CONSAVE 2050 - G4MA-CT-2002-04013

CONSAVE 2050
Executive Summary

Ralf Berghof, Alf Schmitt (DLR)
Coordinators

Chris Eyers (QinetiQ), Karlheinz Haag (DLH), Jan Middel (NLR), Michael Hepting (DLR)
Partners

Arnulf Grübler (IIASA), Richard Hancox (MVA)
Sub-Contractors

COMPETITIVE AND SUSTAINABLE GROWTH

July 2005

Key Action: GROW-2001-4: New Perspectives in Aeronautics

Accompanying Measure 2: Studies in preparation of future activities, addressing with a European Perspective RTD policy issues related to industrial competitiveness and sustainable growth or focussing on important specific socio-economic problems, emerging technologies, industrial sectors, etc.

Administration Page

Project Title	***CONSAVE 2050*** Constrained Scenarios on Aviation and Emissions
Customer Organisation	European Commission
Customer Contact	Mr Andrzej B. Podsadowski (up to 4/2005: Rolando Simonini)
Contract number	G4MA-CT-2002-04013
Date due	July 2005

Principal authors

Ralf Berghof	Ralf.Berghof@dlr.de	0049 2203 6013180
Deutsches Zentrum für Luft- und Raumfahrt (DLR) Linder Höhe, D-51147 Köln, Germany		

Alf Schmitt	Alfons.Schmitt@dlr.de	0049 2204 483972
Deutsches Zentrum für Luft- und Raumfahrt (DLR) Linder Höhe, D-51147 Köln, Germany		

Additional authors

Jan Middel	Middel@nlr.nl	0031 20511 3559
Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) Anthony Fokkerweg 2, 1059 CM Amsterdam, Netherlands		

Chris Eyers	CJEyers@qinetiq.com	0044 1252 392269
QinetiQ plc, Cody Technology Park Farnborough, Hampshire, GU14 0LX, United Kingdom		

Richard Hancox	RHancox@mva.co.uk	0044 161 2346944
MVA Ltd Sunley Tower, Piccadilly Plaza, Manchester, M1 4BT, United Kingdom		

Arnulf Gruebler	Gruebler@iiasa.ac.at	0043 2236 807470
International Institute for Applied Systems Analysis (IIASA) A-2361 Laxenburg, Austria		

Michael Hepting	Michael.Hepting@dlr.de	0049 2203 6012189
Deutsches Zentrum für Luft- und Raumfahrt (DLR) Linder Höhe, D-51147 Köln, Germany		

1. EXECUTIVE SUMMARY

This summary comprises a description of the CONSAVE work performed and a presentation of the main results, main conclusions, and proposals for future work.

Overview on the work process

CONSAVE 2050 was started in September 2002 as an EC Accompanying Measure Project. The project consists of developing scenarios on aviation and emissions which address the key aspects of interest to stakeholders, specifically the aviation industry, policy makers, climatologists and transport researchers. The main focus is on the Year 2050, with a look at shorter term (Year 2025) and longer term (Year 2100) developments relevant to aviation industry planning and climate models respectively. CONSAVE 2050 includes constraining conditions plus the latest "background" data on influences external to land and air transport, hence setting the framework for the long term development in aviation.

The following work was performed within the five work packages of CONSAVE 2050.

WP 1A – In WP 1A, the key factors and qualitative background scenarios were developed. The substantive technical project work started with the examination, review and choice of the key scenario descriptors that were later to be quantified in the scenarios on aviation and its emissions. These scenario descriptors were selected from the perspective of possible customers and were needed as input for other work packages (WP 2: Quantification of background scenarios + WP 3: Quantification of scenarios on aviation and its emissions). To assess the draft set of key scenario descriptors, a questionnaire was sent to experts representing a broad range of the aviation community (including AERONET-members). Responses were evaluated and used to improve and extend the list of key factors which was then reviewed by the CONSAVE Advisory Committee founded by DLH. Based on the outcome of these activities, a final catalogue of key factors was developed for subsequent quantification.

WP 1B – In work package WP 1B, the main goal was to create a representative set of qualitative "background scenarios", to be used as input for quantification with the AERO-model. "Background Scenarios" are defined as scenarios describing the "scene-setting framework" for the long-term development of aviation, defined by developments in areas external to aviation, but influence the air transport system, including the demand for air transport itself. The activities of work package WP 1B started with an analysis of the outcomes of the qualitative work on background scenarios, already performed under the EU-funded Thematic Network AERONET. The aim was to examine, review and select possible constraints requiring consideration in the scenarios. Other relevant, existing work on global scenarios was also examined. To ensure that the outcome of the project would match the needs and views of stakeholders within aviation, a range of contacts has been made with aviation experts, including the completion of a questionnaire and a review by the Advisory Committee.

IIASA is a subcontractor to the CONSAVE consortium having formerly been leaders of the author team for the IPCC Working Group III Special Report "Emissions Scenarios" (2000). IIASA has assessed the background scenarios developed within the AERONET activity in the context of the latest findings from the IPCC/SRES macro-economic scenario process. Using the outcomes of this assessment, the adaptation, modification and completion of the existing qualitative scenario outlines were discussed at a project workshop. Based on the workshop results, IIASA developed the storylines for a set of representative background scenarios. These storylines were then further discussed and reviewed by the CONSAVE team and by the Advisory Committee, before final modification by IIASA. As a consequence, a set of four CONSAVE Background Scenarios (of three scenario families) i.e. "Unlimited Skies", "Regulatory Push and Pull", (both belonging to scenario family "High Growth"), "Down to Earth" and "Fractured World" were agreed.

WP 2 - Quantification of the set of four Background Scenarios was successfully performed for key parameters using results for those IPCC/SRES scenarios which are similar to the background scenarios developed within WP 1B. A first draft for this quantification was used for discussion on how to bring the outcomes of the Background Scenarios into a structure which met the requirement to be useable as input for the AERO-model. For the final quantification, SRES deduced values are given for Population (global, regional), World GDP (global, regional), and Energy Use (global). Other quantification issues are the Regionalisation of the "Fractured World" and Global Climate Policies in "Down to Earth". IIASA also offered suggestions (in terms of modelling) for Air Transport Demand for comparable Aviation Scenarios which were in line with the characteristics of four Background Scenarios. Subsequently, during the initial quantification work with the AERO-model (WP3), IIASA and the team agreed on a regional differentiation of the energy/kerosene prices based on the R/P ratio of proven regional reserves (R) to annual global production (P). For the final quantification with the AERO-model, a differentiation of the GDP values used for the Unlimited Skies scenario and the Regulatory Push and Pull scenario was developed, with the figures for the latter decreased by ca. 3 percent, an amount consistent with the reduction in the aviation system.

WP 3 –Quantification of the aviation scenarios and their consequent emissions is based on the AERO-model system. The basic prerequisite for the model calculations is the development of a suitable set of assumptions for the inputs needed for the AERO-model. Some of these inputs are not scenario dependent. For these features, it was possible to apply default values developed for the AERO-model system. For the CONSAVE 2050 project work, the scenario-dependent input assumptions can be subdivided into three groups: (a) AERO-model assumptions on factors/features external to aviation, (b) assumptions on the development in aviation technology for the four CONSAVE aviation scenarios, and (c) assumptions characterising other features of the aviation system needed as input for the AERO-model. Furthermore, some aspects of factors, identified in WP 1 to be relevant for the aviation scenarios but which are not / or not fully addressed in the set of inputs by the initial AERO-model – such as noise, air quality, airport capacity - could be also included for the quantification of the aviation scenarios. The quantification of the background scenarios, developed in WP 2, is used for the definition of the assumptions of category (a). Team partner QinetiQ developed the technology assumptions of category (b), primarily to assess the fuel efficiency, emissions and noise technology that might be developed under the four background scenarios. Kerosene-powered aircraft and post-kerosene aircraft were considered. DLR, supported by NLR and by the team, developed the assumptions in group (c). NLR and its subcontractor MVA generated some important modifications to the AERO-model in order to be able to include infrastructure, noise and air quality aspects within the CONSAVE scenarios. Based on a first complete set of inputs, quantification of the CONSAVE aviation scenarios with the adjusted AERO-model was started. After an intensive internal team review of the initial model outputs, the AERO-model inputs were partly modified and the new input set was applied for a second, new run with the AERO-model. A detailed description of this first phase of work of WP3 was then used as a base for the broad external European CONSAVE Review Process. This review consisted of a questionnaire activity followed by a Review Workshop (held in Athens in April 2004). The findings of the CONSAVE Review Process together with additional ideas from the CONSAVE team were then used for final modification of the reviewed preliminary scenario results.

WP 4A - A concept for the planned European Review of the preliminary study results was developed and presented at the Mid-Term Meeting. It was agreed that the Review Workshop should be held back-to-back with the AERONET III Kick-off Meeting and the workshop was held in Athens at the Technical University (NTUA) on April 29th – 30th 2004. The details of the preparation, the performance and the outcomes of the complete CONSAVE Review Process with its main two steps, (a) questionnaire activity and (b) concluding Review Workshop, are reported within the Deliverable D10. The questionnaire was grouped into four parts, which referred to the three different categories of AERO-model input assumptions: External inputs from the quantified background scenarios (Part 1), scenario-specific assumptions on the development in aviation technology (Part 2), assumptions on other features of inputs to the AERO-model also relevant to the quantification of the aviation scenarios (Part 3), and the available (preliminary) results of the quantification process (Part 4). The questionnaire action was started in late March. 34 persons participated in the Review Process (questionnaire and review workshop), representing a broad spectrum of expertise of the European aviation community. As an additional accompanying activity, a special review meeting with DLH was performed in Frankfurt in April 2004. All proposals for modifications of the CONSAVE preliminary outcomes – the results from the broad review process - were thoroughly considered for an adaptation within the final work on the CONSAVE 2050 project.

WP 4B – As an Accompanying Measure project, the monitoring and analysis of related external work was of special interest for CONSAVE 2050. Close contacts to some of the related external projects were assured by the fact that one or more contractors are team members of those projects (e.g. AERONET, Trade Off, AERO2k). Communication to ACARE/ASTERA and EUROCONTROL was successfully implemented from the very start of the project. In addition, the ICAO/CAEP process and other relevant activities like Scenic were intensively monitored by WP 4B. A comprehensive description of this work (as at May 2004) and its results and consequences for the CONSAVE 2050 project is given within Deliverable D11. With ACARE/ASTERA especially, a continuous exchange of information and reciprocal consideration/use of results was agreed on. In May 2004, the results of the CONSAVE scenario storylines were used as background information for the design of the second version of the ACARE Strategic Research Agenda (SRA II) and for the EUROCONTROL project LTF, an ATM-related forecast for the year 2020. Recently, further activities went into a support for the programme planning of AERONET III and for the new European Network of Excellence ECATS (Environmentally Compatible Air Transport System).

WP 5 – Management and co-ordination: The project work is supported by management and co-ordination activities led by DLR. One important task was to organise the internal assessment of preliminary results of the various work packages by the consortium. An Advisory Committee of stakeholders/customers was founded as part of WP 5 by DLH. Three meetings were held including the final assessment of the Draft Final Report, to ensure that the requirements of users are taken into account. Other activities in this work package included the development and continuous up-dating of a Project Management Plan and the preparation of administrative reports, the Period Report I – IV, and eventually the production of this Final Technical Report. In the light of new perspectives which emerged during the first year of the project, it was decided – without change in total manpower - to intensify the work for WP 3, specifically by giving more emphasis to the development of aircraft technology scenarios, whereas the amount of work for WP 4 could be somewhat reduced without loss in quality. Furthermore, it was decided to shift the time horizon for the short-term scenarios from Year 2025 to Year 2020, mainly, to be able to directly compare CONSAVE outcomes with findings from other related projects, predominantly orientated to a horizon year of 2020. As a reaction to the disturbances to the “normal” development of the aviation system caused by the 11 September 2001 events, it was decided, to start the differentiation of the paths of the four CONSAVE scenarios from the year 2005. To allow the smooth and effective running of the project work, it was important to organise intensive communication between the CONSAVE team partners and with the EU commission, including the preparation and performance of conferences bringing together all partners for a discussion on the state of the ongoing work, the future activities and especially addressing open questions which could not finally solved simply on the basis of e-mail contacts. The official Kick-off meeting for CONSAVE 2050 was performed in September 2002. Further project meetings were held on an agreed regular basis (six months), in London (March 2003), in Toulouse (September 2003; team conference one day before the official Mid Term Meeting), in Cologne (February 2004 and June 2004 (taking into account the results of the review, to decide on an agreed concept for the final calculations with the AERO-model and the additional work for the project). An additional two day work conference of the team was held in Cologne (July 2003). The official Mid Term Meeting was performed in Toulouse in September 2003, hosted by Airbus.

Emphasis was also given to the experts review and the web-based communication of results. A homepage was developed (http://www.dlr.de/consave), where goals of the project are described and activities plus results are presented in a format available for download.

Main results

In the following paragraphs, the main results of the CONSAVE 2050 project are presented.

Scenario selection

Four CONSAVE scenarios with alternative “philosophies” were designed, to be able to cover a broad range of possible futures and to allow for a “pure” discussion of the key study questions, in particular those related to future challenges and constraints for aviation.

The four scenarios are qualitatively described by storylines and assumptions and are quantified for the key descriptors, calculated with the AERO-model, using scenario-specific sets of model-inputs. They were eventually labelled as:

- **“Unlimited Skies” (ULS)**; global, dominant actor: market
- **“Regulatory Push & Pull” (RPP)**; global, dominant actor: policy
- **“Fractured World” (FW)**; regional, dominant actors depending on regions
- **“Down to Earth” (DtE)**; global, dominant actor: society

Each CONSAVE Aviation Scenario is consistently derived from a related CONSAVE Background Scenario. The CONSAVE Background Scenarios were quantified for GDP, population, and key energy issues, applying the respective figures calculated for the “partner” scenarios in the IPCC/SRES exercise (on the basis of a total of six reviewed quantification models).

CONSAVE Scenario	Consistent IPCC 2000 scenario
Unlimited Skies	**IPCC/SRES A1G-Message**
Regulatory Push & Pull	**IPCC/SRES A1T-Message**
Fractured World	**IPCC/SRES A2 Message**
Down to Earth	**IPCC/SRES B1 Message**

Some modifications of the energy related data from IPCC were made to account for typical aviation aspects of the CONSAVE scenarios.

The main characteristics and assumption of the four scenarios are:

Assumptions for 2020/2050	Unlimited Skies (ULS)	Regulatory Push & Pull (RPP)	Fractured World (FW)	Down to Earth (DtE)
Population/Billion	7.5/8.7		8.2/11.3	7.5/8.7
World GDP	57/180 Trillion $	57/171 Trillion $	40/82 Trillion $	53/136 Trillion $
GDP growth	3.9 % p. a.	3.8 % p. a.	2.4 % p. a.	3.2 % p. a.
Income per capita (10^3 1990 US $) in 2050	20.8	19.8	7.2	15.6
Energy availability	Available	Available	Dependant upon region; scarcity after 2050 expected	Available, scarcity after 2050 expected
Peak of world oil production (incl. artificial oil)	2080	2050	2020	2020
Energy use EJ	700/1350	610/1100	600/970	580/810
Energy price (1990 = 1)	1.5/2	2/4	4/8	2/4
Environment	No catastrophic change	Significant change; main problems 2052-2058	Little change	Some alarming, but no catastro-phic change
Technology devel-opment	Dynamism of technological innova-tion is broad-based; communication and transportation growth		Heterogeneous, partly incompati-ble, interchange problems	Rapid diffusion of post-fossil technologies
Political develop-ment	Market philosophy	Emission regulations	Regional differences	Pollution sources tightly controlled
Citizens' values	Global orienta-tion, pragmatic solutions	Regulatory ap-proach in envi-ronmental issues	Autarky, regional orientation	Environmental and safety con-cerns
Customer prefer-ences	Convenient and flexible service and mobility	Cheap and envi-ronmentally okay	Security concerns	Stigmatisation of fast/international patterns
Aircraft technology	New very large aircraft available	Like ULS plus hydrogen powered ac	Different standards	Introduction of hydrogen powered ac
Safety & Security	High standards	High standards (regulation)	High effort to en-sure security	High standards
Market Develop-ment	Deregulation, strong competition	Controlled liber-alisation, medium competition	Dominance of national carriers	Decrease in the number of airlines
Air transport sup-ply & demand	Very high increase	High increase	Low growth in interregional flights	Decrease
Airport & ATM Capacity	Constraints	Capacity regulated	Depending to regions	No constraints, but low profitabil-ity
Aviation Costs	Lower specific costs	Lower specific costs	Higher (security & standards)	Higher specific costs

It is of interest to compare the selection of scenarios made by CONSAVE with those of the actually most important external (long term) aviation scenario activities: ACARE/ASTERA and EUROCONTROL LTF. Both, ACARE/ASTERA and EUROCONTROL LTF have designed scenarios with time horizon 2020. As it is can be seen from the following table, three of the CONSAVE scenarios have very similar counterparts in the sets of scenarios developed by these external activities. But both, ACARE/ASTERA and EUROCONTROL LTF, do not have any equivalent to the fourth CONSAVE scenario “Down to Earth”. Related to their specific goals these activities preferred to include a “base case” respectively a “Business as usual“-scenario.

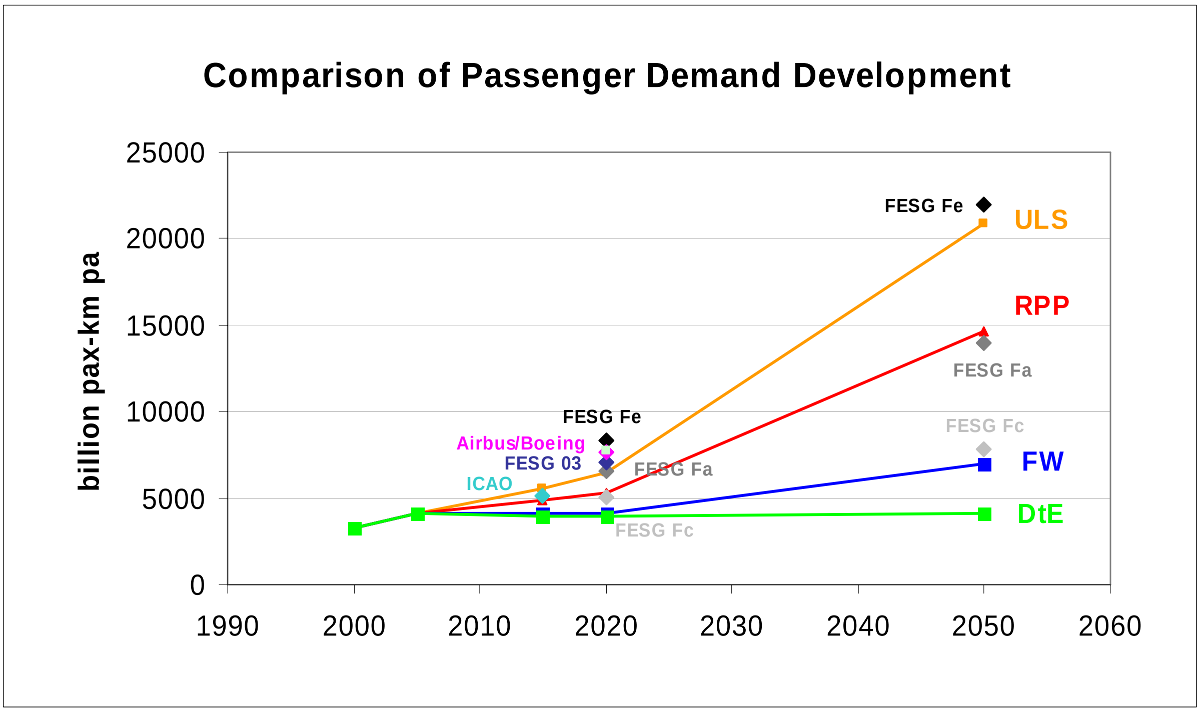
	Unlimited Skies (ULS)	**Regulatory Push & Pull (RPP)**	**Fractured World (FW)**	**Down to Earth (DtE)**
ACARE / ASTERA	Business Model	Constraint Growth	Block building	n. a.
EUROCONTROL LTF	Global Growth	Regulated Growth	Regional Concerns	n. a.

Key features of the development in air transport

Within the AERO-model the dominant features for the quantification of the development of global passenger demand are GDP and population as external factors (taken from IPCC/SRES [8]), air transport related assumptions on elasticities and saturation effects, and the (calculated) ticket prices. The model results for the four scenarios cover a broad range of alternatives:

Billion pax-km pa	**1970**	**2000**	**2005**	**2020**	**2050**	**2000-2020**	**2000-2050**	**2020/ 2000 Factor**	**2050/ 2000 Factor**
History	**551**	**3308**	**4091**						
ULS			**4091**	**6505**	**21185**	**3.4%**	**3.8%**	**2.0**	**6.4**
RPP			**4091**	**5284**	**14636**	**2.4%**	**3.0%**	**1.6**	**4.4**
FW			**4091**	**4157**	**6990**	**1.1%**	**1.5%**	**1.3**	**2.1**
DtE			**4091**	**3920**	**4164**	**0.9%**	**0.5%**	**1.2**	**1.3**

The results for passenger demand (in terms of passenger kilometer) within the constrained CONSAVE scenarios RPP, FW, and DtE for the year 2020 are in line with what would be expected – that is lower than the actual forecasts for the year 2020 from ICAO [26], Airbus [29], Boeing [30], FESG [31]; these forecasts are all close to the outcomes for the CONSAVE ULS scenario. Compared to the outcomes from the FESG scenarios Fa, Fc, Fe (1999) for (2020 and) 2050, the ranges of passenger demand for both sets of scenarios are very much the same, with the exception of the Down to Earth scenario which is characterised by lower development.



Although AERO2k [28] does not report pax-kilometres, a comparison with forecast results of this study is possible on the basis of *aircraft kilometers* of the year 2025, the AERO2k values for 2025 being in the middle of the range for the four CONSAVE scenarios.

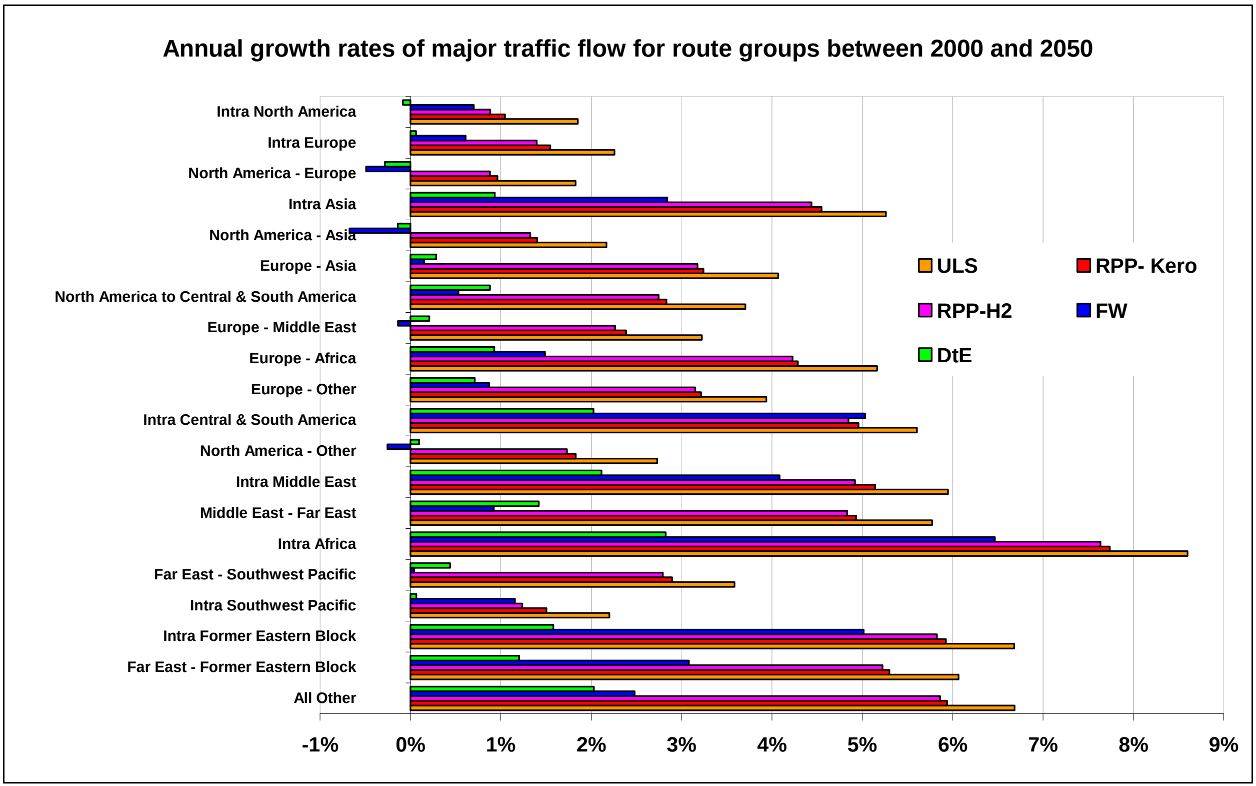
The number of passengers within the four scenarios grows with rates very similar to those for the demand in passenger kilometers, with one exception: For the Fractured World the growth rates for passengers are remarkably higher with respect to the number of passengers than with respect to passenger kilometer, as within this scenario a decrease in long range flights between blocks is combined with a compensating higher air traffic activity within the blocks.

Million pax pa	2000	2020	2050	2000-2020	2000-2050	2020/2000 Factor	2050/2000 Factor
ULS	2023	4121	13861	3.6%	3.9%	2.0	6.9
RPP	2023	3375	9680	2.6%	3.2%	1.7	4.8
FW	2023	3301	6555	2.5%	2.4%	1.6	3.2
DtE	2023	2492	2651	1.0%	0.5%	1.2	1.3

The project also reports figures for the development of air transport within and between the 14 IATA regions, used for the AERO-model system. Scenario-specific traffic flows for major route groups (in billion pax-km) and the number of passengers of the IATA regions (in million pax) have been calculated up to 2050.

The highest increases in absolute numbers are in all scenarios for Intra Asia, followed by Intra Central & South America as they are the largest markets with respect to population. As a consequence, the dominance of the air transport within North America and within Europe will be remarkably reduced.

The growth factors differ significantly within the scenarios and the regions, dependant from the combinations of reasons, described in the study. Intra Africa, as a so far underdeveloped market, shows the highest growth factor (F) in all scenarios. In contrast, Intra North America, the



Annual growth rates of traffic flow for route groups between 2000 and 2050

Intra Europe, and the Intra South Pacific market will have the lowest growth factors: They all will reach a high level of saturation.

Regional growth rates for passenger demand (in pax pa) between 2000 and 2050 range from -0.1% up to about 9%, being quite different depending on the scenarios and the various regions.

The regional differences for the number of air passenger trips per capita (n) decrease over time until 2050, but for the region with the highest number of annual trips per capita (Southwest Pacific, n=4.88 for ULS, n=3.48 for RPP, n=2.26 for FW, n=1.35 for DtE) and the region with the lowest per capita air traffic (Eastern Africa, n=0.54 for ULS, n=0.37 for RPP, n=0.21 for FW, n=0.05 for DtE), the difference still remains very high, with a ratio (r) of the order of r=10 for all scenarios (even higher for DtE).

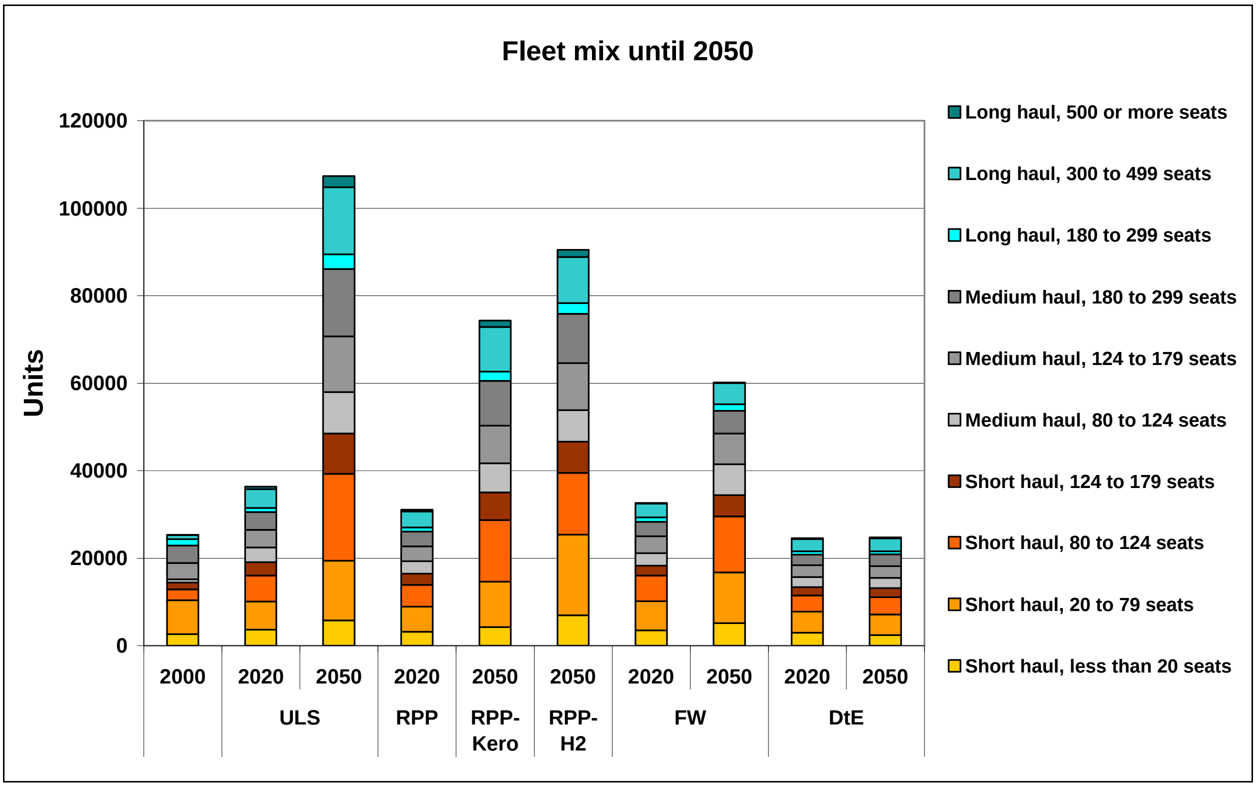
Growth rates for cargo demand, especially those for the DtE scenario, are significantly higher than those for passenger demand:

Billion tonne-km pa	2000	2005	2020	2050	2000-2050
ULS	127.5	179.1	422.5	1954.5	5.6%
RPP	127.5	179.1	351.0	1214.9	4.6%
FW	127.5	179.1	229.6	325.1	1.9%
DtE	127.5	179.1	235.9	279.8	1.6%

The number of additional aircraft needed varies drastically over the four scenarios:

Number of aircraft	2000	2005	2020	2050	Additional AC 2000-2020	Additional AC 2000-2050
ULS	18988	22992	34790	105570	15802	86582
RPP	18988	22992	29278	74346	10290	55358
FW	18988	22992	31216	57070	12228	38082
DtE	18988	22992	22958	23425	3970	4437

The calculation of the aircraft fleet mix development (for passenger and freight transport) for the four basic scenarios and the RPP cryoplane sub-scenario until 2050 shows (among others) a significant increase of the number of aircraft with more than 300 seats for all scenarios.



Fleet mix development until 2050

Key features for emissions, airport air quality and noise

The summarised scenario-dependent results for flight-kilometers, fuel use and emissions from civil aviation are:

Resulting growth factors F for CO2 and NOx for the scenarios ULS; RPP – K; FW from 2000 to 2050 are F= 4.6 / 3.3, 3.1 / 2.2 and 1.8 / 1.2 respectively. For these scenarios the progress in technology does not fully compensate for the increase in transport volume. For the DtE scenario CO2 is growing with a factor of F=1.4 until 2050, whereas NOx is reduced by F= 0.5, reflecting the scenario-specific assumption that within the Down to Earth world strong emphasis is given globally to the reduction of NOx.

The roll-over to the hydrogen technology in the RPP - Cryoplane scenario will result in a strong decrease of CO2 in 2050 of 86% (i.e. F= 0.14) compared to 2000 (although it is important to recognise that CO2 produced during the production process of hydrogen is not included in this figure). However, there is a significant increase in the release of water vapour emissions, and the climate effect of water vapour relative to effects from CO2 emissions is still under discussion. (Reacting with other aviation emissions water vapour can cause the formation of contrails and cirrus clouds.)

The differences in NOx emissions from the hydrogen fleet, compared to a kerosene fuelled fleet, emanate from three sources: a lower NOx emission index, an approximately 2.8 times higher energy per unit mass (partly offset by a greater fuel consumption), and a modernisation effect (as – due to the scenario assumptions – the hydrogen fleet in 2050 is an comparably extremely young fleet, produced almost entirely between 2040 and 2050).

Scenario	Year	AC-km [Billion km]	Fuel [Tg]	CO2 [Tg]	H2O [Tg]	NOx [Tg]	CO* [Tg]	CxHy* [Tg]	SO2* [Tg]
History	2000	31.0	168.1	530.7	207.9	2.228	0.86	0.260	0.155
ULS	2020	60.6	287.1	906.5	355.1	3.495	1.28	0.321	0.264
	2050	202.1	773.4	2441.6	956.7	7.313	3.46	0.774	0.712
RPP Kerosene	2020	50.5	237.2	748.9	293.4	2.871	1.07	0.273	0.218
	2050	138.8	523.9	1653.8	648.1	4.914	2.40	0.560	0.481
RPP H2	2050	127.6	210.7**	75.8	1757.3	1.382	n.c.	n.c.	n.c.
FW	2020	44.2	197.2	622.6	243.9	2.361	1.04	0.265	0.181
	2050	77.2	302.5	955.0	374.2	3.459	1.75	0.425	0.278
DtE	2020	38.0	198.0	624.9	244.9	1.898	0.91	0.245	0.182
	2050	40.7	227.9	719.4	281.9	1.113	1.06	0.3	0.206

n.c. = not calculated
* For CO, CxHy, SO2 the current level of emission regulations is assumed for all scenarios
** Fuel consumption in predominantly hydrogen, but with 8.5% kerosene powered aircraft remaining

Due to further improvements in fuel efficiency in ULS and RPP the specific fuel consumption (kg fuel per ac-km) will be reduced in these scenarios by ca. 30% until 2050. Although technology advances are in the Fractured World only in some regions of the globe comparable to those in ULS and RPP, FW shows in even somewhat higher reduction of the specific fuel consumption (-36%), as the average flight distance in this scenario is significantly lower (and therefore e.g. the take-off-weight relatively lower for the same aircraft). The lowest consumption of kg fuel per aircraft kilometre will be in the RPP H2 sub-scenario (-46%), mainly as the energy density of hydrogen is higher than the energy density of kerosene.

For all scenarios, 3-dimensional emissions inventories for civil aviation addressing AC-kilometers, fuel use, CO2, H2O, NOx, CO, unburned CxHy with a grid scale of 5°x 5°x1km are available at NLR and DLR – for information about access, please see the CONSAVE website (http://www.dlr.de/consave).

Within the CONSAVE 2050 project, Military Aviation was not addressed. However (as for AERO2k) the assumption was made that in the future the total volumes for fuel used and for emissions will increase with very low growth rates or will even oscillate around present values – with some differences among the four scenarios. As there is no reliable information on the future development of military aviation emissions, it is assumed that the respective absolute values for Military Aviation for 2020 and 2050 are in the order of those, given by AERO2k for the year 2002.

The four CONSAVE aviation scenarios can be regarded as being consistently embedded in the CONSAVE background scenarios. The four CONSAVE background scenarios were quantified using the quantified results for key factors of “partner” scenarios of the IPCC/SRES exercise with scenario characteristics closest to those of the four CONSAVE scenarios.

As the IPCC scenarios are related to emissions from all human activities, the contribution from civil aviation to these total emissions can be estimated by comparing the results for the CONSAVE scenarios with the figures calculated for the “partner” scenario of the IPCC/SRES work. For CO2 and NOx, contributions from aviation compared to the respective emissions from all human activities were determined for the years 2020 and 2050:

CO_2 emissions: Share of civil aviation	2000	2020	2050
ULS	1.82%	2.27%	3.11%
RPP – kerosene	1.82%	1.99%	3.68%
RPP – cryoplane	1.82%	1.99%	0.17%
FW	1.82%	1.48%	1.64%
DtE	1.82%	1.86%	2.23%

NOx emissions: Share Of civil aviation	2000	2020	2050
ULS	2.12%	2.31%	2.50%
RPP – kerosene	2.12%	1.90%	2.45%
RPP – cryoplane	2.12%	1.90%	0.42%
FW	2.12%	1.53%	1.60%
DtE	2.12%	1.31%	0.85%

It should be noted that some uncertainties in these figures result from the fact that the scenario assumptions from IPCC/SRES are very close to those for the CONSAVE scenarios, but completely identical only in respect of the dominant aspects GDP and population.

Furthermore, it is important to recognise that the percentage of total anthropogenic CO_2 and NOx emissions attributed to aviation, shown in the table, assumes considerable (scenario specific) technical progress in aviation as well as in other industries. (To put this into context, if aviation were to make no progress in terms of fuel and NOx efficiency, the percentage of aviation CO_2 and NOx emissions for the ULS and RPP (kerosene) scenarios would rise to around 7% of total man-made emissions)

The AERO-model was modified to allow for some results concerning the Airport Air Quality (AAQ) * and Noise aspects of air traffic. Around 65 cities are selected world wide, emphasising the larger airports in the western hemisphere. For each of these cities (or airports) the average changes were calculated for fuel consumption and for nitrogen oxides NOx, as the emission species from aircraft are most relevant for AAQ. Since the AERO model cannot provide the level of details required for estimating the increase in emissions in detail, the results are given by averaged emissions factor across all cities and by the standard deviation to this factor across all cities selected.

Scenario	ULS	RPP Hydrogen	RPP Kerosene	FW	FW	DtE
Region	EU	EU	EU	World	EU	EU
Source weighted reduction	-13.9	-15.8	-14.1	-12.5	-12.6	-15.3
Traffic volume factor	2.26	1.46	1.57	2.82	1.130	0.72
Total noise reduction (Lden*)	-11	-14	-12	-8	-12	-17

*Lden = Day-evening-night level. It is a descriptor of noise level based on energy equivalent noise level (Leq) over a whole day with a penalty of 10 dB(A) for night time noise (22.00–7.00) and an additional penalty of 5 dB(A) for evening noise (i.e. 19.00–23.00).

* The catalogue of AAQ (airport air quality) related emissions includes CO_2, NOx, UHC, CO, SOx, PM (particulate matter as soot), VOC (volatile organic compounds), Pb (lead), benzene and HAP/TAP (hazardous/toxic air pollutants). Most relevant are NOx emissions (as a precursor for the photochemical ozone formation) and PM (see AERONET [32]). Levels of airport PM emissions are estimated to be low, but uncertainties exist in understanding the complex PM formation process.

For three of the four basic scenarios – ULS, RPP (kerosene), and FW - NOx emissions around airports will increase until the year 2050: Compared to the present levels NOx emissions from aircraft will increase with average factors of about 2.4 / 1.6 / 1.5 for the three scenarios with variances values for the whole selected sample of 65 cities of ca. 5.4 / 3.9 / 3.3 respectively. One of the basic scenarios, the Down-to-Earth scenario, shows a reduction of the average NOx emissions from aircraft around airports,. In the RPP Cryoplane sub-scenario aircraft NOx emissions around airports will be as well significantly reduced until 2050.

Differences of the respective results for the various sub-scenarios (with the exception of RPP hydrogen) are small.

Accounting for factors contributing to noise (and air quality) such as local weather conditions etc. was outside the scope for the CONSAVE project. Nevertheless the impact on the noise development of aviation technology advances, fleet built-up, transport volume, and traffic breakdown in flight frequency and aircraft size was addressed for the 'major' cities considered.

As a result of the expected progress in aviation technology, within the EU, the noise (emitted) at ground level will be for all scenarios remarkably reduced by 2050 compared to the situation in 2000.

Economic effects

Within the time period until 2050, the costs/RTK (unit costs) for airlines will increase for all scenarios, with higher growth rates between 2020 and 2050. The effects of the scenario specific constraints on unit costs are lowest for the Unlimited Skies scenario (increase from 0.71 US$ / tonne-km in 1992 to 1.15 US$ in 2050) and highest for the two sub-scenarios of the Regulatory Push & Pull scenarios, kerosene fleet with global 2$ fuel tax and hydrogen fleet roll-over (increase to 2.10 US$, respectively to 2.14 US$ in 2050). The effects of the characteristic constraints of the Fractured World on unit costs are also relatively high (1.91 US$ in 2050), whereas the pressure on costs is more moderate in the Down to Earth scenario.

The pattern of the increase of the revenue/RTK is similar to that of the cost/RTK. Thus, the development of the operating results for airlines mirrors the scenario specific levels of air transport demand.

Airlines Profitability	**Unlimited Skies**	**Regulatory Push & Pull**	**Fractured World**	**Down to Earth**
2020	8,14%	5,05%	5,93%	2,19%
2050	6,88%	4,35%	6,05%	1,95%
Operating costs and revenues in billion US$ (1992)				
Costs 2020	803	776	665	552
Revenues 2020	869	815	705	564
Costs 2050	4678	4351	1961	1049
Revenues 2050	5000	4540	2079	1070

Costs and revenues for airlines are higher in the high growth scenarios and slightly decreasing in all scenarios over time. The profitability is high in the Unlimited Skies scenario and low in the Down-to-Earth scenario, while in the scenarios Regulatory Push & Pull and Fractured World values are within the historical range of 4 until 6%. The comparatively good profitability in FW is explained by differences in the regional development – some regions; especially North America and Eurasia seem to be able to adjust to the assumed fragmentation in the long run, dividing the world into winners and losers of a fractured world. One has to keep in mind, that this conclusion is only valid for the estimated time horizon and under the assumption, that the potential for conflicts and security problems – typically very high in this scenario – does not reach a "wild card" level such as another world war.

Sub-scenarios and tests of the effects of constraints and policy measures

As part of the evaluation and sensitivity checks of the project results, various computations were performed to test the impact of special measures on the results for each of the four scenarios.

For the Unlimited Skies scenario, it could be shown that *cost for additional airport capacity within US and EU* will not be a significant constraint for this scenario: Based on the calculated regional requirements for additional runways resulting from the increasing aviation activity of this scenario and taking into account typical total costs per airport and runway (for development, building, maintenance), it was deduced that an increase of the landing charges by a factor 3 to 6 compared to the 1992 levels is required to finance the additional infrastructure to accommodate all ULS air traffic in US and EU. Two alternative variants of the ULS were calculated under the assumption of an increase of the landing charges of a factor of 10 and 20 compared to 1992 levels, resulting in an only small contribution to the overall unit costs per RTK (costs are passed to passengers) and only a small decrease in passenger demand in the year 2050 by 1.5% and 3.0% respectively compared to the "normal" scenario (for which a landing charge factor of 1.1 is assumed)

ULS Landing charge	Reduction compared to "no measure"				Profitability in	
	Demand	**Aircraft**	**Movements**	**NOx**	**2020**	**2050**
ULS (charge factor 1.1)					8.14%	6.88%
ULS (charge factor 10)	1.5%	3.1%	14.0%	0.7%		5.24%
ULS (charge factor 20)	3.0%	5.1%	23.7%	3.0%		4.20%

For the Regulatory Push & Pull scenario a sub-scenario with a rapid fleet roll-over from kerosene to hydrogen as propellant, starting in 2040, was computed. The scenario shows a substantial reduction in CO2 emissions which could be a large environmental advantage, if research eventually shows that there is no significant negative out-balancing effect on the climate caused by hydrogen through the production of water vapour or the formation of contrails or cirrus clouds or through the environmental effects of hydrogen production. On the other hand, the results for this sub-scenario imply a situation that, in the absence of governmental subsidies aviation will be for some stakeholders, especially for airlines (profitability -4%), a loss making business for a considerable period of time, due to the cost of the roll-over, even if the costs of ground infrastructures changes are not taken by the air transport sector. In this case, an increase in fares would not improve the situation for airlines, as it would cause a reduction in demand.

For the all kerosene fleet Regulatory Push & Pull scenario, the effects of three types of global and regional fuel taxes of 1.0$/kg to 2.0$/kg were calculated. A global fuel tax of 2.0$/kg would in 2050 enhance the operating revenues of airlines by 13%, and reduce fuel use by 10%, but would cause a reduction of global demand by 5%, of airline related employment by 8%, and would produce a negative balance in the operating finances. The profitability of airlines would decrease from 4.4 % within a RPP No-Tax-Scenario to -0.7%. Both other sub-scenarios also show a remarkable reduction with respect to the profitability of airlines: In simple terms, the financial effects of the reductions in demand over-compensate the increases in operating revenues.

RPP Fuel Tax and Cryoplane	Reduction compared to "no measure"				Profitability in	
	Demand	**Aircraft**	**CO2**	**NOx**	**2020**	**2050**
RPP (Kerosene/no tax)					5.05%	4.35%
RPP (1$/kg)	2.6%	8.4%	5.5%	5.4%		1.01%
RPP (2$/kg)	5.1%	14.5%	10.2%	10.1%		-0.72%
RPP Cryoplane	5.1%	8.6%	95.4%	71.9%		-3.99%

For the Down to Earth scenario, the effect of the introduction of a landing charge increased by a factor of 3 compared to the level of 2000 was tested. Since, within DtE, “avoidable” flights are already strongly reduced, the remaining demand is quite price-inelastic. Consequently, by 2050 the reduction of the total passenger and cargo demand caused by the higher fares of the sub-scenario is very small, specifically a decrease of 1% compared to the scenario without additional charges.

Main conclusions

From the work performed and the results achieved, various conclusions can be drawn:

The design of a representative set of robust constrained scenarios on aviation and its emissions for 2020, 2050 with an outlook to 2100 has been completed. The scenarios are fully developed, quantified, tested and broadly reviewed, and based on newest information for the “Background Scenarios” for those fields which set the framework for the long-term development in aviation. This work is an important step beyond existing scenario work, delivering a foundation for the short-, medium-, and long-term planning, enabling more efficient consideration of possible futures and consideration of the implications for technology development and other possible responses.

Rather then looking for mixed “realistic” futures developing along “most-likely” paths, the concept of CONSAVE to design a set of “pure”, even extreme, scenarios, allows the definition of robust boundaries for the range of possible growth of aviation and its emissions until 2050.This approach provides essential information for the policy and regulation community, the aviation industry, and for researchers including climatologists, and is a valuable input for further RTD activities within FP7.

By implementing intensive contacts and interactions especially to ACARE/ASTERA, AERONET, EUROCONTROL and AERO2K, the project has been able to successfully contribute to the development of a common European understanding of critical aspects of the long-term development of aviation and its related emissions: The work of the Accompanying Measure Project CONSAVE has been used as prerequisite for the development of the second version of the ACARE Strategic Research Agenda (SRA II), for the development of the new forecast for 2020 of EUROCONTROL, as input information for many discussions on the level of AERONET II, and for comparison within the AERO2K project.

Whereas the broad European activity ACARE is referring to the year 2020 as a time horizon, the CONSAVE study with its major time horizon year 2050 can be regarded as a complimentary additional project, as some key developments for the future in aviation will become strongly relevant only beyond 2020.

Two examples of such developments in two key driver fields:

- Within the time period from 2020 – 2050 for the energy sector, a strong increase in fuel prices or, dependant on scenario, even an availability problem, can be expected, enforcing the change of conventional kerosene to synfuels or to other substitutes.
- Beyond 2020, it can be assumed that in the field of environment, knowledge of the impacts of emissions from human activities (including those from aviation) on climate change and their resulting effects on the habitat of human beings, has reached a high enough level of accuracy and precision, followed – if the results indicates a high enough level of danger for man - by a significantly enhanced pressure for strong policy measures or sharp society responses, thus supporting scenario developments like the CONSAVE scenarios Regulatory Push & Pull or Down to Earth.

Additionally, ASTERA has developed for ACARE a set of scenarios which has nearly identical basic features compared to those designed (and quantified) by CONSAVE; with one meaningful exception: ASTERA did not include a scenario comparable to the CONSAVE scenario Down to Earth, for the good reasons that only after a long enough time period of around two decades, i.e. beyond the year 2020, can it be expected that such a scenario will contrast enough from other scenario developments. However, especially from the view point of the sustainability aspects, the discussion of a scenario like Down to Earth is of high relevance for strategic planning, especially for industry stakeholders in aviation.

The project has clearly shown the sensitivity of air transport to technological and societal changes and political measures, and how different long-term futures for aviation can be conceived. They require quite different, even opposite strategies for actions and reactions of the stakeholders.

Technological developments require a considerable time for implementation. With the help of the robust, detailed, and quantified scenarios developed by CONSAVE, there is the prospect for an improved stakeholder response to pressures arising from future air transport demand, its environmental impact and related political measures, thus enhancing the competitiveness of the European aeronautics industry.

The results of discussion in the CONSAVE project over a possible fleet roll-over to a new hydrogen fuel technology in aviation have clearly indicated the importance of being aware of typical necessary response times to solve the problems arising, and to cope with challenges and constraints.

The concept of the project to develop the Background Scenarios for CONSAVE in close consistency with scenarios of the new IPCC/SRES work, which refers to the total emissions caused by human activities but does not explicitly identify aviation and its emissions, has the consequence that the CONSAVE findings can be regarded as detailed “zoomed-in” scenario information for the special field of aviation and related emissions which are embedded in the “complete” scenarios for the emissions of all human activities, thus supplementing and strengthening the work of IPCC/SRES.

The analysis of each of the CONSAVE scenarios clearly shows the future need for adequate political activities, at the European and global level, supporting the sustainable development of air transport and the aviation industry in the European Union.

Proposals for future work

A wide range of open questions were be addressed by CONSAVE. Nonetheless, during the performance of the project it became clear that various complimentary additional aspects would benefit from study in the near future: These could not be dealt within CONSAVE, as they were outside the given frame for project-funding and project-time. Based on what could be already achieved by CONSAVE, a group of proposals for future work emerged which should follow the project to further enhance the value of the study:

- To perform a EU-supported and -funded pilot study on the definition of the detailed requirements for the instalment of an effective European Monitoring System on Aviation Development (EMSAD), including the development of agreed objectives, tasks, specific tools, network of information sources and of principles for the organisational structure. (The willingness to co-operate within such a project and for some financial support after the pilot study and to participate in a Steering Committee has already been declared by various stakeholders)

- To develop – based on the now modified version – an AERO-model specially adjusted for application as a tool for the typical tasks of a monitoring system.

- To develop more detailed scenarios studying additional alternative long-term developments in the field of energy / fuel technology / aircraft emissions (e.g. addressing air quality aspects around airport) for example for EU projects such as ECATS.

- To visualise the scenario storylines, by producing video-movies to further enhance the understanding and acceptance of the main messages of the outcomes from CONSAVE 2050.

- To study potential (aviation related) wild card events, including, for example, possible (sector specific) effects, defining adequate reactions aiming to minimize the negative impacts, and of possible precautionary measures (such as the organisation of an early warning system, as part of the monitoring system)

- To further clarify critical aspects (financing infrastructure, environmental impacts, timing) of a possible introduction of the hydrogen technology for aviation.

- To study more details on special aspects, on alternative scenarios, on combination of scenarios, etc. of interest for the different stakeholders of the aviation community from their specific point of view and strategy design requirements.

It could be highly effective to combine some of the recommendations above into one (EU-) project.

Some further proposals for future work, resulting from findings of the quantification process are listed in Deliverable D9 (see Part II, Annex 9).