ABC Impacts – Users' committee meeting – 26 March 2010

Workshop on aviation scenarios and climate impacts

Minutes

Attendances

ABC Impact research team	– Sandrine Meyer (CEESE-ULB) – Julien Matheys (ETEC-VUB) – Annalia Bernardini, Tom van Lier, Pr. Cathy Macharis (MOSI-T-VUB) – Andrew Ferrone, Patrick Grenier, Philippe Marbaix, Ben Matthews (ASTR-UCL) Excused : Pr. Walter Hecq (CEESE-ULB), Pr. Joeri Van Mierlo (ETEC-VUB), Pr. Jean-Pascal van Ypersele (ASTR-UCL)
Workshop guests	– Chris Eyers (QINETIQ) – Christime Frömming (DLR) – Carmen Köhler (DWD, DLR)
Users' committee members	– Pierre Courbe (IEW) – Caroline De Bosscher and Caroline De Geest (Vlaamse Milieumaatschappij) – Pieter Deschamps (Vlaamse Luchthavencommissie) – Georges Jamart (The Belgian Scientific Policy) – Maarten Maes (The Brussels Airport Company) – Elisabeth Peeters (Belgocontrol) – Pierre Sohier (SPF Mobilité et Transport) Excused : Liesbeth Clerick and Ruth Declerck (AMINAL), Guy Verluyten (Belgocontrol), Bruno Van Zeebroeck (BBL), Rasa Sceponavisciute (EU)

Agenda of the meeting

1. Welcome ………………………………………………………………………………………… (09.30)
2. Synthesis ABC Impacts project results and forthcoming work ……………………………… (09.40)
   (Sandrine Meyer ; CEESE-ULB)
3. Technology developments and aviation growth up to 2050 ……………………………… (10.00)
   (Chris Eyers ; QINETIQ)
4. Impacts of flight altitude changes on aviation climate forcing ……………………………… (10.30)
   (Christine Frömming ; Deutsches Zentrum für Luft- und Raumfahrt, DLR)

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5. Prediction of ice-supersaturated regions in the DWD weather models ……………………… (11.15)
   (Carmen Köhler ; Deutscher Wetterdienst, DWD ; DLR)
6. Multi Criteria Analysis in the ABC Impacts project ……………………………………… (11.45)
   (Annalia Bernardini ; MOSI-T-VUB)
7. Discussion / Questions ………………………………………………………………………… (12.05)
8. Conclusions and closure ……………………………………………………………………… (13.00)

Remark: all the words appearing in blue in the text are explained in more detail in the ABC Impacts glossary (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_in_brief.php#glossary).

1. Welcome

Seeing that the last users' committee was organised in parallel with a workshop dedicated to "Non-CO_2 aviation climate impacts" and that the form was successful, the ABC consortium decided to set up a third workshop for the sixth and last ABC users' committee. To be in line with the finalisation of the ABC Impacts project, the topic chosen for the workshop is "Aviation scenarios and climate impacts".

2. Synthesis ABC Impacts – project results and forthcoming work

Sandrine Meyer's presentation: see ABC Impacts website → Open Section → Project publications → Workshops (http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/workshop_26_march_2010_CEESE_ABC.pdf)

2.1 Draft final report of September 2009

In September 2009, a draft final report has been written and reviewed by external experts. This report is not publicly available but can be obtained on request from the ABC consortium: comments and remarks are welcome. The final report will be a public document and is expected at the end of July 2010 (end of the ABC Impacts project).

The following points synthesize the major topics broached in the draft report trying not to repeat what has already been presented during the former users' committee meetings.

2.2 Market trends

On average all transport registered a strong increase in the EU(27) from 1995 to 2007 regarding passengers transport (+27%), as well as freight transport (+38%). Aviation showed the sharpest growth in both market segments (+ 70,4% passengers, + 55% cargo), while for maritime transport figures are by far contrasted with – 7,7% as regards passengers transport and + 37% as regards cargo.

This trend was however softened by the economic crisis which started at the end of 2008. Eurocontrol's graph (slide 4) concerning IFR flights within the ESRA (European Statistical Reference Area) illustrates the decline due to the crisis and the differences in the market segmentation: low cost and traditional airlines experienced the heaviest fall, while non-scheduled flights and cargo seemed to be relatively spared from the crisis. The business segment has been confronted to a situation in the middle of these two extremes.

Having a look at the forecasted trends, Boeing expects by 2028 a high growth in aviation activity with a more intensive aircraft utilization (the fleet increase will be less important than the growth in pkm and tkm). The Asia-Pacific area may consolidate its dominant position in aviation going from 32% of total air traffic nowadays to more than 41% by 2028.

As regards Europe, Eurocontrol highlights that rapid trains are expected to compete with air traffic on major EU city-pairs, but in average air traffic in 2030 should anyway reach 1,7 to 2,2 times the traffic volume in 2007. Concerning the economic crisis, eastern European countries seem to be less hit than western European countries. Globally, the crisis should correspond to a delay of +/- 4 years in the traffic volume compared to previous expectations.

At the Belgium-Luxembourg level, overflights accentuate their climate impacts compared to flights operating from local airports (LTO flights) with a growing gap in emission levels (slide 6). This trend is expected to go on in the following years. However, so far both overflights and LTO flights have suffered from the economic crisis with their respective fuel consumption and related emissions registering a decline in 2009 (slide 6).

2.2 Technology improvements and emission trends

Taking into account the different potentials of emission reduction on the one hand and considering the expected activity growth in the aviation sector by 2050 on the other hand, technological improvement

(R&D and ATM) will not be sufficient to balance aviation climate impacts.

Moreover, alternative fuels seem not to be an adequate response to the stake due to several questions they raise as regard their environmental effectiveness and equity issues:

- What is/will be the real climate impact related to their production? Will the production be dedicated to aviation or to other uses?
- Agro-fuels risk to compete with the food sector and to intensify deforestation.
- Different alternative fuels, and especially H_2, will probably increase non-CO_2 aviation climate impacts.

Taking these considerations into account, priority should be given to technological improvements that first reduce drastically the aircraft fuel consumption (which is in line with airlines goals) and then reduce fuel sulphur content in order to limit AIC formation (also in line with the improvement of air quality around airports). Presentations of Christine Frömming and Carmen Köhler will explain how it is possible to avoid contrails formation thanks to improved ATM and flight planning tool.

2.4 Aviation climate impacts

There is a specific trade-off between CO_2 and non-CO_2 aviation climate impacts according to the flight altitude (slide 10). An optimisation of the fuel consumption will not minimise the total climate impacts: flying at higher altitude reduces the fuel consumption, while flying at a lower level would minimise the aviation total climate impacts even if the fuel consumption is not optimised.

This should be kept in mind while improving Air Traffic Management systems to help mitigating aviation total climate impact.

More details on the theory of this phenomenon will be found in the presentation of Christine Frömming. Carmen Köhler works also on this topic in order to improve the prediction of ice-supersaturated regions. This knowledge is then used to develop software able to optimise flight route taking into account the total climate impact of the aircraft.

In the ABC Impacts project, a regional climate modelling approach has been developed in order to study non-CO_2 aviation climate impacts and more specifically the contrails and cirrus formation (AIC). It is based on the Schmidt-Appleman criterion (slide 11) which determines the atmospheric conditions (temperature and partial water vapour pressure) under which a specific aircraft will induce linear (green area on the graph) or persistent contrails (red area on the graph). It is important to note that a more efficient aircraft (that is to say an aircraft with smaller fuel consumption) will meet more often the right conditions to generate AIC.

The relationships described on the representation of the Schmidt-Appleman criterion have been combined with a climate model in order to simulate the cloud cover above Europe that has been induced by aircraft.

The graph on slide 12 shows areas (in dark red) where aviation has an influence on the formation of the high cloud cover. This is the result of the difference between two regional climate model runs:

- one giving the cloud cover taking into account the air traffic,
- and the second one giving the cloud cover assuming that no aircraft has flown in the sky.

The result of this calculation gives the additional cloud cover due to aviation activities.

The altitudes where contrails are more prone to form are situated between 8 and 12 km. Seasonal and diurnal cycles are observed (more contrails in the winter and during the night).

The modelling is quite robust seeing that the comparison of the results of the regional climate model with satellite observations of contrails formation shows a relative good similarity.

At another scale, the simple climate model JCM has been updated and used to test the consequences of three hypotheses. The climate impact of the aviation sector has been compared to the climate impact due to the development of the other sectors, under the constraint of a climate stabilisation (which has been translated into a target of limiting the global warming at a maximum of +2°C).

1. First hypothesis: aviation climate impacts are not mitigated at all (column 1);
2. Second hypothesis: mitigation policy is applied to the aviation sector of Annex-I countries only (column 2);
3. Third hypothesis: mitigation policies applied to aviation are in line with the emission reduction objectives for other sectors (column 3).

The leeway left to the development of other sectors is greatly dependent on the magnitude of the mitigation objectives of the total climate impact of the aviation sector (see first line, the difference between total fossil fuel emissions and bunker fuel emissions in grey).

2.5 Climate policy options and Multi Criteria Analysis (MCA)

In order to mitigate aviation climate impacts and in the absence of a world-wide consensus, the European Union adopted a new directive to include aviation CO_2 emissions in the EU-ETS. This measure does not tackle the total aviation climate impacts given that non-CO_2 aviation climate impacts and flights departing from or arriving at a non-EU airport are not covered.

Therefore, the ABC Impacts project will use a multi-criteria analysis to study potential complementary policy measures to improve the mitigation of the total climate impact of the aviation sector. The objective is to study characteristics of potential policy mixes and make recommendations to Belgian policy makers.

2.6 Work in progress

The final report is expected at the end of July 2010. Until then, the regional climate modelling and the emission calculator will be refined, and the multi-criteria analysis will be performed.

2.7 Preliminary conclusions

From the Belgian point of view, it is important to take into account climate impacts due to overflights (mainly AIC) along with the impacts from national LTOs and to put the emphasis on operational measures (e.g. reduce AIC formation) and modal shift mainly for intra-EU travels.

From the global point of view, if the objective is to stabilise global warming at +2℃, it implies that aviation has to reduce its total climate impact in order to avoid impeding other sectors' development too much. Moreover, it has to be considered that AIC has a greater climate impact than NO_x (AIC from aviation has a climate impact of the same order of magnitude as CO_2).

From both points of view, ignoring non-CO_2 aviation climate impacts will reduce climate policy measures effectiveness and could even worsen aviation climate impacts (cf. several trades-offs).

2.8 Questions / remarks

- *Chris Eyers highlights that no error bars are included in the JCM graph and asks if uncertainties have been taken into account.*

  Andrew Ferrone explains that uncertainties have been integrated on the basis of the best guest values and that researchers are aware of the ranges around these values. Ben Matthews adds that it is difficult to integrate the error dimension on such plots and that integration over time represents also as big factor as uncertainties. The most important point to keep in mind is not specifically the error range but the minimum value showing that climate impact of non-CO_2 aviation emissions is on the same order of magnitude than CO_2 emissions.

  Chris Eyers agrees and recognises that politicians do not like error bars but that this has to be kept in mind for research works. Moreover, it is an important factor to determine appropriate policy measures.

3. Technology developments and aviation growth up to 2050

Chris Eyers' presentation: see ABC Impacts website → Open Section → Project publications → Workshops (http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/workshop_26_march_2010_Eyers.pdf)

3.1. Demand side

Historically, the aviation sector annual growth factor varies between 4-5% since the 40's, which means on average a doubling of the activity every 20 years. Some special events (such as recessions or wild card events) have impeded the trajectory but generally after a small delay, the growth has continued its general trend.

Different forecasts have been made as regards forthcoming aviation development. Those from CAEP include moderate technology and operational improvement in the BAU scenarios, while other scenarios integrate better performances.

Slides 6 and 7 give an overview of the main aviation projections showing a great discrepancy between values for 2050 according to the development scenario adopted. The lower values in 2050 are related to scenarios implying world evolutions with radical shifts compared to the current trend but, up to now, there are no signs that future evolutions go into these directions.

3.2 Targets

Compared to different global GHG emission reduction scenarios, even freezing international aviation emissions to the 1990 level will not be sufficient to let some space for other sectors around 2050. The middle orange line represents the air sector proposal. It is situated between the BAU scenario and the objectives brought up in Copenhagen in December 2009.

3.3 Abatement options

There are four main technological options to mitigate aviation emissions:

1. Evolutionary airframe and engine
2. Radical airframe and engine
3. Fuels
4. ATM and operational improvements.

Concerning the evolutionary airframe and engine technology, slides 12 and 13 synthesise respectively the main technological options and their related potential emission reduction. Another important point is summarised in the fourth column, namely if the improvement is limited to new aircraft/engine or if it could be adopted by older planes too (retrofit). On average, these measures could reduce aviation CO_2 emissions by maximum 20% by 2020 (cf. target of the European ACARE project).

To be able to reduce emission more drastically, more radical concepts are needed. However, due to the long time needed to develop these technologies, none is expected to be available on the market before 2025. Some of the options are illustrated from slide 15 to slide 23. Many options will be relatively expensive and some of them will need a complete adaptation of the infrastructures. Airships are expected to be rather slow and thus dedicated to cargo. Supersonic aircraft could reduce the travel time but at the expense of the climate impact which is expected to be five time worse than for a traditional aircraft. Several options will probably encounter a hard public reluctance, such as unmanned or nuclear aircraft. Finally, these radical changes will never be applicable to older aircraft (no retrofit). It is expected that a maximum 30% of CO_2 emission reduction will be reachable thanks to these radical changes by 2025.

Having a look at alternative fuels raises the question of their real climate benefit at the aircraft level and taking into account the production processes. Moreover, the adoption of hydrogen as main aviation fuel will require adapting not only the planes but also the refuelling infrastructures.

Finally, the improvement of ATM and operational measures should deliver another maximum 25% of CO_2 emission reduction by 2030 (the European project ACARE targets a 10% emission reduction).

3.4 Drawing some lines in the sand

Slide 29 summarises the different CO_2 emission reduction potentials in the aviation sector for the following years, separately for each option category, while slide 30 estimates the reduction potentials when different categories are combined (according to specific policy measures and context more or less favourable to the adoption of those technological options). All in all, technological solutions could reduce by 2030 aviation CO_2 emissions by maximum 25% to 65%, according to the socio-economic and political context.

3.5 Future scenarios

Compared to the aviation BAU scenario, technological improvements and alternative fuels will not be sufficient to help reducing CO_2 emissions of the whole aviation sector (cf. the expected sharp growth in activities). Market-based measures and other policy measures will be necessary; especially as alternative fuels scenarios are highly uncertain as regards their potential availability and production capacity compared to the aviation needs.

Combining scenarios from technology, operational measures and alternatives fuels, four specific scenarios have been selected: the “Baseline”, the “Blue sky”, the “Green – Technology” and the “Green – Fuel”. Even with the selection of the most optimistic emission reduction potentials of the three categories, CO_2 emissions from the aviation sector will continue to grow until 2025 and could possibly stabilise around 2035.

Market based measures have to complete the technological options to be able to follow any emission reduction objective for the aviation sector. These measures could take the form of demand reduction measures or offset measures and would have to induce a large impact to be effective. Besides this, studies are still needed to determine the measures that are the most equitable and effective in economic, societal and environmental terms.

3.6 … and finally

Will the recent economic recession have an impact on aviation growth forecasts? ICAO/CAEP does not give any opinion but historically the air sector has recovered after a short downturn. However the real big issue concerning the air traffic growth is to know what will the ultimate growth constraint be (e.g. socio-economic development, climate extreme events, fuel availability, climate policy, etc.)?

3.7 Questions / remarks

- *Julien Matheys asks if Mr. Eyers could explain how point-to-point operations could reduce CO_2 emissions in his opinion.*

  Chris Eyers says that indeed, many claim that hub-and-spoke systems are more efficient thanks to the use of larger aircraft. However, he indicates that it depends if larger aircraft are really only more efficient when they are configured efficiently (depending on on-board facilities for example).

- *Carmen Köhler asks if airport infrastructures will not be the growth constraint for the aviation sector.*

  Chris Eyers answers that it could be the case (for some airports) in the EU and the USA but that in the other parts of the world, where the aviation will grow most, this constraint does not exist. In the EU and the USA a large amount of money is already spent in research programme like SESAR in order to avoid ATM being a constraint for the development of the air sector.

- *Ben Matthews suggests that aircraft could fly at a lower speed and altitude (i.e ground effect planes) and that several short-haul flights could be replaced by train.*

  Chris Eyers mentions that ground effect induces security issues and that support to an intermodal shift has to be based on a full lifecycle assessment (taking into account the infrastructures) and taking into account the load factor.

4. Impacts of flight altitude changes on aviation climate forcing

Christine Frömming’s presentation is not available

4.1 Aviation climate impacts

The radiative forcing caused by aircraft can be split into several components: CO_2 (warming), NO_x (warming by O_3 formation and cooling by CH_4 depletion), contrails and cirrus (warming), H_2O (warming), sulphate aerosol (cooling), soot aerosol (warming). The total effect is a warming impact that is more important than CO_2 warming alone.

The flight altitude has an influence on these components' radiative forcing, among others due to the change in meteorological and physico-chemical conditions. As regards CO_2, the flight altitude influences the fuel consumption and its related CO_2 emissions (lower altitude => higher fuel consumption). Concerning NO_x, the interaction with the chemistry of the atmosphere depends on the altitude, while for contrails and cirrus the altitude determines the coverage and the radiative properties of the clouds. In the end, H_2O lifetime depends on the altitude where it occurs.

4.2 Study of the impacts of the flight altitude

Global 3-dimensional air traffic inventories have been gathered and several scenarios with new flight altitudes have been tested (base case, 2.000 ft higher, 2.000 ft lower, 4.000 ft lower, 6.000 ft lower) in the TRADEOFF project, keeping the flight distance constant for each scenario. Simulations have been performed and the radiative forcing of the different components has been calculated by mean of "ECHAM4.L39(DLR)/CHEM" and "AIRCLIM" models.

CO_2 and NO_x emissions increase with lower flight altitudes due to growing drag. Moreover, NO_x loss processes are more efficient which implies decreasing NO_x and O_3 mixing ratios (net ozone decrease for lower flight altitudes).

Concerning contrails, higher flight altitudes tend to increase the contrail coverage in the tropics and to reduce it in northern mid latitudes (and vice-versa), but globally higher flight altitudes induce a bigger contrail cover on a yearly average. Beside regional differences, strong seasonal effects have to be taken into account too.

For water vapour, the residence time decreases with decreasing flight level which means that less water vapour accumulates at lower flight levels.

On a global annual average, all non-CO_2 effects decrease for lower flight altitudes and increase for higher flight altitudes, but there are strong regional and seasonal effects.

The future impact and the trade-off between non-CO_2 effects and CO_2 effects which work in the opposite direction are dependent on the future scenario. As long as air traffic growth rates are positive, the radiative effects of the non-CO_2 effects dominate, implying a total decrease of RF for lower flight altitudes and a total increase of RF for higher flight altitudes. On the contrary, when air traffic emissions are stopped, in the end only the CO_2 radiative forcing survives which implies a total increase of RF for lower flight altitudes and a total decrease of RF for higher flight altitudes.

4.3 Main conclusions of the study

Through changes of flight altitudes considerable changes of aviation induced radiative forcing could be reached.

CO_2 effects and non-CO_2 effects work in the opposite direction. On a global annual average, the RF of all non-CO_2 effects decreases for lower flight altitudes and increases for higher flight altitudes, while the RF of CO_2 increases for lower flight altitudes and decreases for higher flight altitudes.

The relative importance of the individual contributions and their possible trade-offs is dependent on the assumed future scenario. For future scenarios with increasing air traffic, non-CO_2 effects are dominant. For a termination of air traffic emissions, in the end only CO_2 effect survives.

For the Fa1 future scenario in 2100 up to ~20 % reduction of the total aviation radiative forcing could be achieved but contrail cirrus is not included yet (⇨ reduction potential could be even larger).

This study is only a parametric study that analyses global changes of flight altitudes with highly simplified assumptions. However it shows that the mitigation potential for contrails can be enhanced through the adaptation of flight altitude change to regional and seasonal effects. It has however to be kept in mind that the CO_2 effect could also be modified through aircraft design, flight speed, etc.

In principle every flight should be optimized according to the actual weather situation and background chemistry. This is the objective of the UFO-Project for contrails and the European project called "REACT4C EU-7FP" for contrails, contrail cirrus and chemical effects (www.react4c.eu).

4.4 Questions / remarks

- *Chris Eyers suggests that the aircraft design could be optimized for the recommended flight altitude.*

Christine Frömming answers that changes in aircraft design were not taken into account in this work but that the DLR CATS project will. She underlines that flying at a lower altitude induces not only a higher fuel consumption but higher turbulence too.

- *Chris Eyers asks if the air capacity will not be reduced by the adoption of lower levels of flight altitude.*

  According to Christine Frömming, this may be the case. She adds however that the air capacity could be improved thanks to a better management of flight frequencies and the use of bigger aircraft.

- *Ben Matthews asks if the effect of polar stratospheric cloud has been included in the work.*

  Christine Frömming answers in the affirmative but points out that there are few polar flights.

- *Ben Matthews asks if climate feedbacks have been included in the declining scenario. Has an intermediate scenario also been tested?*

  Christine Frömming explains that the surface temperature changes relatively slowly compared to RF due to the strong buffer effect of oceans. In the AIRCLIM model, the carbon cycle is included but not in the other model. Concerning the intermediate scenario, a third scenario with constant emissions from 2050 has been analyzed. Results are qualitatively the same as for the FA1 scenario.

5. Prediction of ice-supersaturated regions in the DWD weather models

Carmen Köhler's presentation: see ABC Impacts website → Open Section → Project publications → Workshops (http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/workshop_26_march_2010_Kohler.pdf)

The presentation will give an overview of the UFO-Project and of the work carried out at DWD.

5.1 Introduction to UFO-Project and to the Lufthansa flight planning tool

This research project has one main objective: to evaluate the feasibility of a route optimization including the climate impact of potential contrail formation (cf. ice-supersaturated areas are relatively thin: 200-500m in average up to 1-2 km). Consequently the overall climate impact of air traffic could be reduced by additionally considering contrails and by including the impact of potential contrail formation into flight planning. The optimisation phase is based on environmental criteria (global climate benefits), as well as on economic efficiency and safety aspects.

The LIDO OC software is already used by 20 airlines to optimise their flight routes. It is connected to online weather and aeronautical data. The UFO project consists in adapting this software to include DWD meteorological data in the optimisation process. Therefore, it is possible to optimise the flight route before take-off according to different constraints. The modified software is already ready for use with different optimisation options.

5.2 Numerical weather predictions at DWD

To assess the quality of data for the ice-supersaturated regions, results have been compared to other models. In the DWD model, DWD data of humidity fields are used in order to calculate the potential contrail forcing (ΔE) according to the ice water content and the contrail life-time (see slide 6). Among other assumptions, the forcing depends on ice crystal size and number densities.

The operational models of the DWD (see slide 7) with a higher resolution have been used to analyse ice-supersaturated regions and the nucleation process in more detail.

5.3 Current status at DWD

It is possible to analyse ice-supersaturated regions in the GME and COSMO models but results are often too low compared to reality. This may be due to an overestimation of ice nucleation. Therefore, the current nucleation scheme has to be analysed taking into account the two ice nucleation processes (homogeneous and heterogeneous). The climate effect of contrails is in fact different according to the nucleation process. This analysis is needed to develop a new parameterisation for ice nucleation in numerical weather prediction models. New results had to be evaluated and verified. They are now validated and tested in a model environment: COSMO-DE.

With the help of the COSMO-DE model, test- and reference calculations are performed. The relevant processes for cirrus cloud formations such as orographic and convective effects are captured due to its resolution of 2,8 km. Calculation serves as test for the parameterisation and the high resolution data set can then be used in further investigations concerning the coarser gridded GME. Calculations have been performed for June/July 2009 and slide 13 shows the results for the 10^{th} June 2009.

5.4 Conclusions

Concerning the UFO project and the Lufthansa flight planning tool:

- The flight planning tool is ready for operational use.
- The potential contrail forcing has to be verified.

As regards research carried out at DWD:

- The new parameterisation of ice nucleation has to be implemented into the GME.
- Results have to be validated with satellite data (CloudSat) due to strong sensitivity in cloud ice mixing ratio QI.

5.5 Questions / remarks

- *Christine Frömming asks if the model takes into account the role of aerosols in the formation at a later time of contrails ("contrails outbreak").*

  Carmen Köhler explains that this is too complex to be taken into account and that up to now the model focuses on ice-supersaturated areas only. This could be an interesting point to add to further work.

- *Elisabeth Peeters wonders how AIC are taken into account in the cost minimization of the flight, seeing that for airlines a cost minimization mean fuel and time savings. Are there circumstances where avoiding AIC induces also a cost minimization?*

  According to Carmen Köhler, an evolution of the climate policy and especially of the EU-ETS to take into account AIC is expected. Such a tool will then be useful to optimize flight according to the cost allocated respectively to CO_2 and AIC. The flight planning tool offers different constraints options for the optimization among other the minimization of fuel consumption or the minimization of the total cost.

  Chris Eyers adds that nowadays avoiding AIC always induces increased fuel consumption and flight cost. A market-based measure has to be adopted to make it economically interesting for airlines to avoid AIC.

- *Chris Eyers asks if there is a difference in the RF of contrails along the day. His second question is about cirrus clouds: are they also included in the model (cf. they occur later than contrails)?*

  Carmen Köhler answers in the affirmative to both questions.

6. Multi-criteria analysis of policy options to reduce the total aviation climate impact

Annalia Bernardini's presentation: see ABC Impacts website → Open Section → Project publications → Workshops (http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/workshop_26_march_2010_Bernardini.pdf)

6.1 The ABC project and the multi-criteria analysis (MCA)

There are three main policy option groups studied in the ABC project: technology and R&D investments, operational measures and infrastructures, and market based measures. The use of a multi-criteria approach provides a framework to evaluate these climate policies options (alternatives) through a set of criteria such as environmental performances, achievements and drawbacks / advantages / benefits. By applying the MCA, it is possible to some extent to outline an appropriate platform for future compromises according to selected objectives.

6.2 The MCA methods

The method follows tree steps: the definition of the problems/goals to be achieved, the identification of the criteria and the prioritization of the alternatives.

Two main approaches have been developed: the analytical hierarchy process (AHP) and the Promethee/Gaia softwares.

In the first approach, different hierarchy levels are determined on the basis of pair wise comparisons between the ultimate goal and the criteria and sub-criteria, between alternatives and criteria, and the classification of the alternatives (see slides 5 and 6). This approach needs a lot of comparison work especially for complex issue where the numbers of selected alternatives and criteria are high.

In the second approach, the Promethee software data (in the ABC example: the policy alternatives and the criteria) are directly exploited in a performance matrix (see slide 7). The related Gaia software offers many visual representations of the results.

6.3 Promethee applied to the ABC Impacts project

The objective of the multi-criteria comparison between different policy options is to be able to reduce the total aviation climate impact. The policy options are the alternatives (see slide 8) that will be compared by mean of selected criteria (see slide 9).

In the performance matrix, each alternative has to be scored according to its “efficiency” against each selected criteria (see slide 10).

The results of these scorings can then be graphically represented in several types of graphs thanks to the Gaia software (see slides 11 to 16).

6.4 Conclusions and perspectives

Further work on the MCA will require the participation of stakeholders in order to provide feedbacks by indicating their assessments and provide weights for criteria (cf. Promethee method).

Therefore, an online tool will be developed and practical exercises will be suggested to the ABC Impacts users’ committee members, concerning both MCA approaches (analytical hierarchy process and Promethee/Gaia).

6.5 Questions / remarks

- *Andrew Ferrone highlights that the results presented are more examples than real preliminary results seeing that the MCA is still in progress. Annalia Bernardini insists that these illustrations are given to show the methodological approach and are not definitive.*
- *Chris Eyers explains that the USA invest a lot in qualitative tools which are real black boxes for Europeans as regards the methodology. The support of the pair wise comparisons could therefore be interesting. When data are not available, non-quantitative approaches helps to move forward but they are too often “black boxes”. However, it is a powerful tool for policy makers. That is the reason why such approaches have to be further developed but we need to be very careful with the presentation of the results to avoid misunderstandings and misleading interpretations.*
- *Annalia Bernardini adds that this MCA methodology allows for detailed analysis of pros and cons of each policy option.*

7. Discussion

- *Elisabeth Peeters wonders if the accent has to be put on limiting CO_2 emissions or avoiding AIC in the selection of the best short route.*

  Christine Frömming answers that it depends on future aviation developments. Up to now, it is quite certain that air traffic will continue to grow. In that context, non-CO_2 aviation climate impacts will become more and more important.

  Carmen Köhler adds that the optimisation of the flight route is not an easy work because it has to balance the long term global climate impacts of CO_2 emissions with more regional and short term climate impacts of AIC.

According to Christine Frömming, best options would be those reducing both short term and long term impacts. Otherwise, we have to keep in mind that CO_2 emissions are common to many other sectors and that reducing CO_2 emissions is certainly not a bad thing.

Elisabeth Peeters explains that it is easier to focus on CO_2 emission reduction and that it is the current political priority.

Christine Frömming highlights that AIC climate impacts are of the same order of magnitude than CO_2 climate impacts or even worse. It could be easier and less costly for the aviation sector to reduce AIC climate impacts inside the sector and make agreements with other sectors to reduce CO_2 emissions elsewhere.

Elisabeth Peeters mentions that taking AIC into account in ATM will complicate the systems and increase related development costs.

Chris Eyers answers that the aviation sector needs to invest in new high-performance ATM systems due to high expected growth in traffic. Therefore, the additional investment could be quite limited: the aviation sector has much more to gain than to lose.

- *Andrew Ferrone explains that lowering flight altitude helps to reduce AIC but increases fuel consumption. Therefore, he wonders if it would be possible to find a new aircraft design that could simultaneously reduce both AIC and CO_2 climate impacts.*

  Christine Frömming adds that lowering the speed of the aircraft could also be a solution.

- *Ben Matthews highlights that we have to be careful when comparing short term and long term climate impacts because short term impacts also induce long term changes due to feedback loops in the carbon cycle.*

- *Chris Eyers says that up to now CO_2 emission reductions are always win-win options, while it is less certain for non-CO_2 climate impacts. This uncertainty is quite difficult to manage in investment strategies.*

  Ben Matthews answers that there are specific cases where there is a real benefit to avoid AIC and that efforts have to begin there.

  Chris Eyers agrees but explains that avoiding AIC induces increasing CO_2 emissions and this is opposite to airlines objective to minimise costs.

  Philippe Marbaix explains that ignoring non-CO_2 aviation climate impacts could be worse for climate than accepting uncertainties.

  Chris Eyers hopes that scientists will be able to reduce error bars on AIC.

  Andrew Ferrone answers that new developments have already lowered the uncertainties and that the sign has always been clear: AIC radiative forcing is positive.

- *Carmen Köhler explains that the flight planning tool do not avoid all AIC formation areas but helps to avoid worst cases.*

- *Elisabeth Peeters repeats that it is manageable to reduce CO_2 emissions. Moreover, reducing CO_2 emissions reduce also other kind of emissions. Therefore, it should stay the priority. If politicians introduce incentives to avoid AIC, the aviation sector will take this into account.*

  Julien Matheys asks if a financial compensation was or is expected to be introduced in Germany to avoid AIC to explain that the UFO research project includes all aviation climate impacts in its optimisation calculations.

  Carmen Köhler explains that Lufthansa Systems developed an enhancement for the LIDO OC to include non-CO_2 aviation climate impacts. This tool is ready for use in case the government should decide to introduce such an incentive.

- *Andrew Ferrone explains that there is a specific note on a suggested variable multiplier for non-CO_2 aviation climate impacts available on the ABC Impacts website and that comments are most welcome* *(http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/Note_to_stakeholders_aviation_nonco2_May2009.pdf).*

Chris Eyers wonders how a metric could describe all aviation climate impacts.

Ben Matthews and Andrew Ferrone add that it is a political choice to determine the time horizon to be considered and that it depends on the question raised (e.g. do we want to reduce the global climate impact or to avoid a temperature elevation). Different regions could have different answers.

Christine Frömming asks how it is possible to translate this in monetary terms. It seems to be important to take into account (cf. Stern report) that early actions could reduce total costs.

Ben Matthews highlights that the new IPCC report will introduce several improvements in this topic.

- *Chris Eyers repeats that reducing regional climate impacts are not specifically a win-win solution for everybody, which seems to be the case with CO_2 emission reduction.*

  Ben Matthews says that it could be then interesting to work with local groups.

  Carmen Köhler explains that the use of the flight planning tool could induce a small price increase in the air ticket but that the airline would have the opportunity to lower its total climate impacts and to exploit this for marketing campaign. With a shift in passenger mentality (thanks to public awareness on the total aviation climate impacts), the use of this tool could become an asset even in the absence of other economic incentive.

  Chris Eyers adds that another incentive could be the development of a climate label for flights as it already exists for some consumer goods.

- *Discussion about chemtrails: chemtrails do not really exist as such. The difficulty for administrations confronted with citizens' complaints about potential chemtrails is that up to now no online tool with a sufficient quality exists to be able to couple contrails to the aircraft that has generated them (cf. flight data not available instantly). The only tools available to detect contrails seem to be trajectory models.*

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