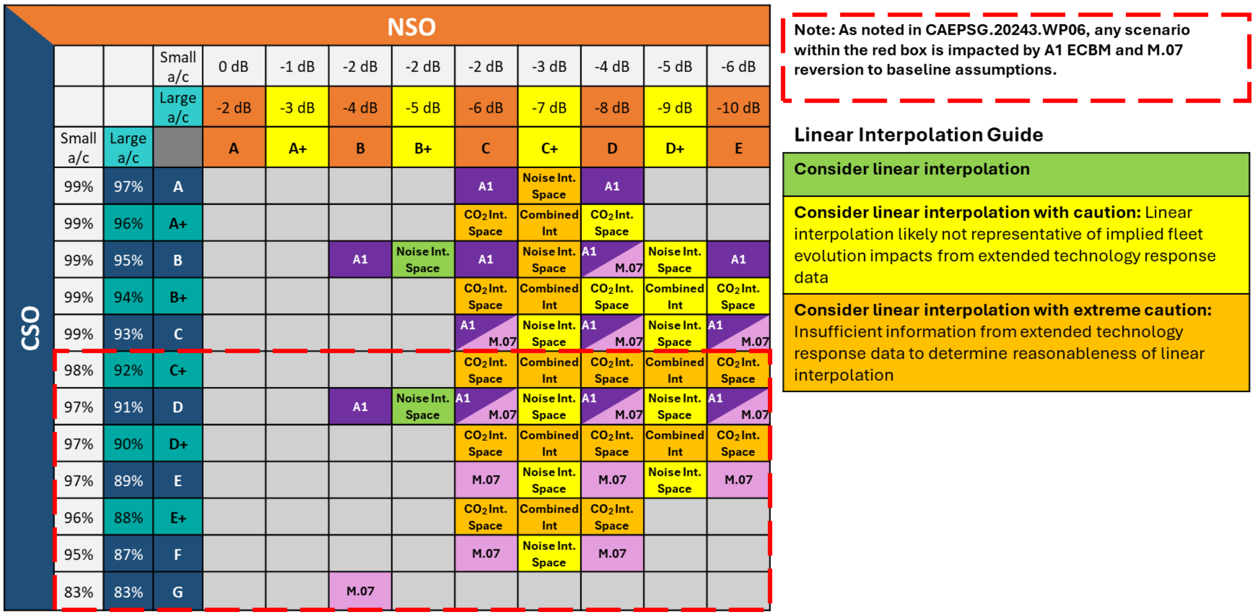

Figure 57. NT Interpolation Matrix with Linear Interpolation Guide

18.4 NT A1 Interpolated Results

18.4.1 Figure 61 shows the interpolated cost results for the NT A1 approach. Interpolated results are incorporated into the existing agreed-upon formats for cost results presentation. Modelled IDS results are differentiated from interpolated results using colour shading.

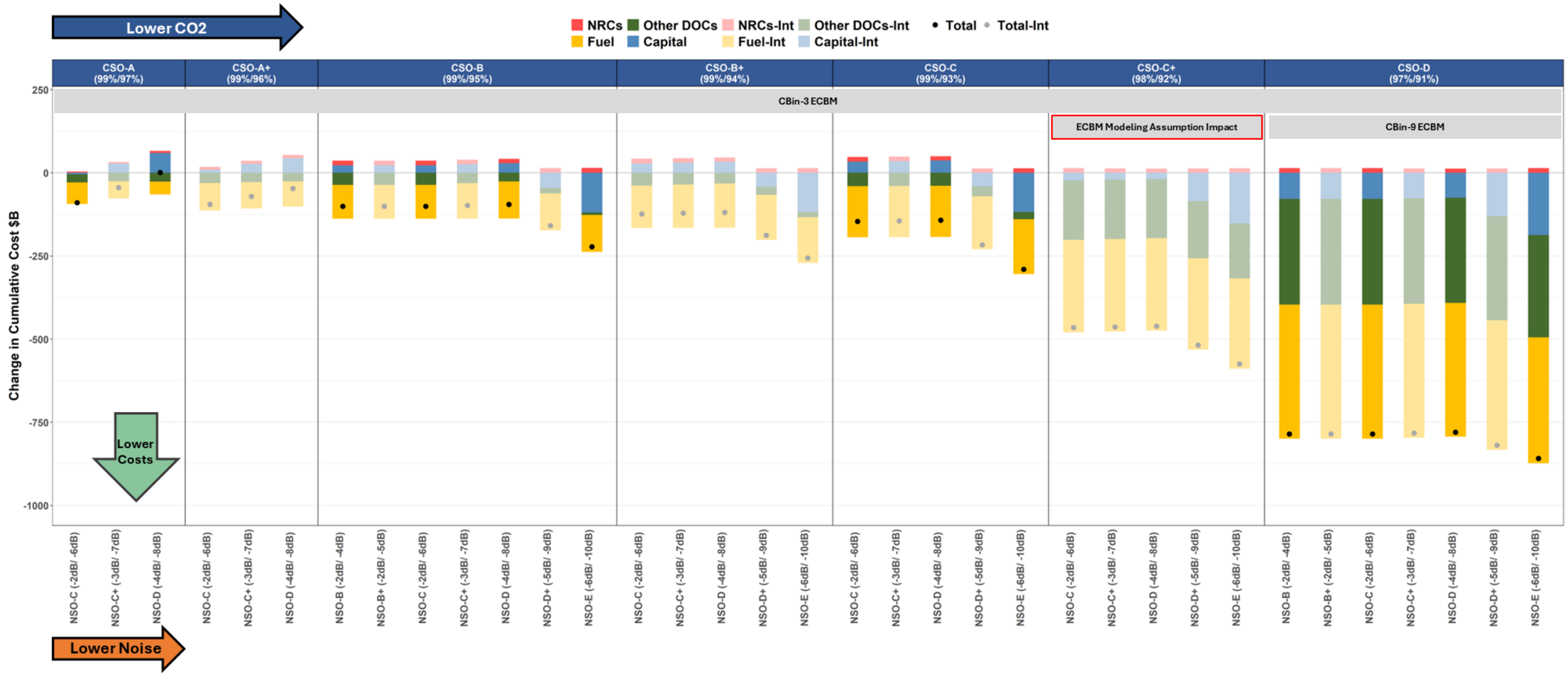

Figure 58: NT A1 Cost Result Interpolation

18.4.2 Figure 62 shows the change in CO_2 on the Y axis, the change in noise (55 dB population avoided) on the X axis and the change in total cost represented by the size of each dot in the scatter plot (larger circles represent a larger change in costs relative to the baseline).

18.4.3 Colours indicate the type of results presented, where purple circles are A1 modelled results as presented above and grey circles are interpolated results. The calculated interpolated results follow a linear trend between the modelled results. For example, B\C+ is the midpoint of B\C and B/D; B+\C is the midpoint of B\C and C\C; and B+\C+ is the average of B\C, B\D, C\C, and C\D for each of the metrics shown.

18.4.4 The interpolated results for the A1 approach fit within the CO_2, noise, and cost reduction trends by CSO and NSO as defined by the modelled IDS results. Interpolated results do not extrapolate beyond previously presented results above and follow the pattern of linear interpolation between relevant scenarios.

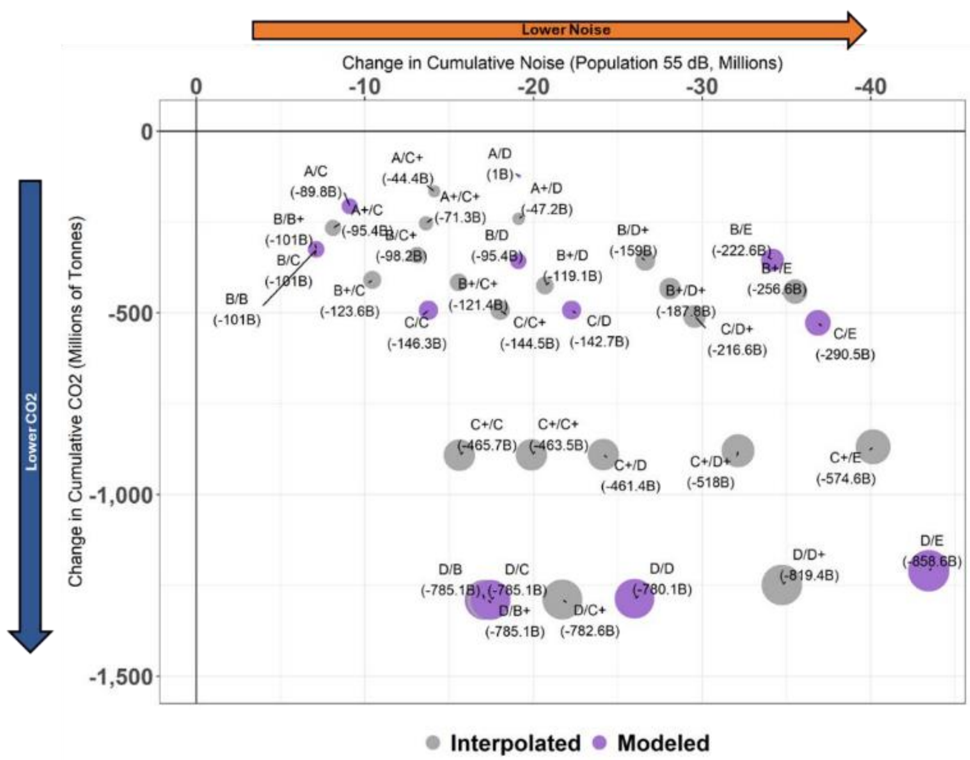

Figure 59: Change in Cumulative CO_2 (Millions of Tonnes), 55 dB Population (Millions) and Costs ($Billions) - NT A1 Approach with Interpolated Results

18.4.5 Figure 63 presents the values for cumulative changes relative to the baseline for costs, CO_2 and noise (population and area avoided at 55 dB), with larger reductions in a metric show by a darker colouring for modelled results. Interpolated results are shaded grey.

18.4.6 As interpolation does not extrapolate beyond the existing cost, CO_2, and noise responses, the smallest and largest changes relative to the baseline remain the same as presented above.

NT A1 Cost Results, Cumulative (2029-2050) — Change in Cost (Billions $)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)					-89.8	-44.4	1.0		
A+ (99%/96%)					-95.4	-71.3	-47.2		
B (99%/95%)			-101.0	-101.0	-101.0	-98.2	-95.4	-159.0	-222.6
B+ (99%/94%)					-123.6	-121.4	-119.1	-187.8	-256.6
C (99%/93%)					-146.3	-144.5	-142.7	-216.6	-290.5
C+ (98%/92%)					-465.7	-463.5	-461.4	-518.0	-574.6
D (97%/91%)			-785.1	-785.1	-785.1	-782.6	-780.1	-819.4	-858.6
D+ (97%/90%)	Outside of A1 Analytical Space								
E (97%/89%)									
E+ (96%/88%)									
F (95%/87%)									
G (83%/83%)									

NT A1 Cost Results, Cumulative (2029-2050) — Change in Tonnes CO2 (Millions)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)					-207.2	-165.8	-124.4		
A+ (99%/96%)					-266.5	-253.7	-240.9		
B (99%/95%)			-325.7	-325.7	-325.7	-341.6	-357.4	-356.1	-354.8
B+ (99%/94%)					-409.1	-417.1	-425.0	-433.2	-441.4
C (99%/93%)					-492.6	-492.6	-492.6	-510.3	-528.1
C+ (98%/92%)					-891.2	-890.5	-889.8	-879.4	-869.0
D (97%/91%)			-1289.7	-1289.7	-1289.7	-1288.4	-1287.1	-1248.6	-1210.0
D+ (97%/90%)	Outside of A1 Analytical Space								
E (97%/89%)									
E+ (96%/88%)									
F (95%/87%)									
G (83%/83%)									

NT A1 Cost Results, Cumulative (2029-2050) — Change in 55 dB Population (Millions)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)					-9.1	-14.1	-19.1		
A+ (99%/96%)					-8.1	-13.6	-19.1		
B (99%/95%)			-7.1	-7.1	-7.1	-13.1	-19.1	-26.6	-34.2
B+ (99%/94%)					-10.4	-15.6	-20.7	-28.1	-35.5
C (99%/93%)					-13.8	-18.0	-22.3	-29.6	-36.9
C+ (98%/92%)					-15.6	-19.9	-24.1	-32.1	-40.1
D (97%/91%)			-17.1	-17.3	-17.4	-21.7	-26.0	-34.7	-43.4
D+ (97%/90%)	Outside of A1 Analytical Space								
E (97%/89%)									
E+ (96%/88%)									
F (95%/87%)									
G (83%/83%)									

NT A1 Cost Results, Cumulative (2029-2050) — Change in 55 dB Area (Thousands)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)					-5.0	-7.7	-10.5		
A+ (99%/96%)					-5.1	-7.8	-10.5		
B (99%/95%)			-5.3	-5.3	-5.3	-7.9	-10.5	-13.4	-16.3
B+ (99%/94%)					-6.9	-9.1	-11.2	-14.0	-16.9
C (99%/93%)					-8.6	-10.2	-11.9	-14.7	-17.5
C+ (98%/92%)					-9.7	-11.4	-13.1	-16.1	-19.2
D (97%/91%)			-10.8	-10.8	-10.9	-12.6	-14.2	-17.5	-20.8
D+ (97%/90%)	Outside of A1 Analytical Space								
E (97%/89%)									
E+ (96%/88%)									
F (95%/87%)									
G (83%/83%)									

Figure 60: NT A1 Cost and Environmental Cumulative Results with Interpolation

18.5 NT M.07 Interpolated Results

18.5.1 Figure 64 shows the interpolated cost results for the NT M.07 approach. Interpolated results are incorporated into the existing agreed-upon formats for cost results presentation. Modelled results are differentiated from interpolated results using colour shading.

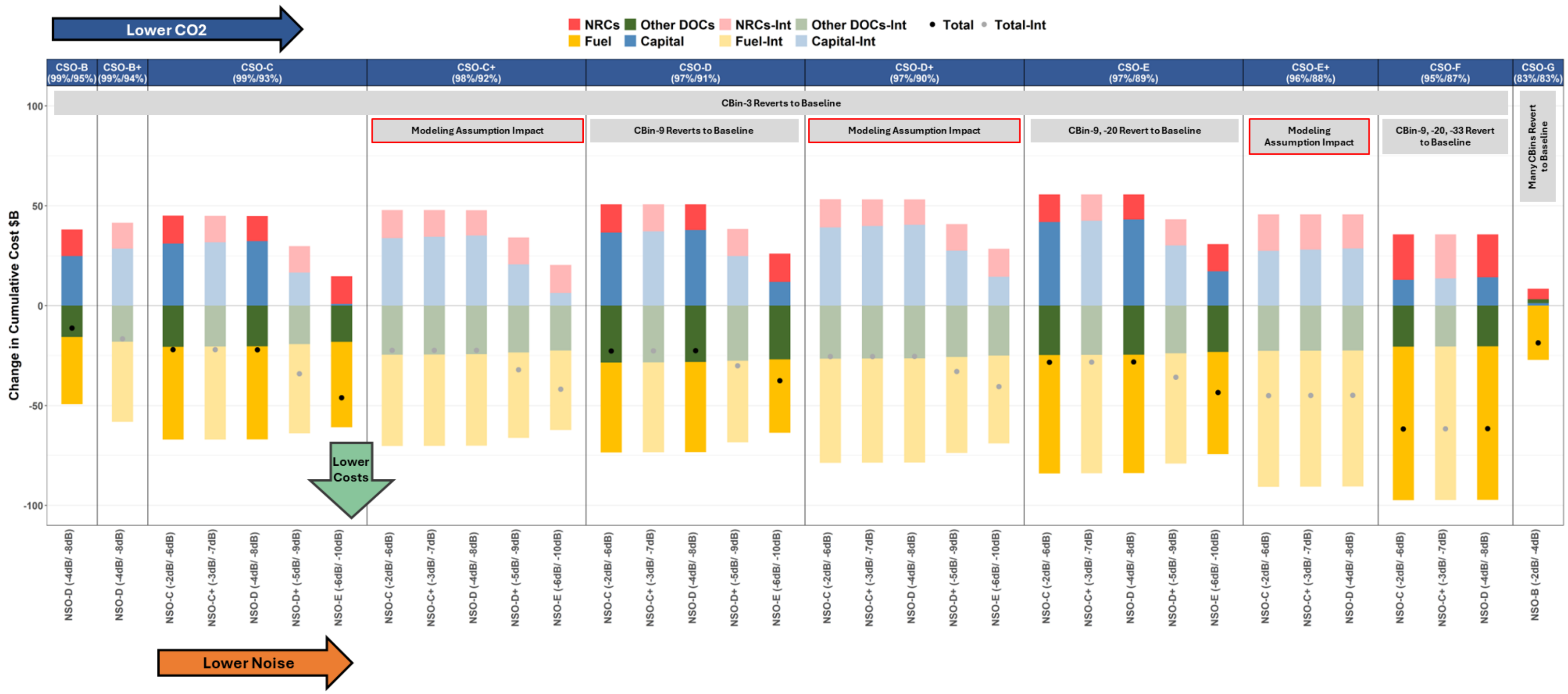

Figure 61: NT M.07 Cost Result Interpolation

18.5.2 For each scenario run using M.07, results show the cumulative change from 2029 through 2050 relative to the baseline. Results are presented using a scatter plot format and then a set of matrices present the change in each metric. When reviewing M.07 results it is important to note that the analytical space is not the same as run for A1.

18.5.3 Figure 65 presents the change relative to the baseline for total cumulative costs, total cumulative CO2 and total cumulative noise (55 dB population and area avoided) for approach M.07 with the change in CO2 on the Y axis, the change in noise (55 dB population avoided) on the X axis and the change in total cost represented by the size of each dot in the scatter plot (larger dots represent a larger change in costs relative to the baseline).

18.5.4 Colours indicate the type of results presented, where pink circles are M.07 modelled results as presented in the section above, and grey circles are interpolated results. Calculation of interpolated results follows linear interpolated results for the midpoint scenarios between modelled results where possible. For example, C\C+ is the midpoint of C\C and C\D; C+\C is the midpoint of C\C and D\C; and C+\C+ is the average of C\C, C\D, D\C, and D\D for each of the metrics shown.

18.5.5 The interpolated results for the M.07 approach fit within the CO2, noise, and cost reduction trends by CSO and NSO as defined by the modelled IDS results. Interpolated results do not extrapolate beyond previously presented results above and follow the pattern of linear interpolation between relevant scenarios.

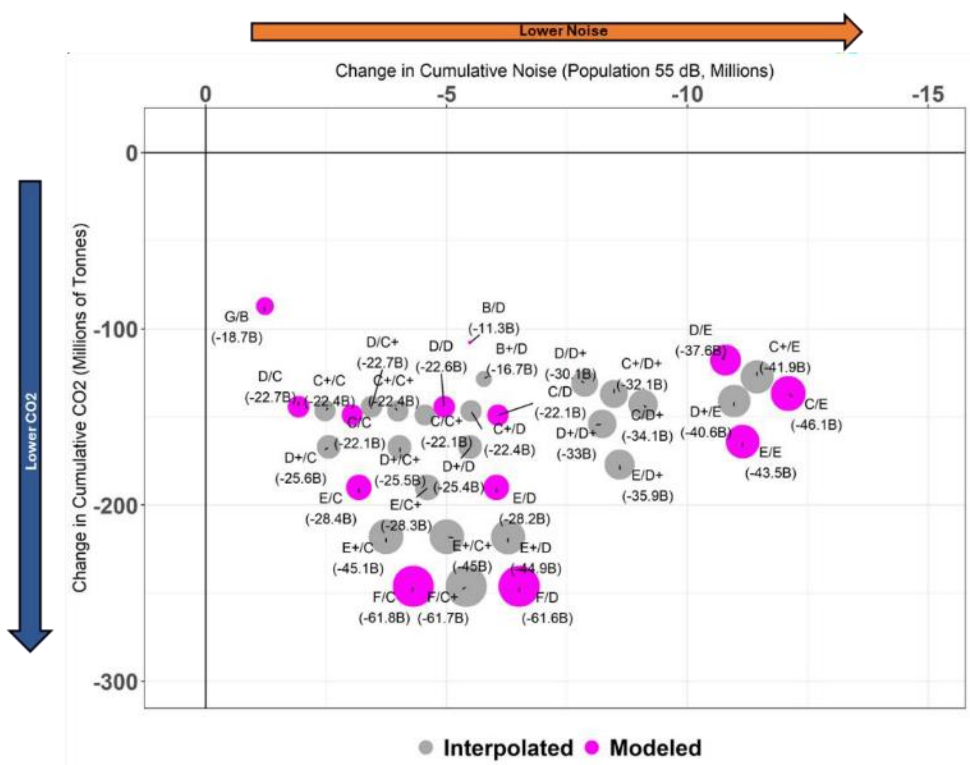

Figure 62: Change in Cumulative CO_2 (Millions of Tonnes), 55 dB Population (Millions) and Costs ($Billions) – NT M.07 Approach with Interpolation

18.5.6 Figure 66 presents the M.07 values for cumulative changes relative to the baseline for costs, CO2 and noise (population and area avoided at 55 dB), with larger reductions in a metric show by a darker colouring for modelled results. Interpolated results are shaded grey.

18.5.7 As interpolation does not extrapolate beyond the existing cost, CO2, and noise responses, the smallest and largest changes relative to the baseline as shown in Chapter 19.

NT M.07 Cost Results, Cumulative (2029-2050)									
Change in Cost (Billions $)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)									
A+ (99%/96%)									
B (99%/95%)							-11.3		
B+ (99%/94%)							-16.7		
C (99%/93%)					-22.1	-22.1	-22.1	-34.1	-46.1
C+ (98%/92%)					-22.4	-22.4	-22.4	-32.1	-41.9
D (97%/91%)					-22.7	-22.7	-22.6	-30.1	-37.6
D+ (97%/90%)					-25.6	-25.5	-25.4	-33.0	-40.6
E (97%/89%)					-28.4	-28.3	-28.2	-35.9	-43.5
E+ (96%/88%)					-45.1	-45.0	-44.9		
F (95%/87%)					-61.8	-61.7	-61.6		
G (83%/83%)			-18.7						

NT M.07 Cost Results, Cumulative (2029-2050)									
Change in Tonnes CO2 (Millions)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)									
A+ (99%/96%)									
B (99%/95%)							-107.8		
B+ (99%/94%)							-128.4		
C (99%/93%)					-148.8	-148.9	-149.0	-142.9	-136.7
C+ (98%/92%)					-146.5	-146.5	-146.6	-136.9	-127.3
D (97%/91%)					-144.2	-144.2	-144.2	-131.0	-117.8
D+ (97%/90%)					-167.1	-167.1	-167.1	-154.0	-140.9
E (97%/89%)					-189.9	-190.0	-190.0	-176.9	-163.9
E+ (96%/88%)					-218.0	-218.1	-218.1		
F (95%/87%)					-246.2	-246.2	-246.2		
G (83%/83%)			-86.9						

NT M.07 Cost Results, Cumulative (2029-2050)									
Change in 55 dB Population (Millions)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)									
A+ (99%/96%)									
B (99%/95%)							-5.5		
B+ (99%/94%)							-5.8		
C (99%/93%)					-3.0	-4.5	-6.1	-9.1	-12.1
C+ (98%/92%)					-2.5	-4.0	-5.5	-8.5	-11.4
D (97%/91%)					-1.9	-3.4	-4.9	-7.9	-10.8
D+ (97%/90%)					-2.5	-4.0	-5.5	-8.2	-11.0
E (97%/89%)					-3.2	-4.6	-6.0	-8.6	-11.1
E+ (96%/88%)					-3.7	-5.0	-6.3		
F (95%/87%)					-4.3	-5.4	-6.5		
G (83%/83%)			-1.2						

NT M.07 Cost Results, Cumulative (2029-2050)									
Change in 55 dB Area (Thousands)									
CSO \ NSO	A (0dB/-2dB)	A+ (-1dB/-3dB)	B (-2dB/-4dB)	B+ (-2dB/-5dB)	C (-2dB/-6dB)	C+ (-3dB/-7dB)	D (-4dB/-8dB)	D+ (-5dB/-9dB)	E (-6dB/-10dB)
A (99%/97%)									
A+ (99%/96%)									
B (99%/95%)							-2.4		
B+ (99%/94%)							-2.6		
C (99%/93%)					-1.3	-2.0	-2.7	-4.0	-5.4
C+ (98%/92%)					-1.1	-1.8	-2.4	-3.8	-5.1
D (97%/91%)					-0.9	-1.5	-2.2	-3.5	-4.8
D+ (97%/90%)					-1.1	-1.8	-2.4	-3.7	-4.9
E (97%/89%)					-1.4	-2.0	-2.7	-3.8	-4.9
E+ (96%/88%)					-1.7	-2.2	-2.8		
F (95%/87%)					-1.9	-2.4	-2.9		
G (83%/83%)			-0.5						

Figure 63: NT M.07 Cost and Environmental Cumulative Results with Interpolation

19. MAIN ANALYSIS (TECHNOLOGY) RESULTS (INP): PASS AND FIX RATES OF AEROPLANES IN THE GROWTH AND REPLACEMENT DATABASE

19.1 The pass & fix rates of InP aeroplanes in the MA GRdb with respect to the InP CSOs, after TR ("pass+fix"), are summarized in the table below. Unlike for the NT SOs, OEMs whose aeroplanes would not be able to meet the stated limits would be forced to stop production of those aeroplanes by 2035.

Table 24. Percentage of aeroplanes that can remain in production from 2035

InP CO_2 SO	Percentage of aeroplanes that can remain in production from 2035						
	All (92)	Regional aeroplanes (11)	Narrow bodies (25)	Wide bodies (15)	Light BJs (12)	Med+ Large BJs (17)	Corporate BJs (12)
A (102%/100%)	98%	82%	100%	100%	100%	100%	100%
A* (100%/100%)	97%	82%	100%	100%	100%	94%	100%
B (102%/98%)	98%	82%	100%	100%	100%	100%	100%
C (100%/95%)	80%	82%	72%	73%	100%	94%	67%
D (98%/93%)	65%	73%	48%	47%	100%	94%	42%
D+ (98%/93%)	75%	73%	72%	53%	100%	100%	50%

19.2 It is worth noting that one CBin, CBin-3 (smaller RJs), fails InP SOs D and D+.

20. MAIN ANALYSIS (MODELLING) RESULTS (INP): FLEET EVOLUTION

20.1 InP Approach A1 – Fleet Wide Results

20.1.1 This section contains the full set of InP scenario A1 Fleet-Builder results, showing operation changes in percentage terms relative to the baseline at the total and market level.[98]

20.1.2 Considering the full set of InP A1 runs, the fleet evolution results show decreases in operations in all scenarios (Figure 67 and Figure 68). Differences in 2050 operations, relative to the baseline, in scenarios A, A*, and B are driven by changes in the RJ market (Figure 67), while for C and D, there are also changes in operations in the NB and WB markets.

Figure 64: Total Operations Delta to Baseline by InP A1 Scenario (FB)

20.1.3 In the RJ market, there is a 1.9% decrease in 2050 operations for scenarios A, A*, B and C, and a larger change is seen under D and D+, and a smaller decrease of 0.05% under D+.[9 9] In the Narrow Body Market, there is a 0.3% decrease in operations under C and a 0.4% decrease in operations under D[100]. In the Wide Body market, there is a 0.2% increase in operations under C and a 0.4% decrease in operations under D and a larger decrease of 0.8% at D+.[101]

[98] There are no changes in operations relative to the baseline in the turbo prop market of aeroplanes with less than 19 seats, TP, TP Freighter, WB Freighter or Business Jet markets.

[99] There is no change in operations in CBin 3 for all InP A1 stringencies aside from InP D, under which ECBM occurs. In CBin- 4, one aircraft fails the stringency at all InP A1 stringencies, increasing capacity to 96, compared to 92 in the baseline.

[100] There are no changes in operations in CBin-5. In CBin-6 no aircraft fail at InP A, InP A*, or InP B and at InP C, one aircraft fails, decreasing capacity to 138, and at InP D, six aircraft fail, increasing capacity to 144, compared to 140 in the baseline while at InP D+ three aircraft fail, decreasing average capacity to 138.5. In CBin 7, at InP D and InP D+, one aircraft fails, decreasing capacity to 165 from 167 in the baseline and no aircraft fail at other InP stringency levels. In CBin-8 no aircraft fail at InP A, InP A*, or InP B. At InP C and InP D, six aircraft fail, increasing capacity to 200 from 199 in the baseline. At InP D+, three aircraft fail, increasing average capacity relative to the baseline by a smaller amount to 199.5.

[101] In CBin 9 no aircraft fail at InP A, InP A*, or InP B. For InP C, one aircraft fails, increasing average capacity to 267 from 265 in the baseline, and at InP D and InP D+, three aircraft fail, also increasing average capacity to 267. In CBin 10 no aircraft fail at InP A, InP A*, or InP B. For InP C, two aircraft fail, decreasing average capacity to 339 from 345 in the baseline, at InP D, three aircraft fail, increasing average capacity to 347 and at InP D+, two aircraft fail average increasing capacity to 352. In CBin 11 no aircraft fail at InP A, InP A*, InP B or InP C. For InP D and InP D+, one aircraft fails, decreasing average capacity to 421 from 434 in the baseline.

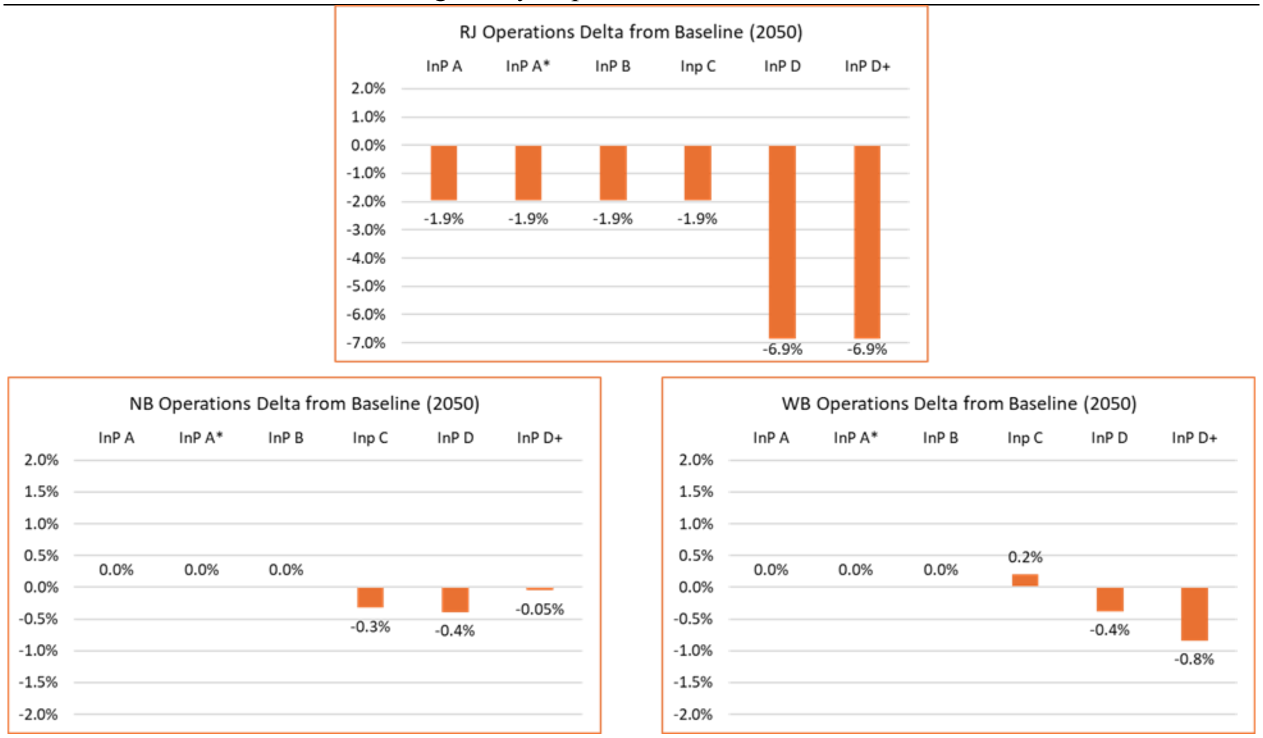

Figure 65: Total changes in operations compared to the baseline by market for CO_2 InP stringency options modelled using the A1 approach (Fleet Builder tool)

21. MAIN ANALYSIS (MODELLING) RESULTS (INP): CO_2 EMISSIONS (INCLUDING NOx TRADE-OFFS) RESULTS

21.1 Introduction

21.1.1 Using the results of the fleet evolution modelling as summarized and reported in the section above, CO_2 emissions (including NOx trade-offs) were estimated for 6 scenarios for an In-Production (InP) standard (CO_2 TRs only). See Figure 28 for details on the set of scenarios analysed.

21.2 Modelling Input and Scenarios

21.2.1 For the purpose of CO_2 emissions (including NOx trade-offs) modelling, TRs for each SO were derived from the MA GRdb13 (v3.5). Fuel burn, and NOx adjustments were provided by OEMs.

21.2.2 The following default MDG GHG modelling assumptions were used:

a) standard day sea level airport with 8 knots headwind during take-off,

b) all engines used for taxi,

c) full power take-off, and

d) 60 percent relative humidity.

21.2.3 The CAEP WG2 provided horizontal and vertical flight inefficiency factors. This same factors from the CAEP/12 Long Term Aspirational Goal (LTAG) Taks Group analysis were used and applied to full flight fuel burn and full flight NOx.

21.2.4 In addition, the latest SAE AIR 8035 recommendation were applied to the taxi fuel burn. This recommendation reduces the fuel flow from Engine Emissions Data bank and used for calculating taxi fuel burn by 20%. Only taxi fuel burn is reduced, and the taxi mode emissions indices (EI) are unaffected.

21.3 Interpretation of CO_2 emissions (including NOx trade-offs) Results

21.3.1 The consensus results used to report results of the IDS analyses are based on the AEDT tool.

21.3.2 As shown in Figure 69, and Figure 70 below, CO_2 InP scenarios are behaving as expected with D+ scenario exhibiting the largest (2.0%) reduction in fuel burn relative to baseline, followed by D, C, B, A*. Scenarios A and A* are practically identical.

21.3.3 Cumulative results (represented as Full Flight CO_2 and derived from the consensus full flight fuel burn results) from the applicability date to 2050 and for both NT A1 and M.07 approach as well as InP A1 scenarios are presented in section 4.2.

Consensus In Production (InP) Applicability: 2050 Fuelburn Change in Mt Relative to Baseline of 644.2 Mt	
CO_2	
A (102%/100%)	-1.6
A* (100%/100%)	
B (102%/98%)	-1.7
C (100%/95%)	-6.4
D (98%/93%)	-11.6
D+ (98%/93%)	-13.0

Figure 66: Change in fuel burn relative to baseline in 2050 (in Mt Fuel) for CO_2 In Production (InP) scenarios

Consensus In Production (InP) Applicability: 2050 Percent Fuelburn Change Relative to Baseline of 644.2 Mt	
CO_2	
A (102%/100%)	-0.2%
A* (100%/100%)	
B (102%/98%)	-0.3%
C (100%/95%)	-1.0%
D (98%/93%)	-1.8%
D+ (98%/93%)	-2.0%

Figure 67: Change in fuel burn relative to baseline in 2050 (in Percent) for CO_2 In Production (InP) scenarios

21.4 **NOx Results Comparisons**

21.4.1 AEDT and IMPACT results align well for the scenarios as well.

21.4.2 As expected, there are larger differences (for scenarios other than the baseline) between AEDT/IMPACT and FAST. FAST currently uses the DLR method for NOx which has known deficiencies in modelling lean burn engines. Lean burn engines become more prominent in scenarios in a few CBins. This is the primary reason for larger differences. The FAST modellers are planning to implement the latest BFFM2 methodology with lean burn corrections later in the CAEP/13 cycle.

21.4.3 The NOx results derived from the AEDT model were chosen as the MDG-FESG consensus results. All charts depicting NOx results below are based on results from the AEDT model.

21.5 Interpretation of NOx Results

21.5.1 As part of the provision of TRs to InP SOs, OEMs provided NOx TRs that had either a small NOx increase, or no NOx change with CO2 emissions reduction. Overall, a small to medium NOx increase would be expected when moving across the CSOs. However, we see this only in SO(s): A, A* and B. For C, D and D+ we have lean burn and rich burn engines fleet mix differences that comes into play. Large NOx increase (relative to baseline) in InP C is due to more lean burn engines dropping out and getting replaced by rich burn engines in CBin-10. For InP D and D+ SO(s) it is the opposite effect (NOx decrease relative to baseline) with more rich burn engines getting replaced by lean burn engines in CBin-09 and CBin-06.

Consensus In Production (InP) Applicability: 2050 NOx Change in Kt Relative to Baseline of 11,609 Kt	
CO_2	
A (102%/100%)	-9.6
A* (100%/100%)	
B (102%/98%)	-9.6
C (100%/95%)	546.7
D (98%/93%)	-259.5
D+ (98%/93%)	-591.4

Figure 68: Change in NOx relative to baseline in 2050 (in kt NOx) for In Production (InP) scenarios

Consensus In Production (InP) Applicability: 2050 Percent NOx Change Relative to Baseline of 11,609 Kt	
CO_2	
A (102%/100%)	-0.1%
A* (100%/100%)	
B (102%/98%)	-0.1%
C (100%/95%)	4.7%
D (98%/93%)	-2.2%
D+ (98%/93%)	-5.1%

Figure 69: Change in NOx relative to the baseline in 2050 (in Percent) for In Production (InP) scenarios

22. MAIN ANALYSIS (MODELLING) RESULTS (INP): NOISE RESULTS

Note: No system level Noise analyses were conducted for CO_2 InP SOs.

23. MAIN ANALYSIS (MODELLING) RESULTS (INP): COST RESULTS

23.1 Introduction

23.1.1 Using the results of the fleet evolution modelling as summarized and reported in the section above, cost results were estimated for the 6 scenarios for an In-Production (InP) standard (CO_2 TRs only). See Figure 28 for details on set of scenarios analysed.

23.2 Integrated Dual Stringency InP Cost Assessment

23.2.1 The IDS InP cost results are described in terms of TRs for each scenario and associated changes in costs relative to the baseline. Specifically, the scenario-dependent sets of TRs (pass/fix/fail) change the GRdb aeroplanes available for fleet evolution within each CBin, altering the composition of the GRdb fleet and the associated costs.

23.2.2 Aeroplanes failing a scenario may lead to a change in the average capacity and price of available GRdb aeroplanes:

a) ***Changes in average capacity*** in a scenario run result in a change in operations, and operational related costs (i.e., other DOCs and fuel cost) relative to the baseline.

b) ***Changes in average aeroplane price*** in a scenario run lead to a change in capital costs relative to the baseline.

23.2.3 Along with fleet mix changes, the number of aeroplanes with a fix response for a scenario influence the change in CO_2 emissions.

23.2.4 For each scenario, the change (relative to the baseline) in fuel costs, capital costs and Other DOCs (i.e., crew, maintenance, route, and landing costs) are discussed and presented. NRCs, which are associated with a fix response, are also included.

23.2.5 Results are presented by CSO level which allows for observing the shift in cost changes from one CSO to the next.

23.3 Cost Results Summary

23.3.1 The largest reduction in total costs for the InP standard is at CSO D (Figure 73). Although CSO D+ has a higher reduction in fuel costs, aeroplane level responses change between the two stringencies, leading to higher capital costs at CSO D+ relative to CSO D and a lower reduction in total costs.

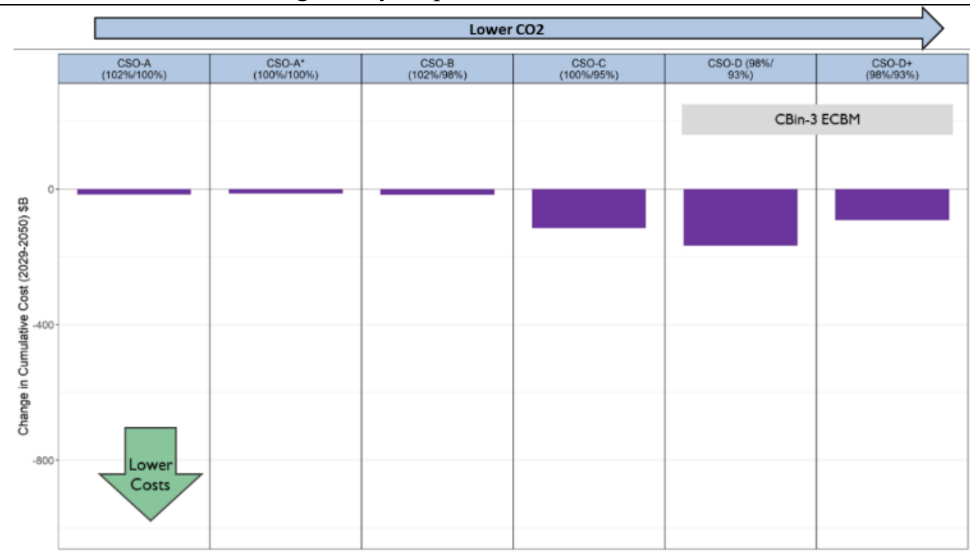

Figure 70: Total costs associated with CO_2 InP stringency options modelled using the A1 approach (Change in Cumulative (2029-2050) Costs Relative to Baseline)

23.4 In-Production Total Cost Narrative

23.4.1 The InP results are generated using the A1 fleet evolution approach. Under the InP analysis, there are 6 CSO-only levels with a standard implementation date of 2035. Therefore, results from the InP runs differ from the NT A1 and M.07 approaches in that the implementation date and response matrix are different (in addition, InP uses ECBM to analyse the CSO scenario space).

23.4.2 InP Growth and Replacement Fleet Responses

23.4.2.1 Table 27 presents the fleet responses for the InP approach. In all 6 CSOs, ECBM is required, however no ECBM is needed for CBin-9.

Table 25. InP growth and replacement aeroplane technology responses[102,103]

Response	InP CSO A	A*	B	C	D	D+
Pass	89	89	82	59	48	48
Fix	2	1	9	16	13	22
Fail	1	2	1	17	31	22
Pass	97%	97%	89%	64%	52%	52%
Fix	2%	1%	10%	17%	14%	24%
Fail	1%	2%	1%	18%	34%	24%
Total	100%	100%	100%	100%	100%	100%

[102] All CBin 3 aircraft fail at InP CSO D and InP CSO D+ and CBin-4 aircraft are used to meet demand under the InP A1 approach.
[103] Counts exclude Niche market aircraft, aircraft which fail the MA Baseline and aircraft with a last made date prior to 2028. InP counts exclude four GRdb aircraft with Noise Only applicability in CBin 23.

23.4.2.2 **CSO A and A***: nearly all aeroplanes pass with only 2 fixes required and 1 failure in A and 1 fix switching to a failure under A*.

23.4.2.3 **CSO B:** 89% of aeroplanes pass, with 9 requiring a fix and only 1 failure.

23.4.2.4 **CSO C:** there is a jump in failures, with 64% of aeroplanes passing, 17% requiring a fix and 18% failing at CSO C.

23.4.2.5 **CSO D and D+:** the number of passes drops to 52% and the primary difference between the two SOs is in the mix of fix and failures, with D+ requiring more fixes (24%) relative to D (14%).

23.4.3 InP Total Operational Changes to the Baseline

23.4.3.1 Table 28 presents the total cumulative operational changes relative to the baseline for the 6 InP CSOs. Overall, the change in operations is minimal for CSO A, A* and B given the limited number failures reported in previous section.

Table 26. InP Operational Change to the Baseline (2050)

	InP CSO A	A*	B	C	D	D+
2050 % Change	-0.1%	-0.1%	-0.1%	-0.4%	-0.8%	-0.6%
2050 Ops Change (millions)	-0.15	-0.15	-0.15	-0.35	-0.83	-0.63

23.4.3.2 At CSO C, operations decrease by 0.35 million due to the additional failures discussed in the previous section. The decrease in operations jumps in CSO D and D+ as a larger number of CBins are impacted by fleet mix and capacity changes with the most significant occurring in CBin-3 due to ECBM. At CSO D+ the change in capacity is smaller in CBin-8 but also larger now in CBin-10.

23.4.4 InP Total Cost Results

23.4.4.1 The total cumulative cost results for the 6 InP CSOs is presented in Figure 74. CSO A, A* and B have very limited impact on total costs relative to the baseline, which should be expected given the limited fleet mix changes and operational impacts. Total costs decrease substantially at CSO C and above, with CSO D having the largest decrease in total costs.

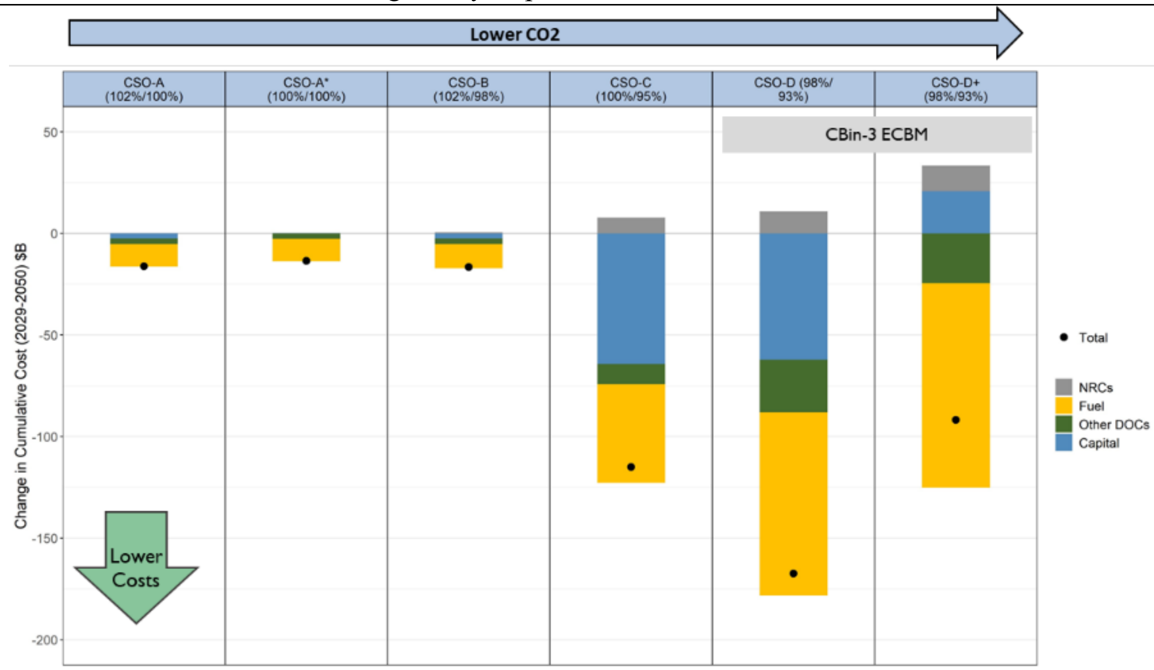

Figure 71: InP A1 - Breakdown of costs and net costs (Change in cumulative (2029-2050) costs relative to the baseline)

23.4.4.2 At CSO A, A* and B, total costs decrease between -$14 to -$17 billion, with the primary cost decrease occurring from fuel costs in CBin-4.

23.4.4.3 At CSO C, there is a significant decrease in capital costs as well as a decrease in other-DOC and fuel costs. The large drop in capital costs occur in CBins 8, 9 and 10 due to fleet mix changes described above. Fuel costs decrease in CBins 9 and 10 but increase slightly in CBin-8.

23.4.4.4 Total cost results for CSO D and D+ show a switch in capital costs, with a large drop in capital costs in CSO D and increase in capital costs at D+. Fuel costs between the two scenarios are close with D+ -$10 billion lower than D. Overall, CSO D has the largest total cost decrease out of the 6 scenarios at -$167 billion.

24. MAIN ANALYSIS (MODELLING) RESULTS (INP): SUMMARY OF INTEGRATED RESULTS

24.1 *CO_2 In Production Standard: Approach A1*

24.1.1 Figure 75 shows the results for the CO_2 InP standard in terms of change relative to the baseline in total cumulative costs and total cumulative CO_2 (noise impacts were not evaluated for the assessment of CO_2 InP SOs). Figure 75 shows the change in CO_2 emissions on the Y axis. The change in total cumulative costs is represented by the size of the bubble.

24.1.2 **InP Response:** Overall there is a general growing reduction in CO_2 emissions and costs moving from CO_2 InP stringency A through to CO_2 InP stringency D and D+. SOs A, A* and B are closely grouped together, for both CO_2 and costs, and considerably smaller than the results for C, D and D+. This is consistent with the high pass rate for these three SOs, which is at 97% for A and A*, and 89% for B.

24.1.3 Moving to SOs C, D and D+, the pass rate declines to 64% for C, and 52% for D and D+. A higher level of responding aeroplanes increases the reduction in CO_2 of D and D+, while at D+ a change in the aeroplanes being affected by the stringency and associated capital cost increase (along with higher NRCs) reduces the total cost change.

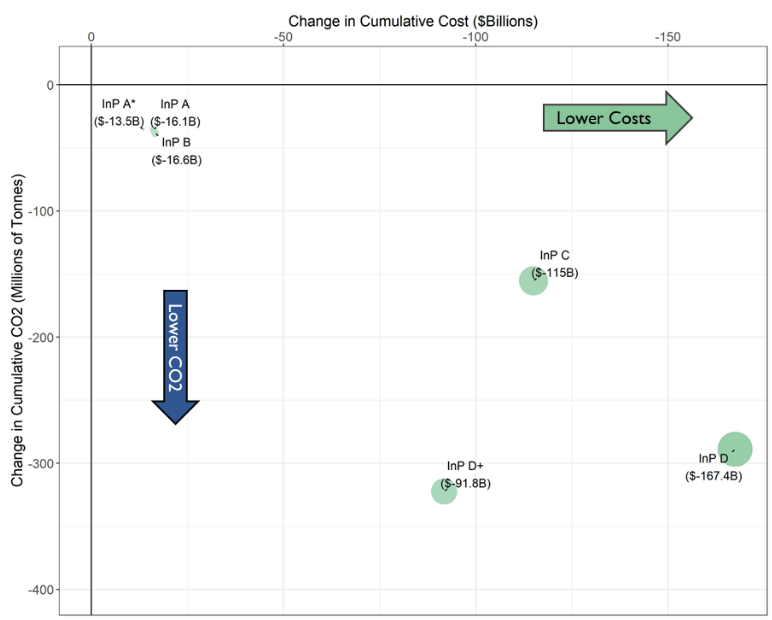

Figure 72: Change in Cumulative CO_2 (Millions of Tonnes) and Costs ($Billions) - InP A1 Approach

24.1.4 **CO_2 InP Rankings:** Figure 77 shows the CO_2 InP scenario ranking results. Ranks are shown for total cumulative costs, and CO_2 for the A1 InP approach.

24.1.5 The lowest net total cumulative cost across the InP scenarios is achieved at SO D, followed by C and D+. The largest CO_2 emissions reductions are observed for SO D+, followed by D and C, which is consistent with the level of TRs across these three options.

24.1.6 **Discount Rates:** There is no change in the rankings for the top three InP SOs when using the alternative discount rates across either costs or CO_2 emissions.

CSO	A1 – Cumulative (2029-2050)							
	Cost Rank				CO2 Rank			
Discount Rate	0%	3%	7%	9%	0%	3%	7%	9%
A (102%/100%)	5	5	4	4	5	5	5	5
A* (100%/100%)	6	6	6	6	6	6	6	5
B (102%/98%)	4	4	5	5	4	4	4	4
C (100%/95%)	2	2	2	2	3	3	3	3
D (98%/93%)	1	1	1	1	2	2	2	2
D+ (98%/93%)	3	3	3	3	1	1	1	1

Figure 73: Scenario Rank by Discount Rate for InP Approach for Cumulative Cost and Environmental Results

CSO	A1 – Cumulative (2029-2050)	
	Cost Rank (Change in Total Costs, $B)	CO2 Rank (CO2 Reduction, Millions of Tonnes)
A (102%/100%)	5 (-16.1)	5 (-35.6)
A* (100%/100%)	6 (-13.5)	6 (-35.3)
B (102%/98%)	4 (-16.6)	4 (-38.3)
C (100%/95%)	2 (-115.0)	3 (-155.3)
D (98%/93%)	1 (-167.4)	2 (-289.0)
D+ (98%/93%)	3 (-91.8)	1 (-322.2)

Figure 74. InP Approach Scenario Ranking by Approach for Cumulative Cost and Environmental Results

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