EUROPEAN
COMMISSION

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PART 2/3

COMMISSION STAFF WORKING DOCUMENT

Full-length report

Accompanying the document

Report from the Commission to the European Parliament and the Council

Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30(4)

{COM(2020) 747 final}

APPENDIX 1 – Task Specifications

EUROPEAN COMMISSION

DIRECTORATE-GENERAL FOR MOBILITY AND TRANSPORT
Directorate E
Unit E1

CALL FOR TENDERS

N° MOVE/E1/2019-475

" EU ETS DIRECTIVE ARTICLE 30(4) ANALYSIS ON THE EFFECTS OF NON-CO_2 AVIATION EMISSIONS ON CLIMATE CHANGE "

TENDER SPECIFICATIONS

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INFORMATION ON TENDERING

Participation

The invitation is based on Article 164 and Annex I Point 11.1(b)(ii) and (iii) of Regulation 2018/1046 of 18 July 2018 on the financial rules applicable to the general budget of Union that provides for a negotiated procedure with 1 candidate due to a monopoly situation, as competition is absent for technical reasons. Director General of DG MOVE has authorised the use of the said procedure given that the contract can only be awarded to the European Union Aviation Safety Agency (EASA).

Contractual conditions

The tenderer should bear in mind the provisions of the draft contract which specifies the rights and obligations of the contractor, particularly those on payments, performance of the contract, confidentiality, and checks and audits.

Compliance with applicable law

The tender must comply with applicable environmental, social and labour law obligations established by Union law, national legislation, collective agreements or the international environmental, social and labour conventions listed in Annex X to Directive 2014/24/EU[1].

Joint tenders

A joint tender is a situation where a tender is submitted by a group of economic operators (natural or legal persons). Joint tenders may include subcontractors in addition to the members of the group.

In case of joint tender, all members of the group assume joint and several liability towards the Contracting Authority for the performance of the contract as a whole, i.e. both financial and operational liability. Nevertheless, tenderers must designate one of the economic operators as a single point of contact (the leader) for the Contracting Authority for administrative and financial aspects as well as operational management of the contract.

After the award, the Contracting Authority will sign the contract either with all members of the group, or with the leader on behalf of all members of the group, authorised by the other members via powers of attorney.

Subcontracting

Subcontracting is permitted but the contractor will retain full liability towards the Contracting Authority for performance of the contract as a whole.

Tenderers are required to identify subcontractors whose share of the contract is above 20 % and those whose capacity is necessary to fulfil the selection criteria.

[1] Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC (OJ L 94, 28.3.2014, p. 65).

During contract performance, the change of any subcontractor identified in the tender or additional subcontracting will be subject to prior written approval of the Contracting Authority.

Structure and content of the tender

The tenders must be presented as follows:

Part A: Identification of the tenderer (see section 1.7)

Part B: Non-exclusion (see section 4.1)

Part C: Selection (see section 4.2)

Part D: Technical offer

The technical offer must cover all aspects and tasks required in the technical specifications and provide all the information needed to apply the award criteria. Offers deviating from the requirements or not covering all requirements may be rejected on the basis of non-compliance with the tender specifications and will not be evaluated.

Part E: Financial offer

The maximum contract price is EUR 250.000 (two hundred and fifty thousands).

The price for the tender must be quoted in euro. Tenderers from countries outside the euro zone have to quote their prices in euro. The price quoted may not be revised in line with exchange rate movements. It is for the tenderer to bear the risks or the benefits deriving from any variation.

Prices must be quoted free of all duties, taxes and other charges, including VAT, as the European Union is exempt from such charges under Articles 3 and 4 of the Protocol on the privileges and immunities of the European Union. The amount of VAT may be shown separately.

The quoted price must be a fixed amount which includes all charges (including travel and subsistence). Travel and subsistence expenses are not refundable separately.

Identification of the tenderer

The tender must include a **cover letter** signed by an authorised representative presenting the name of the tenderer (including all entities in case of joint tender) and identified subcontractors if applicable, and the name of the single contact point (leader) in relation to this procedure.

In case of joint tender, the cover letter must be signed either by an authorised representative for each member, or by the leader authorised by the other members with powers of attorney. The signed powers of attorney must be included in the tender as well. Subcontractors that are identified in the tender must provide a letter of intent signed by an authorised representative

stating their willingness to provide the services presented in the tender and in line with the present tender specifications.

In addition the tenderer must fill and sign Annex I (identification of the Tenderer) and join it to the tender.

TECHNICAL SPECIFICATIONS

PROBLEM STATEMENT

Alongside all other emitting sectors, aviation will need to reduce its GHG emissions so as to provide its fair contribution to the achievement of the temperature goals agreed under the Paris Agreement. Despite major efforts in global technology improvement and facing constant traffic growth, aviation is one of the fastest-growing sources of greenhouse gas (GHG) emissions. As part of GHG emissions, CO_2 emissions from aviation presently account for more than 2% of global CO_2 emissions, featuring among the top 10 global emitters. By 2020, international aviation CO_2 emissions are projected to be around 70% higher than in 2005, and the International Civil Aviation Organisation (ICAO) forecasts that by 2050 they will grow by a further 300-700%.[2] CO_2 emissions from aviation account for 3.3% of the EU's total CO_2 emissions, and 13.3% CO_2e of the EU's total transport GHG emissions.[3]

The impact of aviation on climate change goes beyond CO_2 emissions alone, which are the main target of current policies.[4] Flights i.a. also emit NO_x, SO_2, sulphate aerosols, soot and water vapour which have complex effects on the climate, and when emitted at high altitudes the impacts are estimated to be 2 to 5 times higher than CO_2 emissions. There have been several requests by the co-legislators, particularly the European Parliament, for aviation's non-CO_2 emissions to be scrutinised and possibly addressed through policy/legislative means. In fact the 2006 Impact Assessment to the EU ETS Directive[5] analysed the possibility of also regulating NO_x, while DG MOVE had also commissioned a study, published in 2008,[6] to explore ways in which policy might capture NO_x. Science in this field was not however sufficiently developed to enable a clear determination of a course of action. Since, there have been many scientific developments over the last few years. Nonetheless, the level of scientific understanding of the magnitude of non-CO_2 impacts is medium to very low.[7] The individual emissions and effects have differing warming or cooling impacts, however the overall balance is a warming effect. Moreover, new secondary effects have been identified with potentially large impacts. So far the non-CO_2 effects of aviation on climate change

[2] (European Commission - DG CLIMA)
[3] (European Environment Agency , 2018)
[4] Vide i.a. (Emission Reduction Targets for International Aviation and Shipping, 2015); (Grewe, 2018); and (CE Delft, May 2017)
[5] Commission Staff Working Document, SEC(2006) 1684, Impact Assessment of the inclusion of aviation activities in the scheme for greenhouse gas emissions allowance trading within the Community
[6] Lower NOx at Higher Altitudes - Policies to Reduce the Climate Impact of Aviation NOx Emission; Jasper Faber, Dan Greenwood, David Lee, Michael Mann, Pablo Mendes de Leon, Dagmar Nelissen, Bethan Owen, Malcolm Ralph, John Tilston, André van Velzen, Gerdien van de Vreede; Delft, CE Delft, October 2008
[7] European Aviation Environmental Report 2019, Chap. 7.3

remain largely unaddressed.[8,9] The co-legislators recently reiterated in the EU ETS Directive as last revised (2017),[10] a request to report on and possibly address these effects.

Article 30(4) of the revised EU ETS Directive provides for the following mandate:

'Before 1 January 2020, the Commission shall present an updated analysis of the non-CO2 effects of aviation, accompanied, where appropriate, by a proposal on how best to address those effects.'

OBJECTIVES

Given the mandate, the main questions to be answered and as such tasks to be executed by the contractor are the following:

What is the most recent knowledge on the climate change effects of non-CO_2 emissions from aviation activities?

1A. Which metric and time horizon may be used to measure these effects?

1B. What is the level of scientific understanding of these effects and what are the related uncertainties?

What factors/variables (possibly) have had an impact on these effects? What is the level of that impact? Do these factors/variables exhibit trade-offs or interdependencies between different emissions?

What research has been undertaken on potential policy action to reduce non-CO2 climate impacts?

[8] Certain Landing and Take-Off (LTO) emissions are captured by Annex 16 to the Convention on International Civil Aviation, Environmental Protection Volume II - Aircraft Engine Emissions, 4th Edition July 2017. The ICAO Standards for Engine Emissions are implemented through Article 6 of the Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91; Annex I (Part-21) of the Implementing Regulation, and the Certification Specifications of CS-34 (emissions) and CS-36 (noise).

[9] It should be noted that the cruise emissions of certain air pollutants that are relevant in this context are reported as 'memo items' (i.e. reported but not added to national totals) under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) – i.e. NO_X, NMVOCs, SO_X, NH3, CO, HMs, POPs and PM; and the National Emissions Ceilings (NEC) Directive (2016/2284/EU) – i.e. NO_X, NMVOCs, SO_2 and NH. Guidance on estimating these emissions is provided in the aviation chapter of the EMEP/EEA Guidebook: <https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-a-aviation-2016/view>

[10] Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2915/1814

TASKS:

What is the most recent knowledge on the climate change effects of non-CO_2 from aviation activities?

The legal mandate requires an '*updated analysis'.* As a basis therefore, the study should take the following indicative documentation as a point of departure (with the highlighted being the most relevant from a legal perspective), to then be complemented as appropriate by any existing and/or new relevant report or research analysis:

Aviation and the Global Atmosphere, IPCC 1999[11]

Study on air quality impacts of non-LTO emissions from aviation[12] (ENV 2004 Study)

Giving wings to emission trading - Inclusion of aviation under the European emission trading system (ETS): design and impacts [13] (07/2005 ETS Study)

Commission Staff Working Document, SEC(2005) 1184, Annex to the Communication from the Commission "Reducing the Climate Change Impact of Aviation" Impact Assessment {COM(2005) 459 final} (09/2005 Prelim ETS IA)

Commission Staff Working Document, SEC(2006) 1684, Impact Assessment of the inclusion of aviation activities in the scheme for greenhouse gas emissions allowance trading within the Community (12/2006 Full ETS IA)

Commission Staff Working Document, SEC(2006) 1685, Summary of the Impact Assessment: Inclusion of Aviation in the EU Greenhouse Gas Emissions Trading Scheme (EU ETS) (12/2006 Summary ETS IA)

IPCC, 2007. Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report

Lower NOx at Higher Altitudes Policies to Reduce the Climate Impact of Aviation NOx Emission [14] (2008 DG MOVE Commissioned Study)

Aviation and global climate change in the 21st century (2009)[15]

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report

[11] J.E.Penner, D.H.Lister, D.J.Griggs, D.J.Dokken, M.McFarland (Eds.); Prepared in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer; Cambridge University Press, UK.

[12] Leonor Tarrasón and Jan Eiof Jonson (met.no), Terje K. Berntsen and Kristin Rypdal (CICERO); Norwegian Meteorological Institute, 09 January 2004

[13] R.C.N. (Ron) Wit, B.H. (Bart) Boon and A. (André) van Velzen (CE Delft), M. (Martin) Cames and O. (Odette) Deuber (Oeko-Institut), D.S. (David) Lee (Manchester Metropolitan University); Delft, CE, July 2005.

[14] op.cit. fn.5

[15] Lee D. S., Fahey D., Forster P., Newton P.J., Wit R.C.N., Lim L.L., Owen B., Sausen R.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability Part A: Global and Sectoral Aspects. Working Group II Contribution to the Fifth Assessment Report.

IPCC, 2014. Climate Change 2014 Mitigation of Climate Change. Working Group III Contribution to the Fifth Assessment Report.

Aircraft soot indirect effect on large-scale cirrus clouds: Is the indirect forcing by aircraft soot positive or negative? (2014)[16]

Impact of Coupled NOx/Aerosol Aircraft Emissions on Ozone Photochemistry and Radiative Forcing. (2015)[17]

The global impact of the transport sectors on atmospheric aerosol in 2030 – Part 2: Aviation. (2016)[18]

Impacts of aviation fuel sulphur content on climate and human health. (2016)[19]

Annex 16 to the Convention on International Civil Aviation, Environmental Protection Volume II - Aircraft Engine Emissions, as last amended

Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (1.5°C Report)[20]

A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy COM(2018) 773 final (2050 LTS)

In-depth analysis in support of the Commission Communication COM(2018) 773 (Add. 2050 LTS)

Trading Off Aircraft Fuel Burn and NOx Emissions for Optimal Climate Policy. (2018)[21]

Simple Versus Complex Physical Representation of the Radiative Forcing From Linear Contrails: A Sensitivity Analysis. Journal of Geophysical Research: Atmospheres. (2018)[22]

European Aviation Environmental Report 2019 (EAER 2019)

The current state of scientific understanding of the non-CO2 effects of aviation on climate[23]

[16] Zhou C. and Penner J.
[17] Pitari G., Iachetti D., Di Genova G., De Luca N., Amund Søvde O., Hodnebrog Ø., Lee D.S. and Lim L.
[18] Righi M., Hendricks J., and Sausen R.
[19] Kapadia Z. et al.
[20] Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor, and T. Waterfield (eds.). World Meteorological Organization, Geneva, Switzerland
[21] Sarah Freeman, David S Lee, Ling L. Lim, Agnieszka Skowron and Ruben Rodriguez De León
[22] Rodriguez De Leon, Ruben & L. Lim, Ling & Lee, David & Bennett, Michael & Krämer, Martina.

The following non-exhaustive list of non-CO_2 in-flight[24] emissions and effects on climate change ought to be covered by the assessment:

- Emissions of NO_x (nitric oxide – NO, and nitrogen dioxide – NO_2), PMs (particulate matter) and nvPMs (non-volatile particulate matter), sulphate aerosols, soot aerosols, SO_x (sulphur oxides), and water vapour;

- Effects on ozone chemistry including on the concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), ozone (O_3), and methane (CH_4); (indirect) effects on cloud formation; and the effects of the formation of linear contrails and contrail-cirrus.[25]

The researcher shall take stock of and analyse the most relevant and up to date studies, statistics, reports, research and materials issued, endorsed or funded by the EU and its institutions, International, European or national stakeholder associations, Eurocontrol, as well as independent research institutes and individual stakeholders – particularly academia (e.g. MMU/DLR). To this end, the researcher is requested to liaise with DG RTD to determine the most relevant deliverables from EU funded projects.

This should be accompanied by an identification of whom the potential (academic) interlocutors may be, to engage them in the process of the study. It is expected that an experts/stakeholder meeting/conference is convened at this stage of the study, to set the scene of the study.

This initial phase of the study should provide an updated overview in terms of scientific research and understanding of these emissions and their effects on climate change, with initial results to be made available around 2nd week of October 2019. It should delineate whether indeed there has been anything 'new' in this field since 2005-2008. It is acknowledged that much will depend on the parameters applied to determine the emissions and their effects on climate change, as such this should be highlighted. This initial phase should also enable an assessment in order to provide replies particularly to Questions 1A and 1B, as well as provide inclinations towards the possible results of the study.

Which metric and time horizon may be used to measure these effects?

As the study is set to examine different non-CO_2 emissions, the determination of how climate impacts may be assessed in a comparative manner, possibly also in relation to CO_2, for policy/legislative purposes, is rather relevant. It appears from the 2008 DG MOVE commissioned Study that RF (Radiative Forcing) and RFI (Radiative Forcing Index) are not suitable metrics to determine climate impact for policy purposes, given that these are backward looking (i.e. they analyse past impact). The Study also examines whether GWP (Global Warming Potential) may be used, concluding however that not enough research exists to enable this, albeit it does speculate that given 2-5 years and provided GWP may be

[23] D. Lee, Manchester Metropolitan University; published online on 17 December 2018 UK Government Dept. for Transport

[24] So excluding all aircraft activities that take place at altitudes under 914 meters (3.000 feet), including taxi-in and -out, take-off, climb-out and approach-landing.

[25] Vide op.cit fn.6 and fn. 10, for reasons as to why these emissions are to be assessed.

used, policy/legislative responses would be possible. This given, and provided the legal mandate looks for an 'updated' analysis, it may be warranted that the study looks into the question of metric.

There are physical metrics - e.g. GWP, (I)GTP ((Integrated) Global Temperature Potential), SGTP (Sustained GTP); and there are economic metrics – e.g. RDC (Relative Damage Cost), CETO (Cost-Effective Trade-Off). The researcher is encouraged to examine both types of metrics, albeit given the 'update' nature of the legal mandate it is presumed that a focus on the physical metrics may be more opportune, including in relation to time constraints. Prima facie, it appears that no matter whether physical or economic metrics are used, both provide for several permutations depending on the parameters applied. It is expected that the researcher will take into account the metrics used in both International and EU relevant Climate Change law and policy.

The study should also seek to determine the appropriate timeframe to measure and compare non-CO_2 effects, possibly also with CO_2 effects. Comparing CO_2 vs non-CO_2 RF is effectively a comparison of a long-lived greenhouse gas with short-lived climate forcers and such comparison depends to a large extent on the choice of time horizons and metrics.

The reply/replies to Question 1A should provide more clarity on the research and scientific knowledge status quo in relation with the climate metric and time horizon/s best utilised for policy/legislative purposes. Again it should delineate whether indeed there has been anything 'new' in this field since 2005-2008. The uncertainties, ambiguities and data variability (also depending on the parameters applied), as well as whether there are issues of equivalence,[26] should be highlighted.

What is the level of scientific understanding of these effects and what are the related uncertainties?

Taking account of work undertaken in relation with Questions 1 and 1A, the level of scientific understanding about the climate change effects of the non-CO_2 in-flight emissions should be established here, either emission by emission or effect by effect. This section should enable an understanding of whether the level of scientific understanding has changed since 2005-2008 and to what extent. Uncertainties and knowledge gaps are to be identified and reasons there-for should be highlighted.

N.B. This study's prime concern is non-CO_2 in-flight emissions from aviation. Should uncertainties/knowledge gaps emerge on whether non-CO_2 emissions and their effects are directly or indirectly attributable to aviation, such are to be acknowledged, without however deterring or deviating from the main focus of the study.

What factors/variables (possibly) have had an impact on these effects? What is the level of that impact? Do these factors/variables exhibit trade-offs or interdependencies between different emissions?

In determination of the reply to this question, the following non-exhaustive list of measures is to be considered. All measures are to be examined to the extent they are relevant to non-CO_2 in-flight emissions and addressing their climate change effects.

[26] In treating non-CO_2 emissions in an equivalent manner to CO_2 emissions.

The level of impact of the various relevant measures on the climate change effects should also be assessed, at the very least in qualitative terms.

Should the various relevant measures exhibit trade-offs (in tackling one emission over another[27] and/or in the choice of action undertaken[28]), and/or interdependencies/incentives (one measure would target 2 or more emissions),[29] such should be identified and described.

Fuel Efficiency including engine design, engine specification standards, and fleet upgrading;

Alternative Fuel use: sustainable bio-fuels/synthetic fuels and e-fuels[30]

Flight Path Alteration including Free Route Airspace; avoidance of sensitive climatic zones; alteration of altitude and speed of flights; and time when the flight occurs

Network Flight Efficiency/Capacity constraints and/or Optimisation

Airplane Electrification/Battery-powered aircraft

Innovative/One-off Solutions e.g. electric taxi-ing; winglets/scimitars (United); nano coating to reduce drag (Easyjet); lighter internal components (Lufthansa)

Measures implemented by some EU/EEA/ECAC Member States e.g. charges/taxes/levies

A slight foray into LTO emissions standards, as well as implementation of the NEC Directive/Ambient Air Quality Directives/UNECE CLRTAP may here be warranted. This simply to continue to illustrate the scope of the study (i.e. in-flight emissions), being that LTO emissions are those occurring from all aircraft activities that take place at altitudes under 914 meters (3.000 feet), including taxi-in and -out, take-off, climb-out and approach-landing; and to show coverage of LTO emissions as well as the possible impact of such on in-flight emissions.

The purpose of this section is to determine actions currently undertaken to address, even if indirectly, non-CO_2 in-flight emissions and their effects on climate change, as well as the level of impact/adequacy or otherwise of such actions on the subject at issue. It is not the intent of the study to enter into extensive detail of each measure, as such clear focus and scope should be maintained.

[27] E.g. the 2006 Impact Assessment is based on the premise that CO_2 and NO_x do not have trade-offs, however the Standards for Fuel Efficiency in new engine design have resulted in higher NO_x output.

[28] E.g. With contrails, there seems to be a basic tension between flying the most efficient route to minimise fuel burn/CO_2, and flying a sub-optimal route to minimise contrail formation.

[29] E.g. there is already large commercial incentive in reducing fuel burn. Reducing fuel burn reduces both CO_2 and NO_x emissions.

[30] Given Alternative Fuels also produce non-CO_2 emissions, and one is to take account of an LCA analysis, it may be warranted that this measure is not included in the Study's parameters. Should this be the route taken, it is however argued that a justification should be provided within the Study's report.

What research has been undertaken on potential policy action to reduce non-CO_2 climate impacts?

This section should seek to determine the research already undertaken which explores potential policy action to address non-CO_2 in-flight emissions and their effects on climate change. Here the researcher may explore i.a. studies such as '*Feasibility of climate-optimized air traffic routing for trans-Atlantic flights*'[31] and '*Potential to reduce the climate impact of aviation by climate restricted airspaces*'.[32] The policy options identified in said studies are to be described, with pros and cons, particularly in relation with implementation, clearly identified. A means to compare these policy options is welcomed. Conclusions of said studies are to be viewed taking the answer/s to Q2 into account. Knowledge gaps identified should be delineated. This section may also consider the international context and issues of competitiveness.

DELIVERABLES

Timeline for delivery of tasks

week	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Key deliverables meetings			Conf. call			workshop			Conf. call	Report		conf call				conf call				conf call				conf call					final report

2nd week of October 2019: Initial results to be made available, as described in Question 1 above.

2 December 2019: Delivery of a robust interim report, covering all aspects referred to above, and a significant indication of the direction of travel of (the results) of the final report. This interim report is also expected to showcase the proceedings of the experts meeting mandated in Question 1, also above.

30 March 2020 and no later than 13 April 2020: Delivery of the final completed report as per the above.

In principle, the deadlines set out below cannot be extended. The Contractor is deemed solely responsible for delays occasioned by subcontractors or other third parties (except for rare cases of *force majeure*). Adequate resources and appropriate organisation of the work including management of potential delays should be put in place.

[31] Grewe et al., 2017
[32] Niklaß et al., 2017

CONTENT, STRUCTURE AND GRAPHIC REQUIREMENTS OF THE DELIVERABLES

The contractor must deliver the study and other deliverables as indicated below.

Content

Final study report

The final study report must include:

an abstract of no more than 200 words and an executive summary of maximum 6 pages, both in English and French;

specific identifiers which must be incorporated on the cover page provided by the Contracting Authority;

the following disclaimer:

"The information and views set out in this [report/study/article/publication…] are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein."

Publishable executive summary

The publishable executive summary must be provided in both in English and French and must include:

specific identifiers which must be incorporated on the cover page provided by the Contracting Authority;

the following disclaimer:

"The information and views set out in this [report/study/article/publication…] are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein."

Requirements for publication on Internet

The Commission is committed to making online information as accessible as possible to the largest possible number of users including those with visual, auditory, cognitive or physical disabilities, and those not having the latest technologies. The Commission supports the Web Content Accessibility Guidelines 2.0 of the W3C.

For full details on the Commission policy on accessibility for information providers, see: http://ec.europa.eu/ipg/standards/accessibility/index_en.htm.

For the publishable versions of the study, abstract and executive summary, the contractor must respect the W3C guidelines for accessible pdf documents as provided at: http://www.w3.org/WAI/ .

Graphic requirements

The contractor must deliver the study and all publishable deliverables in full compliance with the corporate visual identity of the European Commission, by applying the graphic rules set out in the European Commission's Visual Identity Manual, including its logo. The graphic rules, the Manual and further information are available at:

http://ec.europa.eu/dgs/communication/services/visual_identity/index_en.htm

A simple Word template will be provided to the contractor after contract signature. The contractor must fill in the cover page in accordance with the instructions provided in the template. The use of templates for studies is exclusive to European Commission's contractors. No template will be provided to tenderers while preparing their tenders.

APPENDIX 2 – Study Telecon / Meeting Schedule

Non-CO2 study telecon/meeting schedule				
Day	**Date**		**Time (CET)**	**Notes**
Thurs.	18-Jul-19	Project Team telecon	09:30	
Thurs.	25-Jul-19			
Thurs.	01-Aug-19			
Thurs.	08-Aug-19			
Thurs.	15-Aug-19			
Thurs.	22-Aug-19			
Mon.	02-Sep-19	Project Team telecon	09:30	
Thurs.	05-Sep-19			
Thurs.	12-Sep-19			
Wed.	17-Sep-19	Project Team Meeting (EASA, Brussels)	09:00-17:00	
Thurs.	26-Sep-19			
Thurs.	03-Oct-19			
Thurs.	10-Oct-19			
Thurs.	17-Oct-19			
Thurs.	24-Oct-19			
Wed.	30-Oct-19			
Thurs.	07-Nov-19	Project Team telecon	09:30	
Thurs.	14-Nov-19			
Wed.	20-Nov-19	Task 1 and 2 Workshop (EASA, Brussels)	09:00-17:00	
Wed.	27-Nov-19	Project Team telecon	09:30	
Thurs.	05-Dec-19			
Fri.	06-Dec-19	Deadline for interim report		
Thurs.	12-Dec-19	Project Team telecon	09:30	
Thurs.	19-Dec-19			
Thurs.	26-Dec-19			
Thurs.	02-Jan-20			
Thurs.	09-Jan-20			
Thurs.	16-Jan-20			
Mon.	20-Jan-20	Project Team telecon	09:30	Task 3 consultation with stakeholders
Thurs.	30-Jan-20			
Thurs.	06-Feb-20			
Thurs.	13-Feb-20			
Thurs.	20-Feb-20	Project Team Meeting (EASA, Brussels)	09:00-17:00	
Thurs.	27-Feb-20			
Thurs.	05-Mar-20			
Fri.	06-Mar-20	Deadline for final draft report		
Thurs.	12-Mar-20	Task 3 Workshop (EASA, Brussels)	13:00-17:00	
Thurs.	19-Mar-20	Project Team telecon	09:30	
Thurs.	26-Mar-20			Plain english review and iteration with DG MOVE / DG CLIMA
Thurs.	02-Apr-20			
Fri.	03-Apr-20	Deadline for final report		
Thurs.	09-Apr-20			
Thurs.	16-Apr-20			
Thurs.	23-Apr-20			

APPENDIX 3 – Task 1 and 2 Workshop on 20 November 2019

EASA

Analysis of the Effects of Non-CO_2 Aviation Emissions on Climate Change

Workshop
20 November 2019

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Background

- Article 30(4) of the revised EU ETS Directive provides for the following mandate:
  '….the Commission shall present an updated analysis of the non-CO_2 effects of aviation, accompanied, where appropriate, by a proposal on how best to address those effects.'
- Focus is on new developments in the field since 2005-2008 period.
- DG MOVE and DG CLIMA have put in place a contract with EASA to manage this analysis and deliver a report by end of April 2020.

EASA 2

Objectives

- Task 1: What is the most recent knowledge on the climate change effects of non-CO_2 emissions from aviation activities?
  - 1A. Which metric and time horizon may be used to measure these effects?
  - 1B. What is the level of scientific understanding of these effects and what are the related uncertainties?
- Task 2: What factors/variables have had an impact on these effects (e.g. technology/design, operations, fuel, market based measures)? What is the level of that impact? Do these factors/variables exhibit trade-offs or interdependencies between different emissions?
- Task 3: What research has been undertaken on potential policy action to reduce non-CO_2 climate impacts?
  - What are the pros and cons of these options in terms of implementation?
  - What knowledge gaps exist?

EASA 3

Project Team

- Steve Arrowsmith, Martin Schaefer (EASA)
- David Lee, Bethen Owen, Agnieszka Skowron (MMU)
- Jasper Faber (CE Delft)
- Jan Fuglestvedt, Marianne Lund (CICERO)
- Olivier Boucher (CNRS)
- Robert Sausen (DLR)
- Ayce Celikel (ENVISA)
- Andrew Watt, Robin Deransy, Stavros Stromatas (Eurocontrol)
- Cheryl Micallef-Borg (DG CLIMA)
- Philippe Lenne, Magnus Gislev, Viktoria Tsitsoni (DG MOVE)

EASA 4

Confidentiality

- The fact that this study is being performed is not confidential.
- However, the details of the discussions are confidential in order to avoid pre-judging the outcome and conclusions of the study.
- Attendees are reminded to not share material or discussions from this workshop.

Aviation non-CO_2 emissions

Task 1 – the science

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Approach

- This is a time-pressured project, so an 'upside down' approach has been taken
- A presentation of a detailed and extensive report on the Autumn timescale was not possible, nor was thought to be the best approach given the contraints
- Drawing on the experience of the science team we have brain-stormed ideas and condensed to provide a set of 'emerging points' that can be presented to an expert term of external scientists (you) for feedback
- These points are largely un-referenced but known to the team as being points that can be robustly justified by the literature
- The science is only half the issue…!
- Assembling the science to make policy-relevant recommendations along with technological, operational and policy options is the other half…

The science team

- → David Lee, Manchester Metropolitan University (UK)
- → Olivier Boucher, IPSL (Fr)
- → Jan Fuglestvedt, CICERO (No)
- → Marianne Lund, CICERO (No)
- → Robert Sausen, DLR (De)
- → Agnieszka Skowron, MMU (UK)

Science analysis and assessment themes

- → Emissions from aviation (Presenter DSL)
- → The effects of aviation on climate
  - → The metric used
  - → Radiative effects
  - → Uncertainties
- → Mitigation opportunities (prior to Task 2, existing measures)
- → Addressing non-CO_2: what are the options from a science persective? (prior to Task 3, potential policy action)
- → CO_2 equivalence metrics (Presenter ML)

Emissions

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- → CO_2, NO_x, water vapour, SO_2, soot

NO_x
- → 1.4 Tg N/yr (avn)
- → cf 42 Tg N/yr (surface anthr.)
- → Well quantified

Soot, S
- → 0.01 Tg soot/yr, 0.2 Tg S/yr (avn)
- → cf 7.5 Tg/yr; 53 Tg/yr (surf anth)
- → Poorly quantified

Water vapour
- → Well quantified

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The effects of aviation on climate

- → There is an accepted shift away from **radiative forcing (RF)** to **'effective radiative forcing' (ERF)**, as proposed by the IPCC in the Fifth Assessment Report (2013)
- → Both RF and ERF are backward-looking metrics of present-day radiative impacts from anthropogenic activities since pre-industrial time
- → **ERF** is a better proxy for future changes in global mean surface temperature response as it includes all 'fast' atmospheric responses to a given climate forcer

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ERF

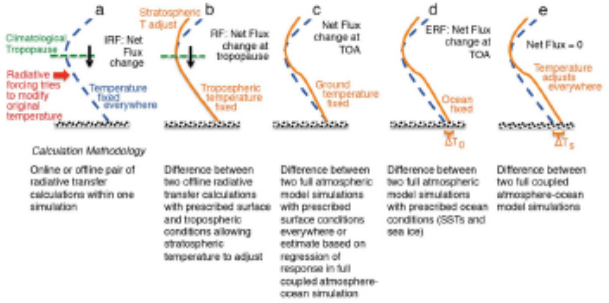

Figure 8.1 Cartoon comparing (a) instantaneous RF, (b) RF, which allows stratospheric temperature to adjust, (c) flux change when the surface temperature is fixed over the whole Earth (a method of calculating ERF), (d) the ERF calculated allowing atmospheric and land temperature to adjust while ocean conditions are fixed and (e) the equilibrium response to the climate forcing agent. The methodology for calculation of each type of forcing is also outlined. ΔT_0 represents the land temperature response, while ΔT_S is the full surface temperature response. (Updated from Hansen et al., 2005.) From AR5 WG1. Chapter 8. Figure 8.1

Aviation radiative effects – Overview

- → The main non-CO_2 radiative effects from aviation are from NO_x and contrails/contrail-cirrus
- → The *direct* radiative impacts of S, BC and water vapour are small
- → Aircraft NO_x results in the production of ozone (O_3) in the UT/LS at timescales of weeks and the destruction of ambient CH_4 at timescales of decades, with a net balance of warming for current day conditions.
- → *Contrail and contrail-cirrus* modelling of radiative effects have improved markedly over recent years with incorporation of process-based modelling into regional and global models
- → In both cases of NO_x and contrail cirrus, significant differences between RF and ERF

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Aviation radiative effects – 'net-NO_x'

- Recent revision of the radiative forcing terms associated with CH_4 also increases the magnitude of the indirect CH_4 effect from aircraft NO_x (more negative), also decreasing the best estimates of the net NO_x effect
- NO_x impacts are linked to the background atmosphere and the chemical system is non-linear. The magnitude of the net NO_x effect can be different for the same aviation emissions but different background concentrations of precursor emissions
- Under scenarios of declining surface emissions of tropospheric ozone precursors (e.g. RCP4.5), a net negative impact (cooling) of aviation NO_x may result

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Graphic to be inserted

Aviation radiative effects – Contrails and contrail cirrus

- Contrail and contrail cirrus process models show a dependence of RF on soot emissions (number)
- Considering the ERF (vs RF) of contrail-cirrus could have a large impact on the results of previous RF estimates of contrail cirrus, reducing the RF results by ~50%, or more

Aviation radiative effects – Aerosol/cloud interactions

- *The indirect radiative effects of S and soot (aerosol-cloud interactions)* are potentially large, relative to other aviation RF effects but are highly uncertain. The radiative effect of S on low-level clouds is likely to be negative (cooling) and potentially of a large magnitude (10s of mW/m^2), relative to other aviation RF effects. The radiative indirect effect of BC on upper tropospheric (cirrus) clouds has been estimated to potentially be relatively very large (100s of mW/m^2) ranging from negative, to near zero, through to positive

Graphic to be inserted

Aviation radiative effects – Uncertainties

- Estimates of the ERFs of the net NO_x effect and contrail-cirrus still have large uncertainties
- The principal uncertainty with the net NO_x effect is associated with future changes in surface emissions (to a change of sign)
- The principal uncertainties around the contrail cirrus effect are the dependence on soot number emissions (soot emission no. is poorly quantified) and the ERF (vs RF)
- Indirect aerosol-cloud interaction radiative effects from soot and S have very large uncertainties that preclude any best estimates

EASA 13

Mitigation opportunities – NO_x

- Changes in the combustion technology for NO_x may involve a fuel-burn penalty (see Technology tradeoffs)
- Operational reductions of NO_x impacts (reducing cruise altitudes) would involve a fuel burn, and therefore CO_2 penalty with net RF changes dependent upon the metric chosen and the time horizon used

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EASA 14

Mitigation opportunities – Contrails and contrail cirrus

- Operational changes in route or time of operation requires a flight-by-flight basis approach and accurate forecasting of ice-supersaturation and temperature
- Day-time only flights have been suggested (avoiding the larger net warming at night), which may reduce impact but the benefit (if any) is uncertain and subject to modelling disagreement
- Changing route, avoiding low-temperature ice-supersaturated air is possible, reducing the positive radiative effects of contrail cirrus (a small proportion of flights produce a large proportion of contrail cirrus). However, on most occasions, this would involve additional CO_2
- In case studies, it has been demonstrated that flight planning according to trajectories with minimal climate impact can substantially (up to 50%) reduce the aircraft climate impacts despite additional CO_2 emissions (however, see next point)
- For trade-offs between reduced non-CO_2 forcing and increased CO_2 forcing, the net benefit or disbenefit depends upon the choice of metric and time-horizon applied. There is a tendency for additional CO_2 to cause a net disbenefit over longer time horizons and all metrics

EASA 15

Mitigation opportunities – Contrails and contrail cirrus

- Contrail cirrus ERF can be reduced by reducing the emission index for soot particle number. This reduces the nucleation sites for the ice crystals, resulting in fewer, larger crystals, reducing the optical density of the clouds, and the lifetime of clouds.
- The degree of impact is not well known and subject to non-linearities and large uncertainties from the emissions quantification of soot number emissions in cruising conditions, and the microphysical and optical properties of contrail cirrus
- This can be achieved with fuels with less aromatic content and less naphthalene

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EASA 16

Options for addressing non-CO_2 – science perspective

An ETS 'add-on' approach

- (1) A simple 'multiplier' approach
- (2) A CO_2 equivalent emissions on a flight-by-flight basis

Issues

- (1) based upon global ERFs and averaged across the fleet and all conditions.
- (1, 2) the inherent scientific uncertainties of the non-CO_2 effects, expressed as their ERFs
- (1, 2) choice of metric and time horizon
- (1, 2) non-incentivization of emissions reductions
- (2) predictive data requirements

EASA 17

Options for addressing non-CO_2 – science perspective

Technology standards

- NO_x reductions from changes in combustion technology

Issues

- Potential perverse outcomes in terms of a reduced rate of CO_2 reductions.
- Future impacts of aircraft NO_x emissions are highly uncertain because of changing background atmospheric conditions from other surface ozone precursor emissions
- This highlights one of the problems of formulating NO_x mitigation policy based on current emissions/conditions

EASA 18

Options for addressing non-CO_2 – science perspective

Operational measures

- Reducing contrail cirrus by changing trajectories

Issues

- Inherent large uncertainties of the effect (including ERF vs RF)
- Potential impacts on increased CO_2 emissions
- Choice of metric and time-horizon
- Prediction of regions of ice supersaturation and temperature

EASA 19

Options for addressing non-CO_2 – science perspective

Fuel specifications

- Reductions in aromatics and naphthalene in fuel will reduced BC emissions (by number)
- Potential co-benefits
  - Lower CO_2 from biofuels
  - Zero CO_2 from synthetic fuels produced from renewable energy

Issues

- Reduction in particle number has been measured at the ground and at cruise from low aromatic fuel
- Reductions in contrail cirrus requires better quantification from measurements and modelling.
- No modification of flight trajectories would be required and no potential CO_2 increase
- Greater understanding of the indirect effects of BC and S (aerosol-cloud interactions) is urgently required to formulate effective policy on non-CO_2 effects, since these may be large in relation to other aviation RF effects

EASA 20

Aviation non-CO_2

Task 1 – emission metrics

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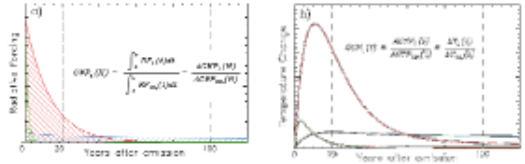
Metrics for calculating CO_2 equivalent emissions

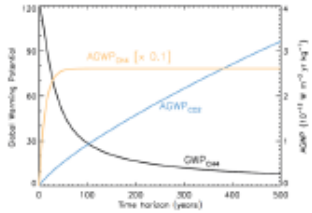
- Many emission metrics available to approximate non-CO_2 emissions to CO_2 equivalent emissions
- Selecting any one metric entails subjective user choices:
  - Time horizon
  - Type of effect or end-point (radiative forcing, temperature change, sea level change)
  - Spatial dimension for emission and response
- Most metrics have an underlying physical basis, such as the response of the climate system to a change in a non-CO_2 climate forcing agent over a selected time horizon in terms of the integrated radiative forcing or the resultant change in temperature, usually expressed as a dimensionless ratio to the same response from an equivalent amount of CO_2 emission.



IPCC (2013), AR5 WG1, Ch.8

2

- No true "equivalence" to CO_2, because of its unique behaviour
- The GWP100 is still the default policy metric for UNFCCC and used in the EU-ETS.
- The cumulative nature of GWP causes particular issues when used for comparing short-lived climate forcers (such as aviation non-CO_2 impacts) with CO_2, as it maintains an 'artificial memory' and hence obtains larger importance with short-lived climate forcers than what is 'felt' by the climate system.



IPCC (2013), AR5 WG1, Ch.8

3

- There are a range of derivative metrics that either express the changes in different ways (e.g. GWP*, iGTP, ATR) or overlay an economic dimension to the physically based metrics. It is also possible to formulate regional metrics that provide additional insight into the geographical distribution of temperature change beyond that available from traditional global metrics.

ATR_H: average global surface temperature change over a defined time horizon H *(Schwartz Dallara et al. 2011)*

Mean Global Temperature Potential: MGTP(H)=IAGTP(H)/H *(Gillett and Matthews 2010)*

The integrated absolute Global Temperature change Potential: IAGTP(H) *(Peters et al. 2011)*

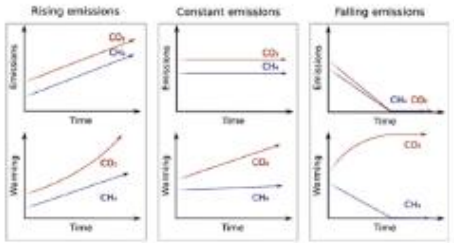
The absolute Regional Temperature change Potential: ARTP(H) *(Shindell and Faluvegi 2010; Lund et al. 2017)*

4

→ A relatively new application of the GWP, the 'GWP*' produces a better temperature-based equivalence of short-lived non-CO_2 climate forcers by reflecting the equivalence between methane emission rates and cumulative CO_2 emissions:

CO_2: warming determined by total cumulative emissions.

Short-lived non-CO_2: impact determined primarily of current rate of emissions in a any given decade.



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Allen et al. (2018), briefing paper

5

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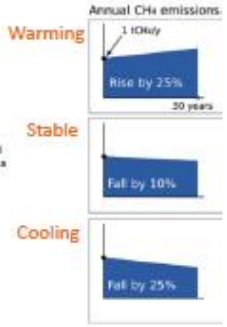

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Allen et al. (2018), briefing paper

6

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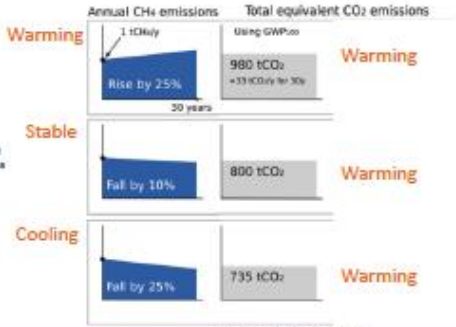

EASA

Allen et al. (2018), briefing paper

7

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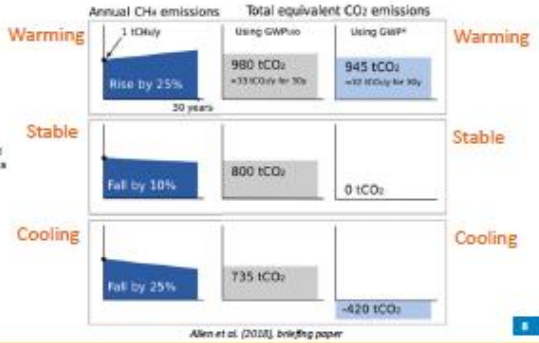

EASA

Allen et al. (2018), briefing paper

8

Metrics for calculating CO_2 equivalent emissions

- Temperature-based metrics, and the GWP* are potentially more useful for temperature-based policy objectives, given the temperature targets of the Paris Agreement.
- All metrics produce different magnitudes of equivalence (or even sign, positive or negative), based on the user's choice of either metric or time-horizon. The GWP* and ATR minimise some dependency of time horizon. Additionally, the ATR provides the same sign for pulse and sustained emissions.
- "Ideally, the climate effects of the calculated CO_2 equivalent emissions should be the same regardless of the mix of components emitted. However, different components have different physical properties, and a metric that establishes equivalence with regard to one effect cannot guarantee equivalence with regard to other effects and over extended time periods.." (IPCC AR5, Chapter 8).

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EASA aviation non-CO_2 project

Workshop

Task 2 – Effect of existing measures on non-CO_2 emissions/impacts and trade-offs

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Overall tasks

Given the mandate, the main questions to be answered and as such tasks to be executed by the contractor are the following:

Task 1. "What is the most recent knowledge on the climate change effects of non-CO_2 emissions from aviation activities?

Task 2. What factors/variables (possibly) have had an impact on these effects? What is the level of that impact? Do these factors/variables exhibit trade-offs or interdependencies between different emissions?

Task 3. What research has been undertaken on potential policy action to reduce non-CO_2 climate impacts?"

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Objectives of the Workshop

- To present proposed approach and describe the main issues
- To gather further inputs for Task 2 from workshop participants:
  a) Is the approach suitable?
  b) Are the main issues covered?
  c) Review data/information collated
  d) Are there any other factors that should be considered?
- Iterate where appropriate
- Collate inputs from workshop participants on Task 2 in Workshop report
- Next steps

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3. Effect of existing measures on non-CO_2 emissions and trade-offs

3.1 Introduction
3.2 Current policies and regulatory framework
3.3 Technology and Potential Trade-Offs
3.4 Operational /ATM Measures and Potential Trade-Offs
3.5 Fuels and Potential Trade-Offs

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3.1 Introduction

The principle non-CO_2 climate impacts identified in Task 1 arise from **NOx emissions at cruise altitude and contrail/cirrus formation.** The effect of existing measures on these non-CO_2 emissions/effects and the main areas of **potential trade off** considered are as follows:

- Technology to control NOx emissions during cruise and potential technology trade offs with fuel burn i.e. a NOx vs CO_2 emissions;
- Technology to control nvPM emissions during cruise and potential technology trade offs with NOx (and fuel burn);
- Operational measures to avoid contrail formation and to reduce NOx impacts by flight path alteration; potential reach of such measures (Eurocontrol); potential fuel burn penalties incurred i.e. contrail and contrail cirrus vs NOx impacts and vs CO_2 emissions; and
- Fuel composition and PM : Contribution of PM to contrail/cirrus formation and identify any potential trade offs with NOx and CO_2 emissions.

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3.2 Current Policy, Regulatory Framework and Research

- Technology Standards - ICAO-CAEP Certification Standards
  - NOx engine certification standards
  - nvPM mass and number engine certification standards
  - CO_2 aeroplane certification standards
- Operation Regulation: also Key EU research CleanSky, § SESAR including REACT4C and ATM4E
- Fuel standards ASTM and DefStan: also reference to EU directive on renewable energy (RED)

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3.3 Technology and potential trade-offs

Combustion Technology

- NOx emissions, nvPM emissions and fuel burn
- Fuel burn and propulsive efficiency (and potential impacts on contrail formation)

Aerodynamics and mass reductions

Generally win-win situations leading to reduction in fuel burn without impacting on other emissions or parameters feeding into non-CO_2 impacts

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Changes in NOx emissions and technology since 2008

- What changes have there been regarding NOx emissions and technology since publication in 2008 of *"Lower NOx at Higher Altitudes: Policies to Reduce the Climate Impact of Aviation NOx Emission"*?
  - NOx Regulation (CAEP/8 stringency in 2010) and most recent recommendations for ICAO NOx Goals (in 2019);
  - Some lean burn and advanced RQL products have come into service and will continue to enter the fleet, but no emerging new NOx control technology beyond these;
  - Certification data shows the trend for increased OPR to reduce fuel burn has resulted in a higher EINOx although more stable EINOx in the last few years. Overall fairly stable and slightly declining NOx emissions per seat-km: NOx g/ASK =0.44 (2005), =0.41 (2014);
  - Uncertainty about the LTO to cruise relationship for staged combustors;
  - New regulations for nvPM based on LAQ health concerns and emerging knowledge on this topic provide an additional challenge for combustor design technology.

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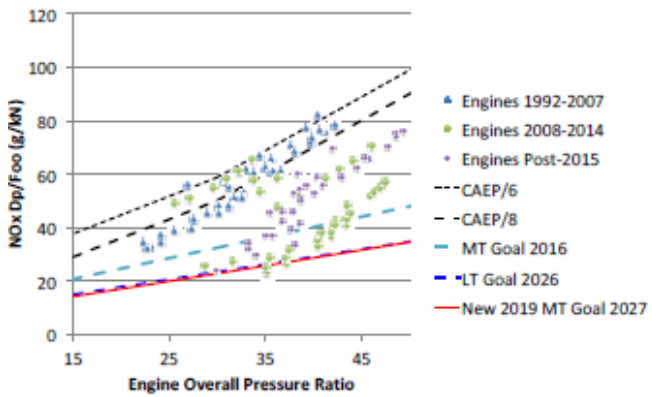
NOx certification trends

LTO emission in grams of NOx per kN rated thrust from ICAO Emissions Data Bank (EDB)



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Technology and nvPM emissions

- What recent developments have there been regarding nvPM emissions and technology?
  - New nvPM Regulations (CAEP/10 nvPM certification standard for maximum mass concentration of nvPM agreed in 2016, based on the smoke number visibility criterion; CAEP/11 nvPM mass and number LTO certification standards agreed in 2019);
  - New regulations for nvPM based on LAQ health concerns and emerging knowledge on this topic provide an additional challenge for combustor design technology;
  - Lean burn and advanced RQL products have come into service with lean-burn technology leading to very low levels of nvPM mass and number during LTO;
  - Uncertainty about the LTO to cruise relationship especially for nvPM number;
  - The recommendations of the ICAO Independent technology review (IEIR) for nvPM (in 2019).

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Technology and CO_2 emissions

- What recent developments have there been regarding CO_2 emissions and technology?
  - ICAO Aeroplane CO_2 certification standards;
  - Propulsive efficiency of a state of the art turbofan is now 80-85% but further improvements are increasingly difficult. The IEIR estimated a potential 5% improvement for SA/TA over the next ten years and possibly a further 5% in the decade after;
  - The recommendations of the ICAO Independent technology review (IEIR) for overall fuel burn improvements (in 2019) is for SA/TA around 1.3%/1.0% per annum to 2027 and around 1.2%/1.3% pa from 2027-37;
  - The expected gains from technology if the mid and long term technology goals are met are therefore in the order of 22% for single aisle and twin aisle aircraft by 2037;
  - Beyond 2037, there is the possibility of more novel technology, for example, electric aircraft etc.

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3.4 Operational measures and potential trade-offs

- Operational measures for potential contrail avoidance and reduction of NOx impacts;
- A number of research studies considering the potential for contrail avoidance and moderation of NOx emissions during cruise through operational measures and changing flight paths: REACT4C, ATM4E and peer review literature;
- Consider the potential level of impact of these proposed measures, review the published evidence with input from Eurocontrol;
- Potential fuel burn penalties, review the published evidence.

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Operational factors and NOx/contrail impacts

- Current Regulatory instruments for operations based on environmental criteria: input from Eurocontrol here may be very useful? Are there current regulations or policies that could be used?
- SESAR reducing routing inefficiencies reduces fuel burn and distance flown to as near as great circle distance as possible which reduces CO_2 emissions and generally all non-CO_2 impacts too (although this may not always be the case on a route by route basis)
- SESAR also aims to improve vertical flight efficiency : Cruising at optimum altitudes reduces fuel burn and CO_2 emissions, and ATM are sensitive to this parameter within the operational constraints of a congested air space.
- SESAR and CleanSky research: REACT4C and ATM4E developed climate cost functions to determine that overall climate impacts could be reduced by reducing the non-CO_2 impacts from contrail-cirrus and NOx even with a fuel burn penalty. The climate cost functions already incorporate a climate metric with a timescale and a relative measure of the importance of the individual forcings

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Avoiding contrail-cirrus and reducing NOx impacts?

- In research studies such as REACT4C, climate cost functions are developed whereby a climate impact (using a particular metric or set of climate metrics) is determined on a route by route basis allowing the most "climate-friendly" routes to be identified, or as in the case of ATM4E the most "environmentally-friendly" routes (as LAQ/noise impacts are also included).
- A climate cost function incorporates the climate impacts of a particular flight (i.e. principally NOx, contrail-cirrus and CO_2 impacts) based on an agreed relative importance of individual species for a reduction of the climate impact from air traffic, an agreed metric and time scale. Generally, fairly large reductions in climate impacts were demonstrated to be possible on some routes based on the assumptions embedded in the data – to determine whether more recent understanding would change these conclusions? Task 1?

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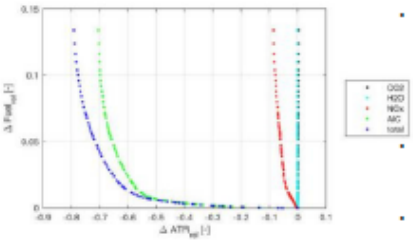
ATM4E Results



- Overall pareto-front (blue) for the top 2000 routes (in terms of ASK) of the European Airspace (intra-ECAC region)
- Can be interpreted in two ways: (1) for a given fuel penalty (y-axis) it yields the maximum climate impact reduction (x-axis) or (2) for a given climate impact reduction (x-axis) it yields the lowest possible fuel penalty (y-axis). This is terms of delta ATR ref.
- It indicates the possibility using these assumptions to reduce the climate impact by almost 60% for a fuel penalty of 1%.
- For higher fuel penalties, the climate impact mitigation efficiency is decreasing rapidly until it reaches saturation at a climate impact reduction of almost 80% with a corresponding fuel penalty of 13.5%

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In terms of basic trade-offs:

- The focus here in Task 2 is actually to provide some more generic commentary on the actual trade-offs between CO_2 and avoiding non-CO_2 impacts through operational means within these studies (rather than the conclusions of the studies which already include interpretations of relative importance of individual forcing agents, time horizons and climate metrics).
- In this case, these studies show that for a fuel penalty of 1% an amount of contrail-cirrus can be avoided (calculated as a reduction in ATR_{ref} from AIC, aircraft induced cirrus, of around -50%). Reductions in the impact of NOx emissions were much smaller (calculated as a reduction in ATR_{ref} of 1 or 2%)
- For a fuel penalty of 5% the calculated reduction in ATR_{ref} from AIC avoidance is around -65%.

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3.5 Fuel composition and potential trade-offs

- Conventional Aviation Fuel composition:
  - Sulphur (S) content impacts on vPM (lower S, lower vPM);
  - Aromatics content on nvPM (lower aromatic, lower nvPM)
  - Potential reduction in aromatics content by removal e.g. by hydro-treating or extractive distillation would have potential energy implications and life cycle emissions would need to be considered with potential CO_2 trade-offs)

- Sustainable Aviation Fuel composition:
  - Lower S and lower aromatics
    - Lower CO_2 and lower nvPM

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Fuel composition opportunities

- Impacts of aromatic content on nvPM mass and number
- Impacts of sulphur (S) content on vPM

Needs further work – both in terms of climate impacts of nvPM and potential CO_2 impacts aromatic removal

- SAF lower S and lower aromatics
- Subject of CAEP work during CAEP/12

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Summary and exchange with Task 1

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Proposed Summary and Conclusions for NOx emissions and technology – let's debate/edit/add

- In the next 10 years it is likely that EINOx will either slightly increase or remain fairly stable - a stable or slightly increased EINOx with improved fuel efficiency will result in lower or stable overall NOx emissions per pax-km.
- Increasing the future stringency of the NOx LTO standard could possibly create fuel penalties but historically both increased fuel efficiency and reduced NOx have been achieved together.
- The NOx LTO and cruise relationship is under review currently and the NOx stringency will be reviewed future in CAEP cycles.
- There are no new NOx control technologies emerging which would offer a reduction in NOx emissions for the following decade (i.e. out to 20 years).

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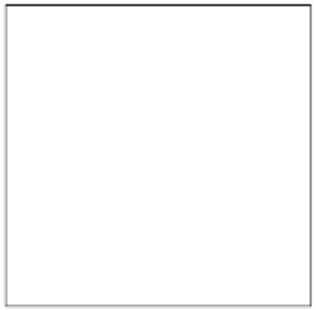
Proposed Summary and Conclusions for nvPM emissions and technology – let's debate/edit/add

- It is possible that nvPM mass and number emissions may decrease in the next 10 years as combustion and nvPM control technology improves.
- The agreement of the new LTO nvPM standards provides an regulatory instrument for the future reduction of nvPM emissions.
- However, the relatively new and complex field of nvPM reduction particularly for nvPM number means that the potential for improvement through technology remain uncertain.



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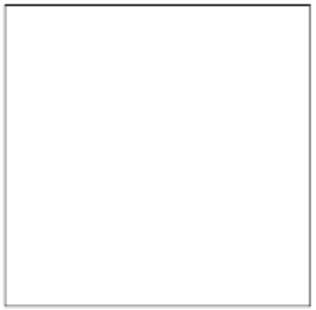
Proposed Summary and Conclusions for CO_2 emissions and technology – let's debate/edit/add

- The ICAO CO_2 standards provide a regulatory instrument for the future reduction of CO_2 emissions through technology in addition to the commercial incentive for lower fuel burn;
- Slowing down of fuel efficiency improvements through technology over the last decade;
- The IEIR decision on CO_2 technology goals during this most recent review provided Fuel burn goals out to 2037 of around 22% below current levels.
- Beyond 20 years – electric hybrid novel structures etc.



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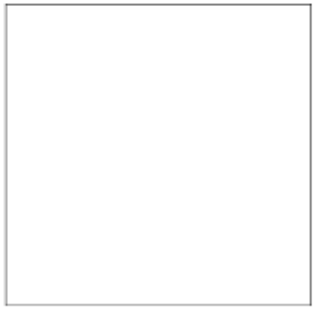
Proposed Summary and Conclusions for contrail-cirrus and NOx impacts and operations – let's debate/edit/add

- Operational options exist for reducing impacts of NO_x (reducing cruise altitudes) but these would involve a fuel burn, and therefore CO_2 penalty. The change in NOx impact due to altitude is subject to uncertainty as described in Task 1.
- Operational opportunities exist for mitigating contrail cirrus. These involve either changing route or changing time of operation. This would be on a flight-by-flight basis and, on most occasions, this would involve additional fuel burn and therefore CO_2.
- Where trade-offs exist between reduced non-CO_2 forcing and increased CO_2 forcing, the net benefit or disbenefit depends upon the choice of metric and time-horizon applied. Research studies have shown some promising results based on the assumptions made.



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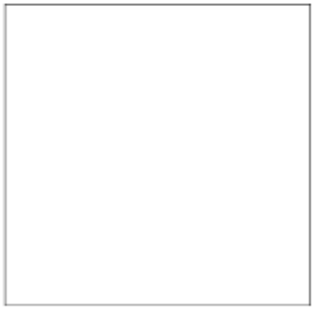
Proposed Summary and Conclusions for fuel composition – let's debate/edit/add

- The chemical composition of fuel impacts on the level of emissions:
  - Reduced aromatic content reduces nvPM mass and number emission; and
  - Reduced Sulphur content reduces the SOx formation in the plume and the mass of vPM.
- Reducing S and aromatic content of conventional aviation fuel would need to consider the energy implications of the removal process.
- Sustainable Aviation Fuel has lower S and aromatics content.
- ICAO is currently conducting research and cost and environmental benefits work on this topic. See Task 1 for uncertainties on the climate impacts of PM emissions
- Consideration of ways of working with fuel standards community.



Aviation non-CO_2 climate impacts

Task 3: Potential policy action

CE Delft

Committed to the Environment

What should policies aim for?

- Reduce all emissions, but mainly CO_2
- Reduce overall climate impact
- Reduce NO_x emission impacts
  - Definitely not at the expense of CO_2 emissions
  - Possibly at the expense of CO_2 emissions
- Reduce contrails/cirrus impacts
  - Definitely not at the expense of CO_2 emissions
  - Possibly at the expense of CO_2 emissions
- Reduce all other emissions

- Are these all options?

What should policies aim for?

Evaluation of the options (1/2)

- Reduce all emissions, but mainly CO_2
  - Best option, because growth is the main problem
    - Sustainable aviation fuels/electrical aircraft. NO_x remains the same. Contrails reduce but not so much. H_2: more contrails, but not NO_x
    - Aviation demand
- Reduce overall climate impact
  - But how can this be measured?
    - Climate-optimised flight paths (metric, CO_2 penalty)
- Reduce NO_x emission impacts, possibly at the expense of CO_2
  - Be careful because NO_x is short-term and CO_2 is long term, see previous option.

What should policies aim for?

Evaluation of the options (2/2)

- Reduce NO_x emission impacts but not at the expense of CO_2
  - Is it possible?
  - Good idea based on Lee et al., 2009 and 2020
  - Don't go there because NO_x *may* be cooling (Etminan et al., 2016) and CO_2 is always warming
- Reduce contrails/cirrus, possibly at the expense of CO_2
  - Be careful because contrails are short-term and CO_2 is long term
- Reduce contrails/cirrus, but not at the expense of CO_2
  - Is it possible?
- Reduce all other emissions
  - Not really worth the effort because the climate impacts are small (Lee et al., 2009 and 2020)

Overview of policy options

Impact/emission		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
	1. Aviation demand	-	-	Aviation taxes - Ticket taxes - Fuel taxes - Carbon taxes EU ETS - Include non-CO_2 element	-	Sustainable aviation fuels mandate (will reduce demand because they are more expensive)
	2. Overall climate impact	-	-	Fuel tax with a NO_x component dependent on the engine	Climate-optimised ATM	
	3. NO_x emissions	Phase-out older engines Introduce new standards for NO_x emissions Develop cruise-NO_x standard	-	LTO NO_x * distance charge Include NO_x in ETS	Lower flight levels	-
	4. Contrails	-	-	-	Contrail-optimised ATM	Low-aromatic fuel mandate; Low-aromatic fuel subsidy -
	5. Soot/nvPM	Phase-out older engines Introduce new standards for soot emissions Develop cruise-soot standard	-	LTO soot * distance charge	-	Low-aromatic fuel mandate; Low-aromatic fuel subsidy

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Policy options and environmental trade-offs

Impact/emission		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
	1. Aviation demand	-	-	Aviation taxes - Ticket taxes - Fuel taxes - Carbon taxes EU ETS - Include non-CO_2 element	-	Sustainable aviation fuels mandate (will reduce demand because they are more expensive)
	Short-term trade-offs (constant technology)			Lower fleet turnover, potentially slower autonomous progress		Lower fleet turnover, potentially slower autonomous progress
	Long-term trade-offs in technology development			Lower demand for new aircraft, potentially less innovation		Lower demand for new aircraft, potentially less innovation

6

Policy options and environmental trade-offs

Impact/emission		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
	2. Overall climate impact	-	-	Fuel tax with a NO_x component dependent on the engine	Climate-optimised ATM	
	Short-term trade-offs (constant technology)					
	Long-term trade-offs in technology development					

7

Policy options and environmental trade-offs

Impact/emission		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
	3. NO_x emissions	1. Phase-out older engines 2. Introduce new standards for LTO NO_x emissions 3. Develop cruise-NO_x standard	-	1. LTO NO_x * distance charge 2. Include NO_x in ETS	Lower flight levels	-
	Short-term trade-offs (constant technology)	1. None 2. None 3. None		1. None 2. None	Higher CO_2 emissions	
	Long-term trade-offs in technology development	1. None 2. Potentially higher CO_2 emissions 3. Potentially higher CO_2 emissions		Higher CO_2 emissions		

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Policy options and environmental trade-offs

		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
Impact/emission	4. Contrails	-	-	-	Contrail-optimised ATM	Low-aromatic fuel mandate; Low-aromatic fuel subsidy
	Short-term trade-offs (constant technology)				Higher CO_2 emissions	Lower tank-to-wing CO_2 emissions, but potentially higher lifecycle CO_2 emissions
	Long-term trade-offs in technology development				None	Lower tank-to-wing CO_2 emissions, but potentially higher lifecycle CO_2 emissions

Policy options and environmental trade-offs

		Type of measure				
		Aircraft and engine technology standard	Aircraft operations standard	Market based measures	ATM	Fuel
Impact/emission	5. Soot/nvPM	1. Phase-out older engines 2. Introduce new standards for LTO soot emissions 3. Develop cruise-soot standard	-	LTO soot * distance change	-	1. Low-aromatic fuel mandate; 2. Low-aromatic fuel subsidy
	Short-term trade-offs (constant technology)	1. None 2. None 3. None		None		Lower tank-to-wing CO_2 emissions because of higher energy density of the fuels, but potentially higher lifecycle CO_2 emissions Potentially lower sulphate emissions
	Long-term trade-offs in technology development	1. None 2. Potentially higher CO_2 and other emissions 3. Potentially higher CO_2 and other emissions		Potentially higher CO_2 and other emissions		Lower tank-to-wing CO_2 emissions, but potentially higher lifecycle CO_2 emissions

Issues to consider in designing policies

- How can the policy be designed
  - Policy level (EU / MS / ICAO)
  - Responsible entity (aircraft manufacturer / aircraft operator / ATM service provider / airport / aviation consumer, …)
  - Type of obligation
  - Monitoring and reporting
  - Enforcement
  - Stringency
- What are the trade-offs that should be considered when designing the policy
  - Short- and long-term impact on emissions
  - Other relevant impacts, e.g. on actors
- Feasibility of implementation

MINUTES OF MEETING

Subject	Workshop on the effects of non-CO_2 aviation emissions on climate change
Date	20.11.2019
Location	EASA Office, Brussels
Organised by	Steve Arrowsmith, EASA Certification Directorate

List of Participants

Attendees	Project Team: Steve ARROWSMITH, EASA Martin SCHAEFER, EASA Philippe LENNE, DG MOVE Viktoria TSITSONI, DG MOVE Cheryl MICALLEF-BORG, DG CLIMA Andrew WATT, EUROCONTROL Stavros STROMATAS, EUROCONTROL David LEE, MMU Bethan OWEN, MMU Agnieszka SKOWRON, MMU Jasper FABER, CE Delft Lisanne VAN WIJNGAARDEN, CE Delft Jan FUGLESTVEDT, CICERO Marianne LUND, CICERO Robert SAUSEN, DLR Olivier BOUCHER, CNRS Ayce CELIKEL, ENVISA *(via WebEx)* External Experts: Myles ALLEN, University of Oxford *(via WebEx)* Volker GREWE, TU Delft *(via WebEx)* Ulrike BURKHARDT, DLR Etienne TERRENOIRE, ONERA Frank DENTENER, DG JRC *(via WebEx)* Matteo PRUSSI, DG JRC *(via WebEx)* Peter VAN VELTHOVEN, KNMI Andre VAN VELZEN, TAKS Chris EYERS, LimitedSkies Martin PLOHR, DLR Stephanie SCHILLING, EEA *(via WebEx)*

AGENDA

Welcome and Introduction
Summary of study ToR and confidentiality
Task 1: Most recent knowledge on the climate change effects of non-CO_2 from aviation
Task 2: Effect of existing measures on non-CO_2 emissions/impacts and trade-offs
Task 3: Policy options to reduce non-CO_2 emissions
Summary of key points from discussions
AOB

Welcome and Introduction

Steve ARROWSMITH welcomed the project team and external experts to the workshop, which was organised in the context of the planned study about non-CO_2 effects of aviation.

Summary of study ToR and confidentiality
Presented by: Steve, Philippe, Cheryl

Steve ARROWSMITH gave an introduction into the planned study, which is triggered by Article 30(4) of the revised EU ETS Directive. The project is funded by the European Commission and managed by EASA. The study assesses non-CO_2 climate impacts of aviation and policy measures to mitigate such impacts, with a focus on new findings since 2005-2008. The goal of the meeting was to discuss preliminary key messages, in particular but not limited to atmospheric science, in order to ensure that those represent a consensus amongst the experts.

Philippe LENNE and Cheryl MICALLEF-BORG highlighted the confidentiality of the study contents. While we can communicate that this project is ongoing, any results and contents shall not be disclosed. Attendees are reminded to not share material or discussions from the workshop.

Task 1: Most recent knowledge on the climate change effects of non-CO_2 from aviation
Presented by: David, Agnieszka, Marianne, Jan

David LEE gave a presentation about 'emerging points' from the study, covering emissions, effects, and metrics.
Regarding **aviation emission quantities**, the discussion focused on knowledge gaps: while emissions of CO_2, water vapour and – to a lower degree – NO_x are comparably well quantified, sulphur and soot emissions can be regarded as poorly quantified. Sulphur emissions depend on fuel properties, which are not well known on a worldwide basis, while only limited number of measurements exist for soot emissions. Bethan OWEN added that ICAO initiatives to collect fuel properties via State Letters has not delivered good results. Cruise emissions of NO_x and particles are an additional source of uncertainty, particularly for unconventional engine combustor configurations. Robert SAUSEN mentioned that insights into actual cruise emissions have been gathered from in-flight measurements, but further work is required.

Effects of aviation on climate were suggested by David to be quantified by means of the effective radiative forcing (ERF), as proposed by IPCC in the 5th Assessment Report (2013). ERF would be a better proxy than RF for future changes in global mean surface temperature response as it takes into account the non-CO_2 'fast' atmospheric forcing effects. Myles ALLEN agreed with this view and stressed the importance of context, plain English and, as far as possible, 'simplicity' when communicating to policymakers (e.g. 1000 billion tonnes of CO_2 emissions results in an increase in RF of 1W/m^2). Ulrike BURKHARDT and Volker GREWE mentioned that both RF and ERF are backward looking and could be useful depending on the goal of an assessment and emissions scenario. Olivier BOUCHER stated that he saw RF and ERF as more overlapping then complementary and that, while ERF is potentially a better predictor of GMST, it is also more uncertain.

Main non-CO_2 radiative effects from aviation are from **NO_x and contrail/contrail-cirrus**. Quantification

of the contrail/contrail-cirrus effects in cloud free air have improved recently, but further research is needed to consider effects within clouds. Robert SAUSEN mentioned that water vapour effects become important should supersonic aircraft witih higher cruise altitudes be reintroduced. Volker GREWE mentioned that the altitude-dependency for water vapour effects are already important for recent subsonic aircraft designs cruising at flight levels 410-430. Peter VAN VELTHOVEN mentioned that an evolution of knowledge for NO_x has taken place, but, as a result, its warming effects must be regarded as less certain than it appeared in the past.

Agnieszka SKOWRON explained in her presentation that the **net NO_x effect** may be lower than previsouly assumed or – in certain future scenarios – even negative. Recent studies show that the climate impact of aviation NO_x depends on surface emissions from other sources. A cleaner background environment mitigates some of the aviation NO_x radiative forcing on a non-linear basis. David pointed out that short-lived climate forcers should be reduced, but care should be taken regarding aircraft NO_x policies given current uncertainties. Peter suggested that priorisation regarding the reduction of different short-lived forcers should be discussed. Myles highlighted the 'big picture' objectives in the Paris Agreement and IPCC 1.5degC report which refers to net zero CO_2 emissions and a reduction in RF from other non-CO_2 climate forcers.

Marianne LUND presented information on **metrics for calculating CO_2 equivalent emissions**. Temperature-based metrics and the GWP* are potentially more useful for temperature-based policy objectives. GWP and GTP are common metrics used by IPCC. GWP100 is the default metric for UNFCCC and EU-ETS, but GWP may not be suitable to assess short-lived climate forcers. Derivative metrics (GWP*, iGTP, ATR) express the changes in different ways or overlay an economic dimension to the physically based metrics. Main discussion item was GWP*: Myles ALLEN clarified that the scientific integrity of GWP* is undisputed, while its application to policy measures can be discussed. Marianne added that the AGTP concept has also been used frequently in recent literature. Stephanie SCHILLING added that no shift from GWP to GWP* had been observed in terms of the UNFCCC submissions. Myles confirmed that the use of GWP* instead of GWP100 makes no difference to CO_2 effects, and mitigates the issue that GWP100 undervalues any increase in short-lived climate species' emission rates, but overvalues ongoing emissions.

Olivier and Myles initiated a discussion about **whether long-lived climate forcers and short-lived forcers should be tradable against each other** in a policy measure ("stock" CO_2 against "flow" non-CO_2 pollutants"). Olivier argued that, although scientifically sound, GWP* does not provide a practical actionable metric for trading. Miles also cautioned that there is not true equivalent, that trading may not be sensible, and suggested that both aspects should be treated separately. This was captured in the IPCC AR5, Chapter 8:
"*Ideally, the climate effects of the calculated CO2 equivalent emissions should be the same regardless of the mix of components emitted. However, different components have different physical properties, and a metric that establishes equivalence with regard to one effect cannot guarantee equivalence with regard to other effects and over extended time periods*."
Robert SAUSEN noted that in the aviation world, CO_2 and non-CO_2 emissions are interrelated, and should be accounted for accordingly in order to set the right incentives to minimize the total aviation effect on climate in the most efficient way. It was agreed that reducing only CO_2, while not addressing non-CO_2 emissions, would be neither enough nor optimal to reach climate goals. Myles also noted that the GWP* was a more appropriate metric if future scenarios included serious plans to mitigate total emissions.

David LEE continued his presentation about **contrail and contrail cirrus effects**. A dependence of contrail/contrail-cirrus formation on soot emissions is shown by the models, and climate effects are potentially large. Uncertainties regarding the magnitude of these effects are high. The use of ERF, instead of RF, to assess contrail-cirrus could have a large impact on the previous results with a reduction of approx. 50%. Ulrike pointed out that when reducing the number of particles from aircraft engines by 50% (e.g. by use of sustainable fuels), their impact on climate could be reduced in the order of 15-20%. The interrelation between soot emissions and contrail/cirrus formation is non-linear, ranging from a small reduction in RF when decreasing soot slightly, a larger reduction of effects with further soot decrease, and an increase in RF should soot emissions be reduced by more than 90%. Indirect aerosol-cloud interaction radiative effects from sulphur also has very large uncertainties that preclude any best estimates.

Etienne TERRENOIRE underlined the fact that reducing strongly the soot emissions at the engines exits could modify the microphysics processes that were up to now identified as crucial. For example, poorly quantified organics matter from the aircraft engines, as well as background ice nuclei, could see their roles in contrails formation (and thus contrails properties) leading to the need for a specific detailed microphysics study dedicated to contrails formation in the plane near-field.

David and Jan FUGLESTVEDT presented a still unpublished **updated ERF chart** intended to summarize the climate effects of aviation. Contrail-cirrus effects are larger than CO_2 efffects when using ERF as a backward-looking metric, but with greater uncertainty and lower confidence level. Net NO_x effects are estimated to be positive for now. Non-CO_2 effects in total represent more than half of the aviation effects on climate. Steve ARROWSMITH asked for more information regarding the confidence levels shown in the chart. David explaind that a qualitative IPCC approach is applied to estimate confidence levels, unlike the level of scientific understanding shown in previous chart from Lee et al. 2009. Ulrike mentioned that the uncertainty bars in the chart do not include the uncertainty related to the conversion of RF to ERF.

Task 2: Effect of existing measures on non-CO_2 emissions/impacts and trade-offs
Presented by: Bethan, David

David shortly introduced **mitigation opportunities** for aviation's climate impacts. Contrail impacts can be mitigated by operational measures, but at the cost of a fuel-burn penalty. Net benefits of such avoidance measures depend on time horizons and metrics, and the uncertainties regarding certain input assumptions (e.g. particle number emissions in cruise) affect the quality of results.

Bethan OWEN gave a presentation on technology and operational measures to reduce aviation emissions. Various technology trade-offs between engine emissions and fuel burn or between different emissions exist and need to be considered. Discussions focused on **certification standards** for NO_x and nvPM emissions of aircraft engines, and the aeroplane CO_2 standard. NO_x standards have been tightened several times in the past, resulting in the development of advanced RQL and staged/lean-burn combustor technology with lower NO_x emissions. Lean-burn combustion has co-benefits in terms of low NO_X and nvPM emissions. No step-change technologies are expected at the aircraft or engine level in the next 20 years. Cruise NO_x emissions and nvPM emissions (by mass and number), in particular for staged/lean-burn combustors, were identified as knowledge gaps that needed to be addressed. Chris EYERS suggested to consider obligatory reporting of cruise NO_x and cruise nvPM emissions by the manufacturers on their aircraft engines. Robert SAUSEN mentioned that

the size distribution of particle emissions is of interest to the atmospheric science community, and that hybrid aircraft with hydrogen powered engines could be feasible in the short term. Martin SCHAEFER raised a concern regarding the observation that conventional combustors replace newly developed lean-burn combustors on some engines for reasons of cost, reduced complexity and a minimal fuel-burn benefit (<0.5%), but at the cost of significantly higher NO_x and nvPM emissions. Chris explained the tradeoff between the nvPM and NO_x emissions during combustor design. It was noted that there may be potential to motivate manufacturers to focus more on nvPM rather than on NO_x by communicating policy preferences on this matter based on the lateast scientific understanding.

Research in the REACT4C and ATM4E projects have combined CO_2 and non-CO_2 effects of aviation for assessing operational mitigation measures (**climate-optimized flight trajectories**). REACT4C and ATM4E use climate cost functions to determine that overall climate impact of flights can be reduced by reducing non-CO_2 impacts (even with a fuel burn penalty). Under a set of specific assumptions, Volker GREWE explained that the contrail impact is typically larger than the NO_x impact when optimising flight profiles for minimum climate impact (e.g. in terms of ATR). In ATM4E, different metrics and time horizons were explored, and those lead to similar results. Intermediate-stop operations and formation flight are **other operational concepts** mentioned by Robert SAUSEN. Andrew WATT added that an element linked to the environmental efficiency of a flight could be added to the route-charging concept.

Fuel composition (sulphur and aromatics) influence nvPM emissions, according to Bethan's presentation, with potential consequences for contrail formation, at least in a situation where formation criteria are met by a high margin. **Synthetic fuels (biofuels or PtL)** also have benefits through the formation of a lower amount of the smaller particles, leading to a reduction in the climate effect of contrail/contrail cirrus.

Task 3: Policy options to reduce non-CO_2 emissions
Presented by: Jasper, David

David LEE introduced options for addressing non-CO_2 from a science perspective. **Multiplier approaches** for use with the ETS (constant multiplier vs. CO_2-equivalent emissions on a flight-by-flight basis) can be discussed, but have disadvantages in terms of data requirements, scientific uncertainty and/or would not set the right incentives. Robert SAUSEN suggested an additional option in between the aforementioned two approaches, i.e. height- and latitude-dependent climate cost functions. Other policy options resulting from Task 2 discussions included more stringent engine emissions technology standards, and reducing contrail cirrus by operational measures. Both options have pros and cons. Fuel-related options include the promotion of sustainable aviation fuels (biofuels, PtL fuels), in order to reduce lifecycle CO_2 emissions with co-benefits for nvPM and reduced aromatics. PtL fuels with zero net CO_2 emissions could be produced using renewable energy. Robert SAUSEN cautioned that CO_2 provision for PtL production is an open issue, at least for large-scale production.

Jasper FABER iniatiated a discussion about **policy aims**. Should policies aim to reduce all emissions (but mainly CO_2), reduce the overall climate impact of aviation, or any other option? Cheryl mentioned the Paris objectives, which need to be considered at a higher level. Volker asked whether the policy aims mentioned by Jasper are for an individual flight or for the whole sector? Jan suggested to focus on temperature goals rather than all climate impacts. In terms of emissions, the net-zero CO_2

emissions goal could play a key role. Robert highlighted that non-CO_2 emissions are important, and temperature goals will not be reached without reducing them.

Jasper initially focused on the aim to **reduce all emissions, but mainly CO_2**. Fuel-based measures and technology measures (electrical or hydrogen-powered aircraft) could be seen as appropriate examples to address such a goal. Ulrike questioned whether H2-powered aircraft would produce more contrails, as mentioned on Jasper's slides, due to the H_2O growing and dropping out quickly. Chris clarified that for H2-powered aircraft with conventional combustion, also NO_x would be produced. An alternative policy aim would be to **reduce the overall climate impact**, e.g. by means of promoting climate-optimised flight trajectories, at the risk of drawbacks in terms of accuracy. Robert SAUSEN mentioned that the accuracy would not have to be high for every individual flight as along as the climate cost function has good results on average. The metrics chosen for such an approach should ensure that effects go in the right direction. Ulrike cautioned to keep such simplified cost functions under review in order to ensure that they correspond to results of climate models, and latest scientific understanding, thereby meeting environmental protection objectives. Olivier shared his thought that long-lived and short-lived species had different "status": the climate effect of CO2 has a high level of certainty and is already considered by airlines because of fuel cost (rather than taxation) while the climate effects of short-lived species is more uncertain and unaccounted for. In a first approach, short-lived species could initially be given a lower weight, which may be increased later as science develops. Olivier also suggested that more importance should be given to contrail/contrail-cirrus than to NOx because i) the magnitude of the NOx effect is being revised downwards, ii) it may be less in a hypothetical future cleaner atmosphere, iii) it has already been addressed to some extent by legislation. @:Volker suggested to define in more detail the time horizons that are of interest for the policy side, and develop an appropriate (combined) metric from there. **Reducing NO_x emissions** and **reducing contrails/cirrus** were presented as further policy aims by Jasper. Andrew WATT pointed out that any policy measure should be easy to communicate and be based on sound science without high levels of uncertainty. Resistance from airlines and the public can be expected otherwise.

Jasper ended his presentation by giving an **overview of different policy options**. A sustainable fuel mandate or aviation taxes would indirectly impact aviation demand. Lower fleet turnover and less innovation could be negative consequences. Steve asked whether a positive short-term impact for market-based measures could be the early retirement of old aircraft, which was confirmed by Jasper. Robert raised doubts whether a negative impact in terms of innovation will be the result, as any such policy could be regarded as incentivising technologies. Climate-optimised ATM and a fuel tax with a NO_x (or nvPM) component were presented as further example measures. NO_x (or nvPM) reduction policies could consider more stringent emission standards, or inclusion of these emissions into market-based systems. Robert mentioned that avoiding only the most important contrails by incentives or penalties to avoid airspace with the biggest effects from supersaturated air, could be an option to discuss. Etienne TERRENOIRE mentioned that the quality of weather forecast information could be a risk for any such measure.

Summary of key points from discussions

Steve ARROWSMITH thanked the participants for attending the workshop and for their expert input into the discussions. Meeting minutes that include a summary of discussions will be distributed for review and comments after the meeting. Any further input by participants would be most welcome

and can be provided by email. Cheryl MICALLEF-BORG thanked the external participants on behalf of the European Commission for their valuable contribution to this workshop.

AOB
-

MoM prepared by	Martin SCHAEFER	**21.11.2019**	
MoM reviewed by	Steve ARROWSMITH	**22.11.2019**	