CONSAVE 2050 - G4MA-CT-2002-04013

CONSAVE 2050
Final Technical Report

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CONSAVE 2050

Final Technical Report

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Probably, the improbable will happen
(Aristotle)

The intention is not to know the future, but to be prepared for the future
(Pericles)

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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.

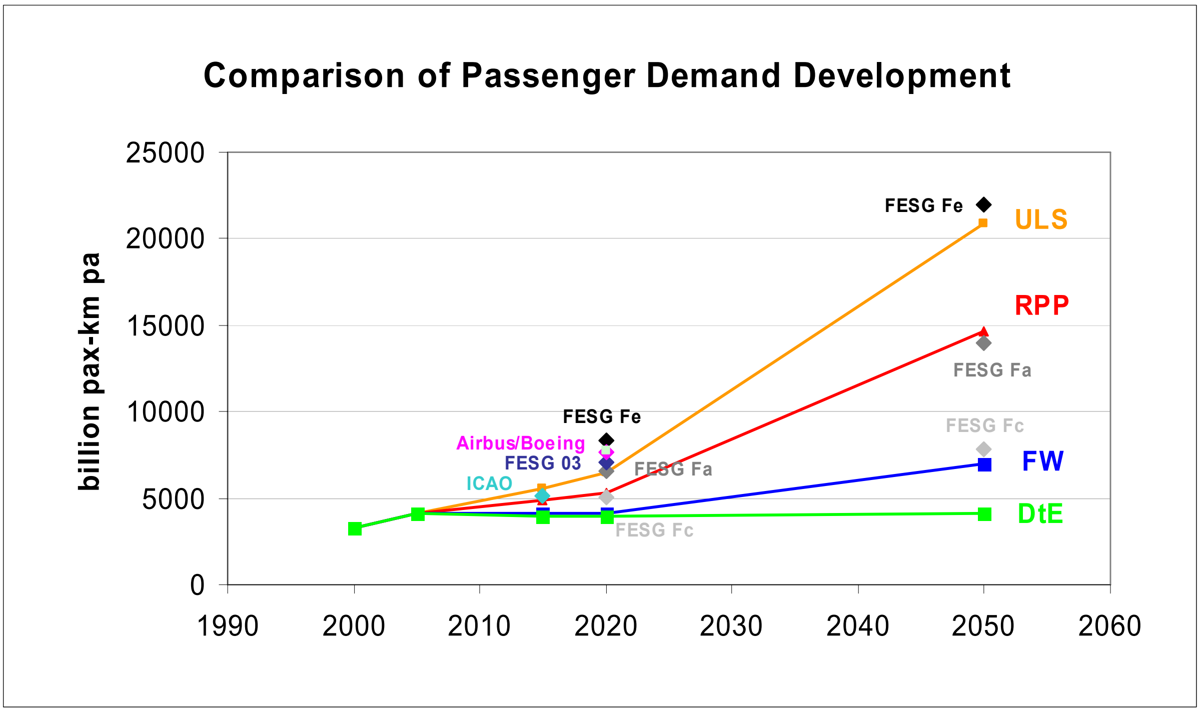
	Unlimited Skies (ULS)	**Regulatory Push & Pull (RPP)**	**Fractured World (FW)**	**Down to Earth (DtE)**
ACARE / ASTERA	Business Model	Constraint Growth	Block building	n. a.
EUROCONTROL LTF	Global Growth	Regulated Growth	Regional Concerns	n. a.

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.

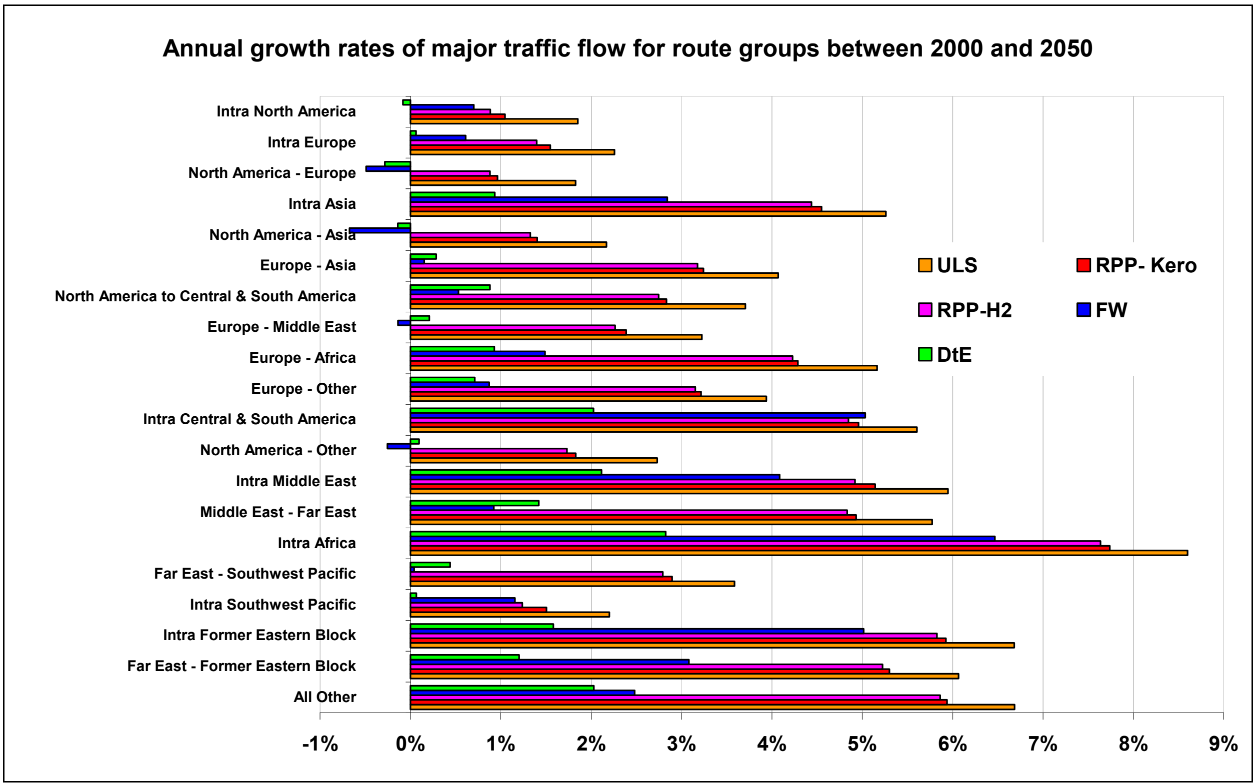
The number of passengers within the four scenarios grows with rates very similar to those for the demand in passenger kilometers, with one exception: For the Fractured World the growth rates for passengers are remarkably higher with respect to the number of passengers than with respect to passenger kilometer, 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).

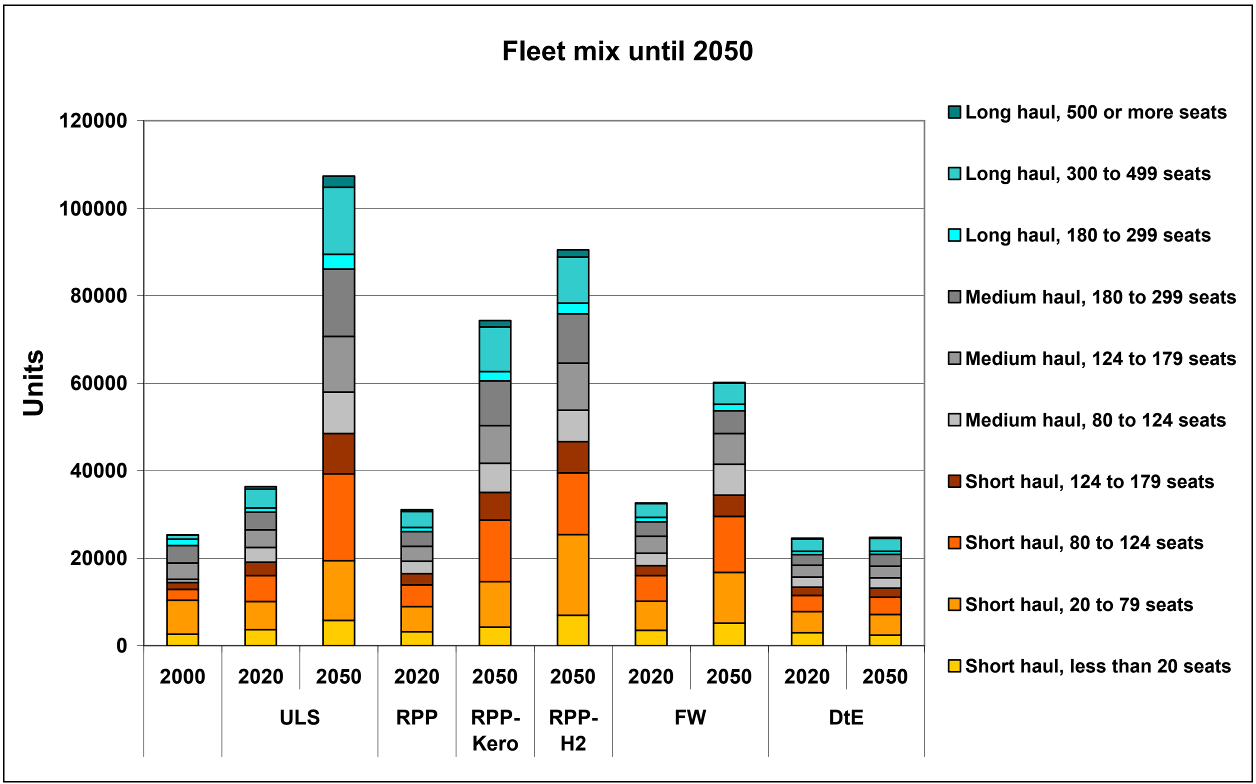
Growth rates for cargo demand, especially those for the DtE scenario, are significantly higher than those for passenger demand:

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:

CO2 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 CO2 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 CO2 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 CO2, 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).

2. INTRODUCTION

CONSAVE 2050 was started in September 2002 as an Accompanying Measure Project of the EC. Meanwhile the study has been successfully performed and a set of four scenarios on aviation and its emissions has been produced by the CONSAVE 2050 Consortium consisting of:

- DLR (co-ordinator), NLR, QinetiQ, DLH as core partners,
- IIASA and MVA as subcontractors of DLR and NLR, respectively
- EADS (Airbus) as supporting partner.

The project results have been intensively reviewed by the CONSAVE Advisory Committee and by a broad European Review Process for CONSAVE. 11 deliverables (listed in 5.4), describing the details of the work and the results achieved were submitted to the EC (for the texts see Part II, Annexes 1 – 11).

During the project life it became obvious how important the selection of a “team of excellence” has been for the successful performance of the project. Only a highly professional group of high level specialists for their working fields could manage to achieve the ambitious objectives of the project.

The aim of this Final Technical Report is to deliver a comprehensive overview on the CONSAVE 2050 project and its results, including an intensive evaluation of the outcomes of the work comparing the initial study intensions with the work actually accomplished. The report delivers

- an Executive Summary (chapter 1)
- an outline of the objectives and expected achievements of CONSAVE 2050 (chapter 3)
- the main features of the overall methodology (chapter 4)
- a scientific and technical documentation and evaluation of the findings of the project with special emphasis on a detailed description of the elaborated set of four quantified CONSAVE 2050 aviation and emission scenarios and the frame-setting corresponding CONSAVE Background Scenarios (chapter 5-8)
- proposals for future work resulting from the findings of the study (chapter 9)

References and acknowledgements are given in (10) and (11); a glossary of definitions, abbreviations, and prefixes used in the study is compiled in (12).

Part II of the report is a collection of “materials”, comprehensively addressing the various parts of the work of CONSAVE 2050 in a set of attachments, which allows further detailed considerations.

Together with the Final Technical Report the final version of the Technical Implementation Plan (TIP) will be submitted to the EC, which documents the ideas and plans of the CONSAVE partners to distribute, further explain and use the outcomes of CONSAVE 2050 to make the project as effective as possible.

3. OBJECTIVES AND STRATEGIC ASPECTS OF CONSAVE 2050

3.1 Background

Aviation – an important part of modern life

Mobility is an essential pre-condition for human well-being and welfare. To cover larger trip distances in appropriate time and to transport heavy goods men have to relay on transportation means. The inventions of steamed ships and of trains, cars and finally aircraft during the last two centuries have dramatically enlarged the range of human activities and enhanced the level of social prosperity. Presently aviation has become an important part of modern life and aviation industry – as airframe and engine manufactures, airlines, airport, aviation control systems, air tourism and related organisations - has become a significant economic factor. According to an ICAO study, air transport generated (from direct and multiplier effects) some 27.7 million jobs and a total output of about U.S. $ 1,360 billion in 1998, accounting for roughly 4.5 percent of the world GDP [24].

Further development in aviation – potentials and problems

Since the invention of the jet aircraft, air traffic has grown with high rates (figure 1), and with respect to the meanwhile dominant international air traffic as part and as a driver for an increasing globalisation of the world. Between 1945 and 2003 air passenger travel in terms of scheduled services has grown at an average annual rate of 11 percent, since 1960 at a rate of 8 percent (which equals to a growth by a factor of nearly 32 since 1960) [24]. As so far – due to ICAO figures - less than 15% of the world population - within the industrialized nations - is contributing by more than 80% to global air traffic, both with respect to domestic and to international air traffic, there is - independent from additional reasons - a high potential for a further significant increase of air transport, if more nations will economically develop during the next decades. Another context in favour for a further increase in air transport demand: As long as the historical experience will be still valid for the future that (a) the total time budget for travelling remains about constant in space and time and (b) the percentage of income spend for travelling approaches asymptotically to levels already reached for high developed markets (as assumed e.g. in [7]), an increase in GDP is directly connected to an further increase in high speed traffic and consequently in air transport as a important part of it.

But what would be the conditions and the costs of a further strong growth in aviation?

For the reflection of this question a wide range of different aspects have to be considered. To name just some important ones:

- Will the necessary “inputs” for the production of air transport - including row materials to built aircraft, all kind of needed infrastructure, the required amount of fuel, etc. - be available and at which prices?
- Will the aviation system be able to operate effectively at such a production level? (What about congestions, delays etc.?)
- What about safety and security within such an expanded aviation system?
- What are the environmental consequences of the related gaseous emissions and of the nuisances from noise?
- What are the social impacts?

In more general terms:

- What will be the challenges, and/or constraints for such a development?
- What about the sustainability aspect?

These questions are to be addressed and sufficiently clarified by the aviation community, to enable a socially accepted development of air transport within the 21st century.

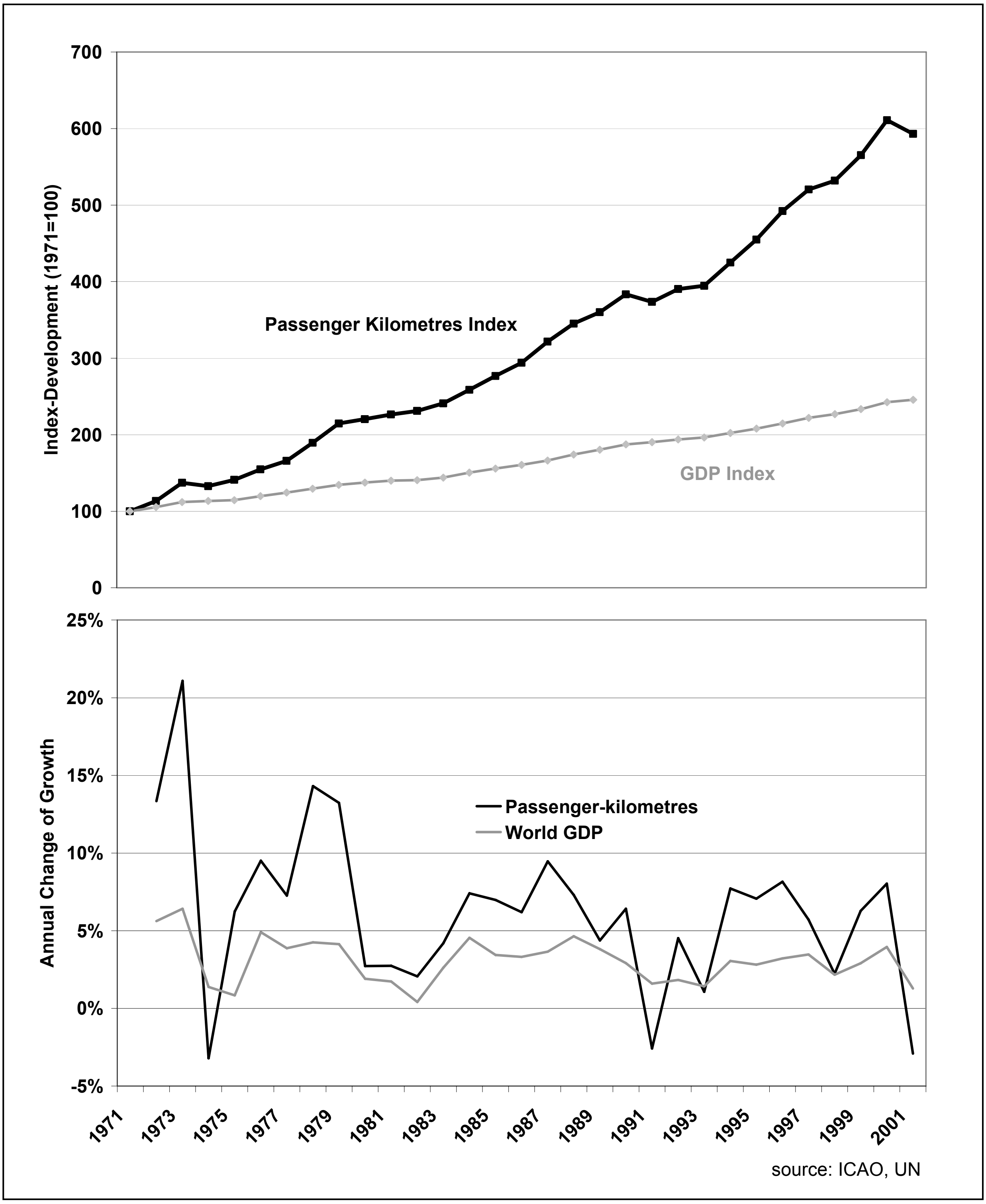


Figure 1: Index-development of global GDP and air transport demand (1971=100)

Sources: ICAO [26], UN [27]

CONSAVE 2050 - A project for the elaboration of strategic input information in support for the discussion on a sustainable future of aviation

The specific meta-goal of the CONSAVE project is to deliver qualitative and quantitative strategic input information in support for the discussion on a sustainable future in aviation by designing a set of quantified scenarios on aviation and its emissions representing the range of possible long-term developments in air transport.

- **Why scenarios?**

Thinking in scenarios - which are combinations of consistent assumptions on the development in key fields for the scenario subject - is the adequate approach for strategic planning. Especially for complex systems it is difficult and with increasing time horizons almost impossible to *predict* the future[1]. Consequently, scenarios are not intending to develop forecasts, they are describing possible alternative images of how the future might unfold and the paths leading to these futures, applying as much available relevant information on the future development as suitable. Using a representative set of qualitative and - as far as possible - quantified scenarios, addressing especially those aspects of the future development which might be critical both with respect to opportunities and risks, will allow for an adequate reflection and, if necessary, modification of the long-, medium-, and short-term strategies and activity plans of the various stakeholders, thus supporting them to be prepared for a broad range of different futures.

- **Adequate time horizon**

The discussion on sustainability aspects in aviation requires considerations with time scales, long enough to allow relevant conclusions on the long-term development. Therefore, scenario paths studied should cover a time period of several decades, a time horizon year 2050 being an adequate selection. On account of the long life-time of CO2-emissions, climatologists are even asking for a time horizon of 100 years, whereas intermediate results for shorter time horizons, e.g. for the year 2020 are of interests for the short- and medium-term planning of aviation industry.

- **The start of aviation scenario activities on the level of AERONET**

Responding to the declared needs of stakeholders, AERONET performed two workshops on the issue of "Long-term Scenarios of Aviation and its Emissions" - hold in Germany at DLR, Cologne in October 2000 and in Spain at the airport of Palma de Mallorca in March 2001 ([1], [2]). In preparation for the workshops, as a first step for the definition of concrete tasks for the scenario activity, a list of proposals for topics which should be addressed from the view of the different stakeholders of the aviation community was collected by an AERONET questionnaire action (see Annex 1). The workshops developed - on the base of identified "Key fields and factors affecting the long-term development in aviation and its emissions" (see Annex 2) – four outline qualitative scenarios. As one of the conclusions of the workshops the participants agreed that the provision of fully usable scenarios, elaborated in detail, tested and quantified, would require comprehensive project work over an about two-year period: The idea for the CONSAVE 2050 project was born.

[1] Future situations can be calculated for close systems describable by known equations / rules with known (functions of the system) variables

3.2 Objectives and expected achievements

Introduction

Based on the findings of the long-term scenario activities of AERONET, the proposal for CONSAVE 2050 (**CON**strained **S**cenarios on **AV**iation and **E**missions) has been developed by a team of the AERONET partners DLH, DLR, NLR, QinetiQ with the central task to design a representative set of robust quantitative, constrained scenarios with focus on the time horizon year 2050, an intermediate view to year 2020[2] and an outlook to year 2100, as

- long-term constrained scenarios provide the basic information for long-term strategic planning in the field of air transport.
- long-term constrained scenarios on aviation and its emissions are important as input for long-term assessment of the impact of these emissions on climate change and on local airport air quality.

The report on "Aviation and the Global Atmosphere" IPCC published in 1999 [3] included a variety of scenarios, analysing the future development of global air transport demand and the consequences of aviation emissions until 2050. But, only scenarios with an unconstrained development of air traffic were considered ([4], [5], [6], [7]). This significant limitation is addressed by CONSAVE 2050. The project foresees explicitly and as it's most important and innovative topic, the development of constrained quantified scenarios on aviation and emissions.

Another key feature of the study is the use of the most recent information from IPCC/SRES [8] on assumptions for the development of population growths, economy, and other areas framesetting for the development in aviation, whereas the IPCC/1999 aviation scenarios, used for calculation of the effects on the atmosphere, were based on now outdated IPCC/1992 background scenarios [9].

The aim of the accompanying measure is to deliver a fundamental prerequisite for many activities involving European stakeholders in the sphere of aviation and its environmental impacts that need to generate a long-term perspective. It addresses - from a European perspective - RTD policy issues (sustainable aviation), competitiveness and sustainable growth issues in the aviation industry, such as the future implementation of clean propulsion technologies for aircraft. The project will account for emerging technologies in the important European aviation industry sector and for important macro- and socio-economic factors influencing growth.

The catalogue of objectives, the problems addressed and the planned contribution to the EU-programme activities are described in the following:

Relevant scientific, technical and socio-economic objectives

The project will develop a set of quantified scenarios that support the atmospheric science community, the aviation industry and the policy and regulatory community. Respectively, these sectors have a need to determine the possible growth of aviation and its emissions to deliver environmental response information, technology response strategies or policy or economic measures. The project, through the establishment of an Advisory Committee of customers, a broad review process on the preliminary results and intensive contacts to the many related external activities shall ensure that a common European understanding on critical issues of aviation scenarios and related emissions will be achieved.

[2] Initially the year 2025 was foreseen as intermediate time horizon, but this was later on changed to 2020, especially to be able to compare the results of CONSAVE with findings from the majority of related external work.

Main socio-economic objectives of the project are (i) to strengthen the European aeronautic industry by delivering sound information which can be used to develop *in time* a strategic orientation of the short-, medium-, and long-term planning and (ii) to ensure sustainable growth of air transportation with regard to environmental issues. To account for the fact that the various customers have different understandings of what might be the most relevant time frame for the scenarios, apart from the main focus on the year 2050, a view will be taken on 2020 developments as a consistency assessment with related industry work and a more simplistic outlook to 2100 to satisfy the scientific horizon. The long-term *constrained* scenarios will show the sensitivity of the air transport system to technological and societal changes and political measures. This will (e.g.) allow for better planning of infrastructure measures and of the long-term research activities for improvement of aircraft efficiency, environmental friendliness and safety (critical technologies). The outlook to year 2100 will generate special data relevant for climatology, supporting the improvements of models for the calculation and assessment of global and regional impacts of emissions from aviation and other sources.

Problems addressed by the proposal

It is impossible to *predict with certainty* long-term futures: the longer the time horizons, the greater the uncertainties. But, any planning is based on assumptions on the future. The only way to address this dilemma is to design consistent alternative possible scenarios for the future using as much sound information, currently available, as possible. The goal of CONSAVE 2050 is to strengthen the ability of European stakeholders to *predict* the future through new and improved understanding of critical aspects of sustainable aviation and its emissions. The work will include, for the first time, constrained scenarios on aviation and related emissions. It is unrealistic to perpetuate the use of unconstrained scenarios, similar to those described in the IPCC Report “Aviation and the Global Atmosphere”, as these do not reflect the real world, just a very extreme case. The use of improved and more recent “background conditions” (i.e. population and economic growth) included in the IPCC/SRES will significantly enhance the quality of this scenario product.

Air transport is one of the strongest growing transport segments, and a further increase is expected for the next decades. Due to the relatively long life-span of an aircraft (~25-30 years), technological developments need a long time for implementation. As a special problem of aviation, this could cause the danger of an unacceptable late response to political (societal, economical and ecological) demands, like the reduction of aircraft noise, fuel consumption, local and global air pollution. With the help of robust scenarios, there is the prospect for improved stakeholder response to pressures arising from future air transport demand, its environmental impact and also the related political demands (and necessary policy measures). Fostering these activities will promote the sustainability of air transport.

Contribution to the overall programme, preparation of further RTD policies

It is critical to the effectiveness of technology development for emissions reduction to be well informed on the constraints and pressures arising from predicted emissions impact. Scenarios are integral to that process and allow for estimation of effects and needs to underpin stakeholder reaction in the long term. This includes assessing the need for new aircraft technologies, airline and fleet management, infrastructure development and changes in air transport management systems. Scenarios therefore improve the planning process of the whole air transport industry.

CONSAVE 2050 meshes well with existing RTD programmes. It builds upon the AERO2K inventory base case and forecast activity, seeks to draw in the information on the performance of emerging technologies from a number of projects and links to ATM and airport and airline developments through AERONET.

Contribution to further RTD activities

CONSAVE 2050 scenarios will support the future definition of RTD need by identifying the air traffic system and emissions consequences of certain boundary or intermediate developments in civil aviation. Factoring this information into proposed research and development activities by industry, operators or the scientific community can only serve to strengthen the way that the sector deals with strong challenges in keeping aviation on a sustainable path. Amongst other things, this will influence research and development in the fields of airframe design, fuel economy, emissions reduction, alternative propulsion systems, etc. Furthermore the scenarios will clearly help to identify the future need for political activities, at the European and global level, supporting the sustainable development of air transport and the aviation industry in the European Union. Many aspects of possible concrete answers will depend on the very *details of the assumed future development* in aviation. In general, human planning of new activities is - conscious or unconscious - based on assumptions on the future development in the relevant fields. However, only those features for which the future is not already fixed, i.e. which cannot be firmly predicted, but can instead develop along alternative paths, can be shaped! Especially for any strategic planning the thinking in alternative scenario developments is the adequate approach to look into the future and should therefore applied for the above described discussion, too. (Using a scenario approach has in addition the advantage that a neglect of relevant information - often necessary for forecasting - can be avoided.)

4. PROJECT METHODOLOGY AND WORKING PROCESS

4.1 Scenario approach of CONSAVE 2050

The production of scenarios is a complex multi-phase process. Typical steps of the scenario technique, e.g. explained in more detail in Annex 3, are

- Task analysis
- External influence analysis
- Projections of influence factors
- Consistency analysis to cluster alternative sets of projections to form logical and plausible images of the future
- Scenario interpretation (e.g. by storylines)
- Consequence analysis
- Wild Card analysis
- Scenario transfer

For CONSAVE 2050 the envisaged technical scenario development and quantification work is broken down in three logical steps (WP 1 – WP 3), addressing the first six of the above mentioned steps of the scenario technique:

1) Analysis of external and internal key factors and features of interest for the project and needed as input for other work packages (Starting version to be developed in WP 1A, final selection in WP 1B, WP 2, WP 3)
2) Design of (a) qualitative and (b) quantitative *Background Scenarios* for those fields frame setting for the long-term development in aviation and its emissions (WP 1B, WP 2)
3) Design of (a) qualitative and (b) quantitative *scenarios on aviation and emissions* (WP 3)

A major special aspect of the CONSAVE 2050 approach is, that the scenarios are quantified, based on tested quantification tools.

A main objective of the scenario work of the CONSAVE 2050 project is to go a step beyond (and improve) existing scenarios on aviation and emissions by special consideration of present and expected future constrains of aviation. Limits of sustainable growth of aviation should be identified and related challenges for the future development should be quantified to estimate needed activities and strategies for actors and stakeholders of the aviation system.

Not or not fully addressed within CONSAVE 2050 are the scenario steps seven and eight of the list above:

Examples for the so-called “wild cards” are unexpected events as wars, terror attacks, epidemics, earthquakes, etc. In some cases probabilities for their occurrence might be known, however, it is typically unknown when, where, and with which “power” they will happen. Of principal interest for CONSAVE 2050 are those wild cards which would disturb the development in aviation. In history, the impact of those events on the demand in air transport was quite different. In most cases they have caused typical “dips” in the development which however have later on, after some time, returned to its “normal” undisturbed path (e.g., in the case of the 1992 Iraqi war). But in principal, long lasting disturbances or down-levelling are possible (as could happen in the case of a World War) and even “dips” may affect the profitability of stakeholders, causing strong influences on competition and on innovation speed.

As empirical data, the historical data used by the AERO-model which is applied for quantification of the CONSAVE scenarios, are including the effects of the aviation related wild cards of the past. The reaction within the work of CONSAVE to the impacts of September 11th event of the year 2001 on aviation is described in (7.4). Future wild cards are only to small extend parts of the CONSAVE storylines, a complete Wild Card Analysis was out of the scope of the project, as it is the case for the scenario step "Scenario Transfer": By concept of the project - as a pre-competition research study - this step is thought to be performed by the various stakeholders themselves, using the results of CONSAVE 2050.

High emphasis was given to ensure, that the outcomes of the project will take into account the needs and views of the stakeholders of the European aviation system. Therefore, a set of close contacts to the aviation community were established (as part of the activities of WP 4 and WP 5) on the following levels:

- Advisory Committee for CONSAVE 2050 (which intends to represent the range of different aviation sectors)
  For permanent advice within all phases of the project
- AERONET (and selected other) experts
  As addressees for the questionnaire activity and for discussions on workshops
- Relevant external project groups, especially ACERA/ASTERA, EUROCONTROL, AERO2k
  For mutual consideration of results
- Other external groups, especially TRADEOFF; SCENIC, IPCC, ICAO/CAEP
  For analysis of programmes and findings
- Special groups of the European aviation industry, especially DLH, Airbus
  For detailed and practical orientated discussion of results and aspects
- Complete interested European aviation community
  As addressee for the European Review on preliminary study results of CONSAVE 2050

Figure 2 illustrates these contributions from external experts.

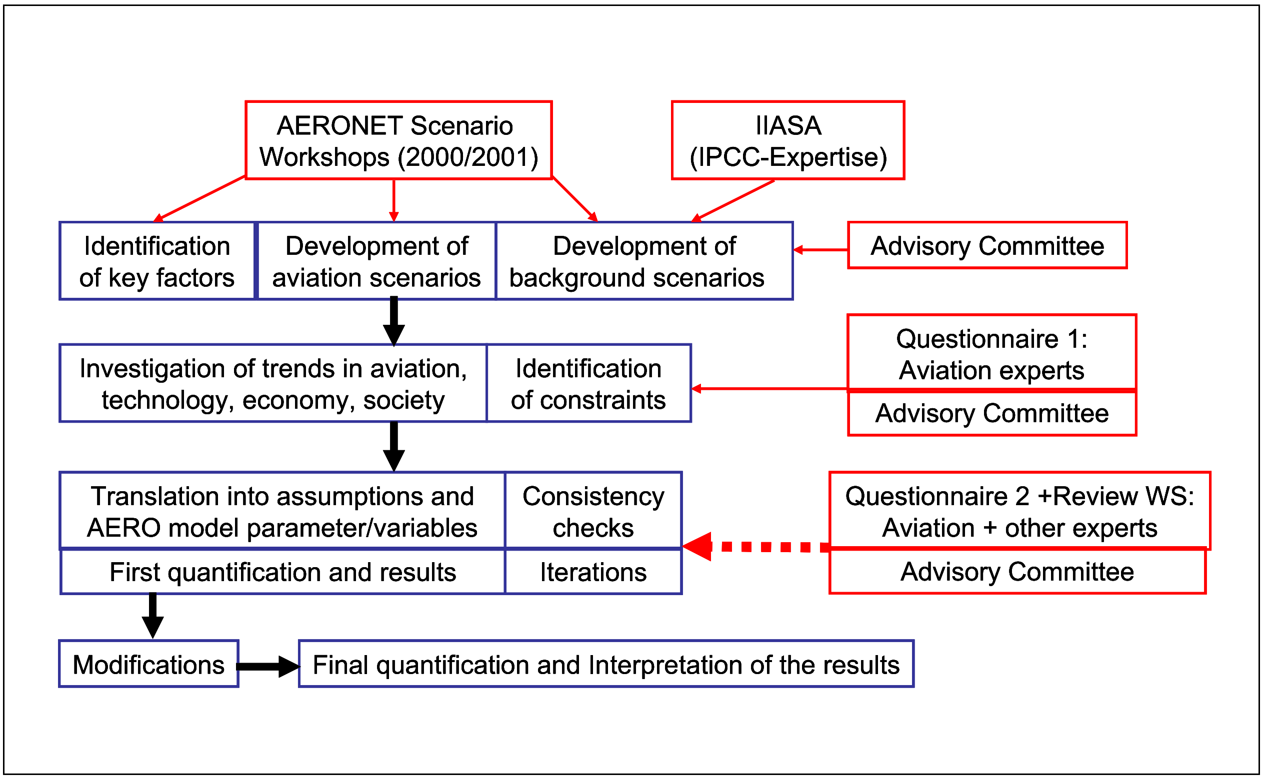


Figure 2: **Working process + external inputs**

4.2 The AERO-model

The AERO (Aviation Emissions and Evaluation of Reduction Options) -model has been selected as calculation tool for the quantification of the CONSAVE scenarios. The model is extremely well suited to forecasting the effects of the alternative scenarios assumptions required by the CONSAVE project. Whilst the AERO-model was used so far as a tool to test policy-options (especially in relation to reducing cruise-altitude emissions), a vital feature of the model is that the user can define the (future) scenario as a context for testing policy measures. The model then generates forecasts for the scenario without as well as with the measures. A great deal of flexibility is provided for defining different scenario specifications.

The AERO-model model has been reviewed and accepted by ICAO/FESG, and earlier versions have been used before for a variety of studies for different clients.

Figure 3 gives an overview on the data flow within the AERO modelling system.

Calculations with the AERO-model requires to determine ca. 70 assumption variables for system parameters, 50 scenario variables, and 50 policy variables. The main scenario variables fall within four major domains: macro-economic, demographic, transport market and technological development. Most scenario variables also allow for differentiation by aircraft characteristics, traffic categories, and world region (IATA region (-pair)), see Figure 4. Basic input assumptions, such as demand elasticities, rates of depreciation, and aircraft emission indices can also varied with time.

The catalogue of those AERO-model inputs which were used to characterize the CONSAVE Scenarios will be described in chapter (5). For the scenario invariant variables the historically observed (default) values are preserved.

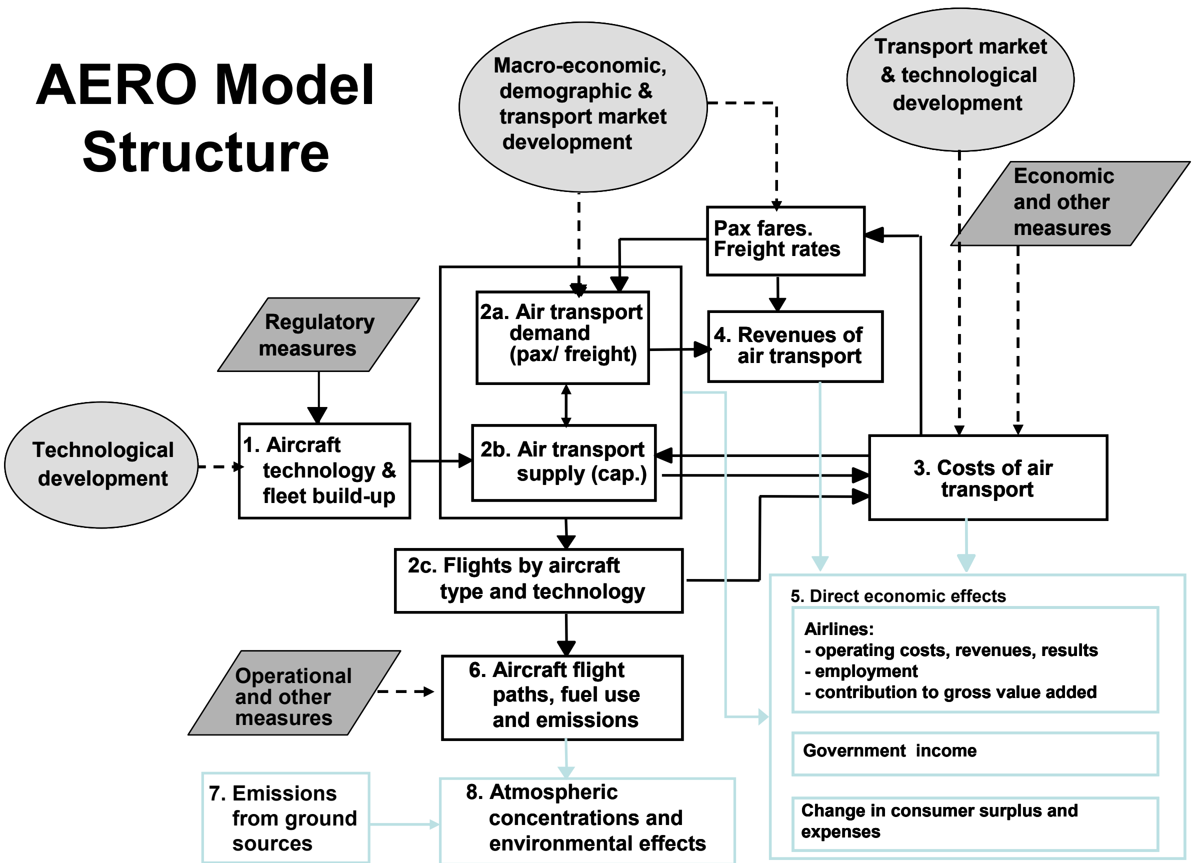


Figure 3: Overview on the computational steps of the AERO-model

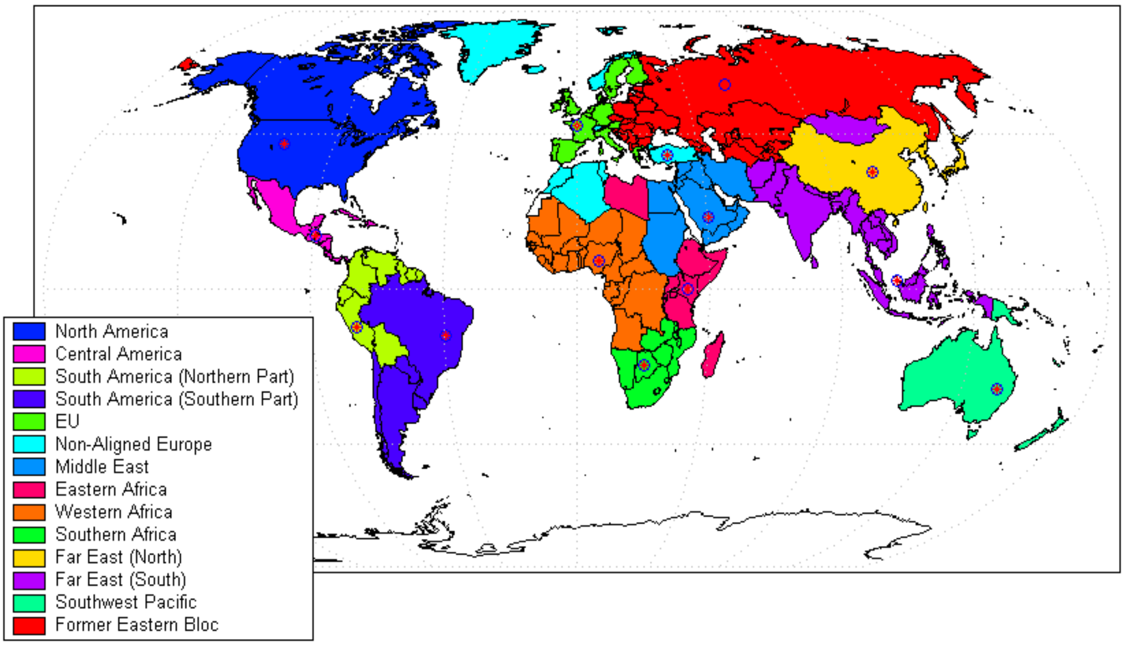


Figure 4: IATA region definition used in the AERO-model

Detailed documentation of the AERO-model is given in Deliverable D9 and in [10]. A full description of the AERO model is also available under: http://www.dlr.de/consave/library/aero-model.pdf.

4.3 CONSAVE work structure and major logical working steps

Within this chapter an overview of the structure of the work for CONSAVE is given. In table 1 the CONSAVE work packages and their deliverables are listed. Figure 5 shows the mutual interdependence of the work packages within the project.

WP No.	Work package Title	Lead contractor	Person months	Start month	End month	Deliverable number
WP1	Key factors and qualitative background scenarios	DLR	11	0	6	D5, D6
WP2	Quantification of background scenarios	DLR	5	5	8	D7
WP3	Quantification of scenarios on aviation and emissions	NLR	13	8	21	D8, D9
WP4	Organisation of an European Review on preliminary study results and contacts to external activities	QinetiQ	9	0	21	D10, D11
WP5	Management and co-ordination	DLR	11	0	24	D1, D2, D3, D4
		TOTAL	49			

Table 1: Work Package List

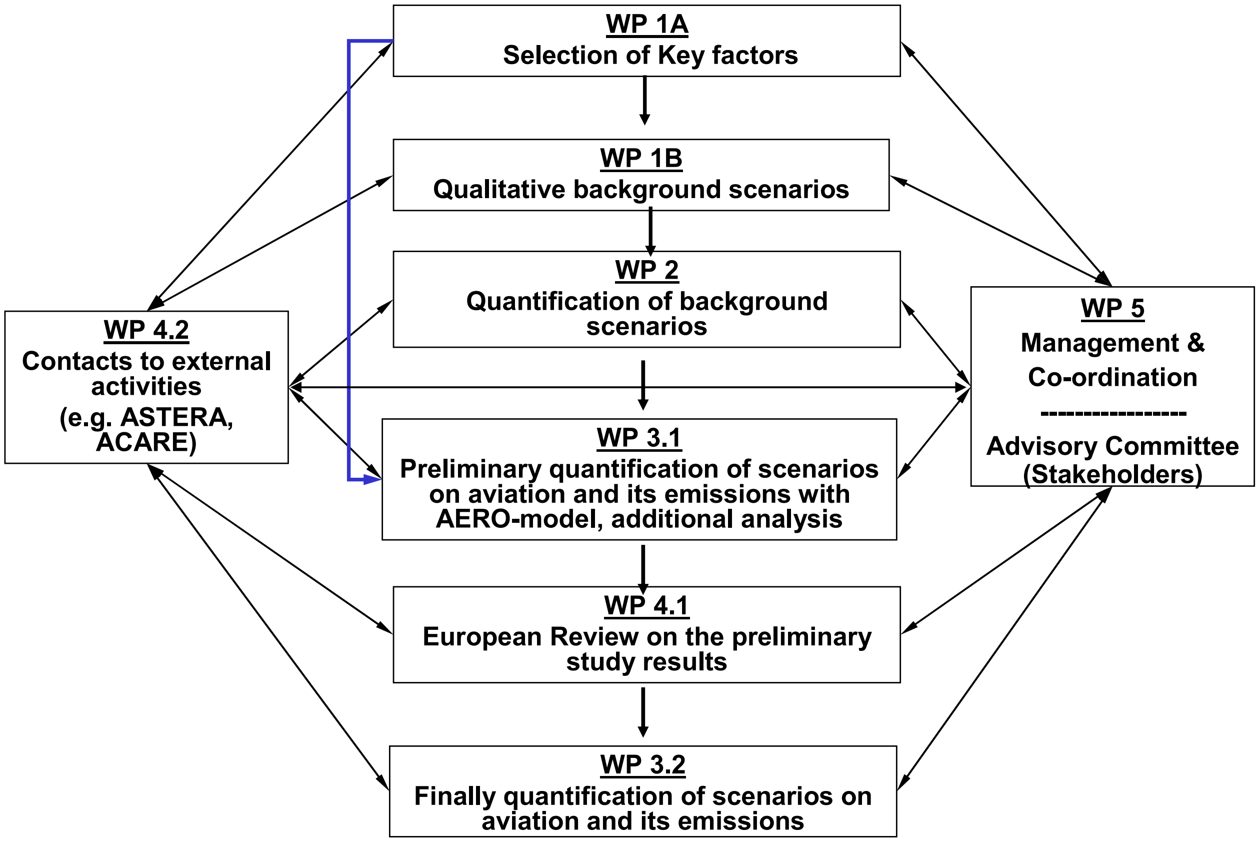


Figure 5: Interaction between work packages

The results of the work of the CONSAVE 2050 were finally achieved running through a series of major steps, performed in close contact to a representative range of experts of the aviation community:

- Synopsis of findings of preceding AERONET activities (questionnaire and two scenario workshops).
- Performance and analysis of the outcome of a CONSAVE questionnaire action about major topics which should be investigated in the study and subsequent modifications as result of an review of internal (team, Advisory Committee) and selected external experts, including comparisons to related external work (especially [11] – [23]).
- A CONSAVE scenario workshop performed in cooperation with IIASA in January 2003 (In Laxenburg/Vienna, Austria) to develop a representative set of qualitative Background Scenarios (frame setting conditions for aviation), which are consistent to the most similar IPCC/SRES scenarios, and subsequent final agreement on the set of CONSAVE Background Scenarios, resulting from internal review of the team and the Advisory Committee.
- Design of storylines for the four selected scenarios and subsequent internal review.
- Quantification of the background scenarios and subsequent internal review.
- Elaboration of storylines for the CONSAVE scenarios for the long-term development in aviation and its emissions in line with the storylines of the Background Scenarios.
- Identification of the inputs needed for quantification of the CONSAVE aviation scenarios with the AERO-model, and determination of agreed respective assumptions by integrating the characteristic features of the different scenario paths, plus definition of needed enhancements of the AERO model.
- First quantification and European Review (including a Review Workshop) on these preliminary results.
- Analysis of the Review Process by the team and conclusive modifications taking into account also the findings of parallel scenario activities, especially those of ACARE/ASTERA (SRA in 2003/2004 [21]) and EUROCONTROL (Long-term Forecast in 2004 [24]).

- Conclusive quantification of the CONSAVE 2050 scenarios taking into account final recommendations of the Advisory Committee and elaboration of this Final Technical Report.

Together with the presentation of the results in the next chapter (5) more detailed information on the work performed is given. A comparison of the activities planned versus the actually accomplished work will follow in chapter (6). The complete project work is documented in the deliverables.

5. SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

5.1 Introduction

In this chapter the results of the CONSAVE 2050 are presented in the following structure:

- Scenario fields, factors, constraints identified as of key interest for the study
- Choice of a representing set of CONSAVE Scenarios
- Description of the four selected CONSAVE Scenarios
- Discussion of the outcomes

Additional aspects of the work performed – a comparison of the activities initially planned versus the work accomplished; management and co-ordination aspects; study conclusions; and proposals for future activities are addressed in the subsequent chapters (6) – (9).

5.2 Key scenario descriptors and constraints, input and output of the AERO-model

The central task to be performed during the first phase of CONSAVE 2050 was the identification of those features which should be addressed and quantified within the project from the perspective of possible customers (aviation industry, policy makers, climatologists, transport researchers):

- Key fields, factors, and features (external and internal) affecting the long-term development in aviation and its emissions which should be
  a) addressed in the scenario storylines,
  b taken into account as elements for the quantification of the background scenarios,
  c) used as input for the AERO-model (used as tool for quantification of the CONSAVE 2050 aviation scenarios);
- challenges, constraints of highest potential influence on the long-term development in aviation and its emissions;
- the intended study outputs.

The identification work for these three categories of features was performed running through a series of steps within the work packages WP 1, WP 2, and WP 3, starting with a questionnaire. As a result of this process - described in (4.2.3) and fully documented in deliverable D5, D6, D7, D9 (see Annex 5,6,7,9 of Part II) - the following outcomes were achieved:

Key scenario fields, factors, and features

Based on the outcome of the questionnaire activity and the subsequent review work within WP 1A, the catalogue of key fields & factors, affecting the long-term development in aviation and its emissions, elaborated by AERONET (see Annex 2), was accepted as basic input for the further work within CONSAVE 2050. The agreed key scenario *fields* are given in column 1 of table 2.

- **Features addressed in storylines for Background Scenarios**

As a result of the discussions during the scenario workshop in Laxenburg and in the final review after the workshop eventually a catalogue of descriptors for the qualitative background scenarios was selected (column 2, table 2) which is nearly identical to the proposal developed from WP 1A. The key fields for these qualitative scenario storylines are structured in the four blocks:

1. Population – Economy – Regional disparity
2. Social Trends – Governance – Environment
3. Resources – Technology
4. Communication – Transport – Air Transport

	Key fields [see Annex 2]	**Addressed in Background-Scenario storylines [see (5.3)]**	**Addressed in Aviation Scenario description [see (5.3)]**	**Quantified as Input for the AERO-Model [see (5.3)]**	**Challenges, Constraints studied [see (5.2)]**
I	Demography	Population		Global + regional Population	
II	Macroeconomics	Economic Development		Global + regional GDP	
		Regional Disparities			
III	Energy/Resources	Resources	(Part of Aviation Costs)	Energy Use Oil Prod. Peak Energy Price	Availability+ Price Price to Cryoplane Technology
IV	Social Trends / Mobility Patterns	Social Trends	Mobility Patterns		Mobility Patterns Global Conflicts
V	Transport	Transport	General Transport Development Transport and IT Technology		
VI	Aviation Effects on Ecology	Environment	Environmental Impacts of Aviation Environmental Regulation		Environmental Impacts
VII	Technology	Technology	Aviation Technology	Various Technical Assumptions, see (5.3)	Lag of Standardisation
		Communication Technology			Maintenance costs
				Cryoplane Intro. Year	
				New Aircraft Price	
				Surface competition	
VIII	Policy/Regulations	Governance	(Part of Environ. Impacts)	Var. Taxes + Charges	Regulations
IX	Air Transport - Supply	Air Transportation	Air Transport - General Supply	Crew needed	
			Airport and ATM	Detour Factor	Infrastructure Capacity
			Safety and Security	Security (as Tax)	Security
			Air Transport Market	Target Profits	
				Load factor	
				Aircraft crap value	
				Interest Rate	
			Aviation Costs	Volume costs	
				Crew salaries	
X	Air Transport - Demand	Air Transportation	Air Transport – Demand	Autonomous Growth Elasticities	Saturation

Table 2: Key fields, factors, features, and constraints addresses in CONSAVE

- **Features quantified in the Background Scenarios**

For the IPCC/SRES exercise growth of population and economy (GDP), and changes in technology and energy patterns have been identified as main scenario driving forces. With the exception of the technology changes these key factors (and the resulting emissions caused by the range of human activities) were quantified within SRES by applying six different calculation models. Based on the resulting SRES databases, quantifications of the CONSAVE Background Scenarios were elaborated for the following variables (column 4 of table 2):

1. Growth of population (global and regional)
2. Growth of GDP (global and regional)
3. Changes in energy demand, resource availability, energy prices (global)

In addition, first ideas for the quantification of

4. Air traffic demand (as part of the modelling of aviation scenarios)

were derived, linking consistently factors of air transport to quantified features of the underlying CONSAVE background scenarios and related IPCC/SRES reference scenarios.

- **Features to be used as input for the AERO-model**

The AERO-model has many input variables and options. Only a subset is needed and was used to describe the CONSAVE scenarios. The set of inputs for the quantification with the AERO-model can be grouped into the following categories:

1. Factors and features qualitatively described and quantified within the background scenarios (developed in WP 1, WP 2)
2. Detailed assumptions on the long-term development of aviation technology (delivered for WP 3 by QinetiQ).
3. Data and assumptions on other scenario relevant aspects (beside aviation technology) of the long-term development of aviation (elaborated within WP 3 by DLR and NLR with assistance from the team)
4. For those features required as input for the AERO-model, but not defined by (1) - (3), as not needed to characterize the CONSAVE Scenarios, default variables (historically observed behaviour) were used.

Based on findings from the other work packages, especially taking into account the storylines of the Background Scenarios, final versions of the inputs for the AERO-model were determined in WP 3, with the concept to bring project input and output data in consistency, if necessary running through iterations.

The inputs assumptions (1) – (3) for the AERO-model which are used to describe the characteristics of the CONSAVE scenarios are summarized in column 4 of table 2. For the complete catalogue of assumptions and inputs used for the CONSAVE calculations with the AERO-model see sections (5.4) and (5.5). For further details see Deliverable D5, D6, and D9.

Challenges and constraints studied within CONSAVE 2050

Within CONSAVE circumstances which require high level efforts of the actors in aviation to guarantee a further positive development in air transport – either by taking given opportunities or by coping with upcoming risks - are called “challenges”.

Those upcoming effects with the potential to significantly decrease the demand side or to hinder the supply side of air transport and are not “normal” external drivers (e.g. GDP, population, competitive technologies) are called “constraints”. A characteristic feature of a constraint for aviation, important for strategic planning, is the typical response time for affected aviation actors. Challenges which are not coped with and “Wild Card” events can be effective as constraints.

Figure 6 shows which external (topics in blue) and internal (in red) fields and factors were identified by the experts and stakeholders responding to the questionnaire as candidates for significant constraints which are of special interest for the CONSAVE study (with the ranking following the answers of the questionnaire):
As results of further discussion within the team and with external experts eventually the following challenges, respectively constraints were selected to be studied within CONSAVE, as the ones with of the actually highest interest for the aviation system (column 5 of table 2):

- *Regulations* to reduce environmental impacts caused by air transport (emissions, noise) and related cost effects
- *Energy related challenges/constraints*: problems caused by price, scarcity, change in technology (introduction of cryoplanes)
- *ATM capacity challenges/constraints* due to high growth in air transport
- *Airport capacity challenges/constraints* due to high demand for air transport (especially relevant for Europe)
- *Security problems* caused by *global conflicts, terrorism* and *fragmentation*
- *Changes in mobility patterns* / Lifestyle and value changes and their possible impact towards a *reserved attitude to air travelling* (effecting especially Tourism)

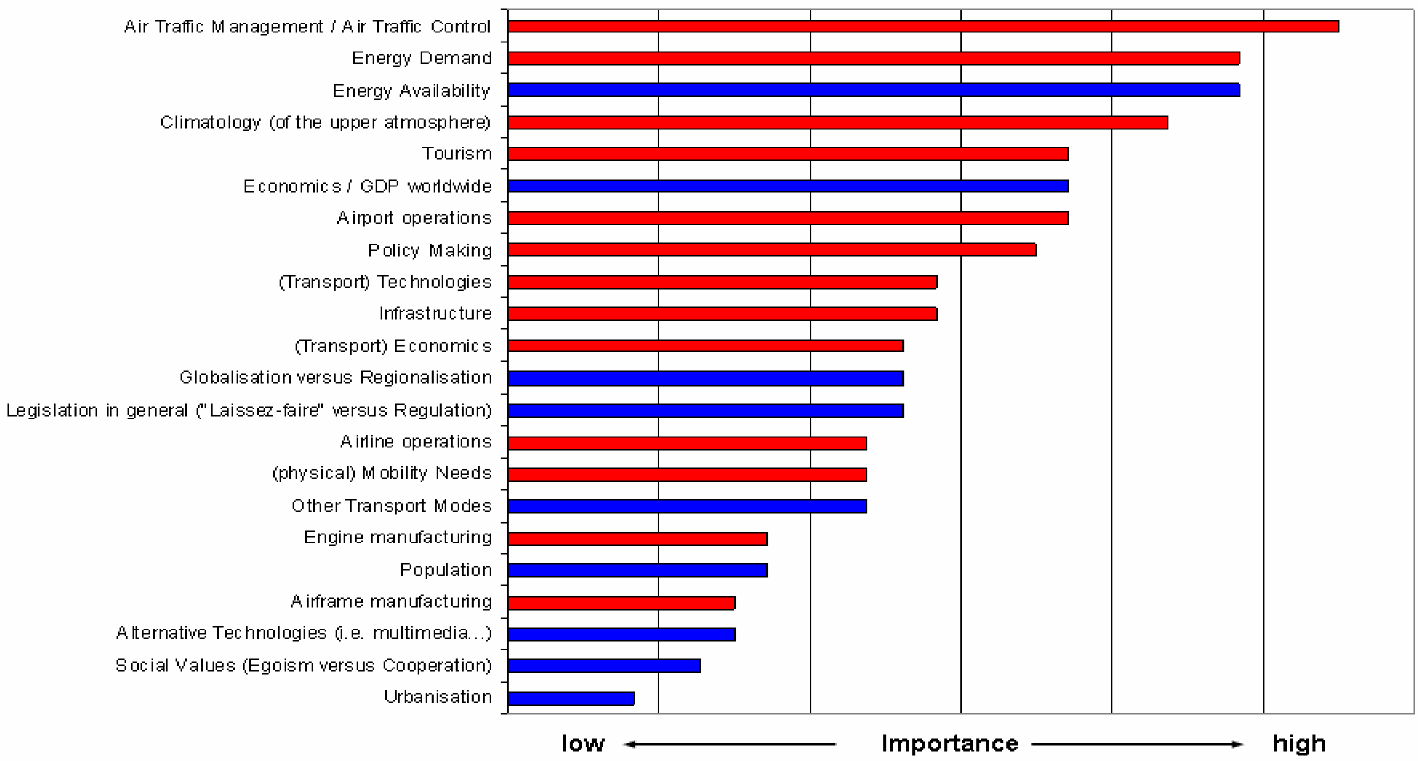


Figure 6: Internal and external fields, which could cause constraints for the future aviation system

Intended study outputs

Concerning the intended study outputs a catalogue of 14 features (a) of the presented possible scorecard of the AERO-model and four additional aspects (b) was selected by the experts of the questionnaire and as result of the subsequent review, because it was assumed that the complete list of (a) and (b) together represents the major features of interest and concerns for the future development of the aviation system.

(a) Following the answers to the questionnaire outputs with high importance are:

- Fuel use and emission characteristics by aircraft type and technology level
- Air transport demand and traffic (passengers/ freight transported, flights by aircraft type and technology level, fares and freight rates) forecast
- Fuel use and emissions (CO2, NOx, SO2, CxH, CO, H2O) in 3-dimensional space (5° by 5° horizontal grid cells and 15 equidistant altitude bands of 1 km plus 1° by 1° by horizontal grid)
- Extent and composition of airline fleets (by carrier group/IATA region)
- Concentrations of CO2, NOx, O3 (36x24 horizontal grid cells and 19 layers)
- Aircraft flights (by flight stage, Aircraft type and technology level)
- Aircraft operating costs (by aircraft type, technology level and region pair)
- Unit operating costs (per passengers and kg freight by aircraft type, technology level and flight stage)
- Aircraft purchase prices (because of price developments and possible measures)

Of medium to small importance for the project were assessed:

- Unit composite costs
- Changes in consumer surplus and consumer expenses (by carrier group/IATA region)
- Government income from charges
- Airline related employment
- Airline contribution to gross value added

It was agreed that for those aspects in the starting list of possible outputs of the AERO-model which are related to the quantification of the *effects of aviation emissions*, e.g. of "Effective UV-radiation" and the "Change in global warming potential" best estimations should be made directly by the experts of the climatology community - using the CONSAVE results on fuel use and emissions - as there are ongoing improvements in climate modelling. The calculation of the *effects* of the emission from aviation within CONSAVE 2050 would be outside the scope of the project.

(b) Additional aspects identified as to be of interest which should to be addressed in the study output as well, at the time of the start of project not covered by the AERO-model are:

- Noise
- Infrastructure / capacity (airports and ATM especially in Europe)
- Local air quality in the airport vicinity
- Safety and security aspects

The final scorecard used for the AERO-model outputs was developed on the base of these results, documenting as well some additional quantifiable aspects identified as of interest during the calculation process (see 5.5).

5.3 Choice of a representative set of long-term scenarios

5.3.1 Introduction

The approach of CONSAVE 2050 was that the aviation scenarios to be designed should be consistently embedded in a set of CONSAVE "background" scenarios on external fields frame-setting for the long-term development in aviation and its emissions which should be as far as possible consistent with the results of the IPCC/SRES exercise.

The design of background scenarios for CONSAVE 2050 was split into two parts: the task of WP 1B was the development of a representative set of *qualitative* scenarios, featured by detailed storylines, the task of WP 2 was the *quantification* of these scenarios, both using findings of the IPCC/SRES work. The background scenario paths are considered until the year 2100, with main emphasis on the scenario development until 2050 and an additional look on the year 2020. Within WP 3 aviation scenarios consistent to the background scenarios were elaborated.

5.3.2 The selection

The work of WP 1B was started with a 3-day project workshop for the design of (qualitative) background scenarios, held at IIASA, Laxenburg in Austria. In the beginning the scenarios developed during two AERONET workshops were intensively checked especially with respect to (a) the completeness of the list of key descriptors which should be addressed in the study due to the findings of WP 1A and (b) the internal consistency and modified taking into account the results of a comparison of the AERONET scenarios with those developed by the IPCC/SRES exercise. (The comparison was performed and presented at the workshop by the subcontractor IIASA. For the viewgraphs see deliverable D6 in Part II): The concept of the project was to develop the CONSAVE background scenarios as consistent as possible to the IPCC "Special Report on Emissions Scenarios" (SRES), published in 2000 [8], to ensure that the study can take profit from the intensive work of this globally reviewed exercise. While the IPCC/SRES work is not explicitly addressing air transport, the scenarios on aviation and its emissions, designed by CONSAVE 2050, should fit as far as possible and reasonable to the world-wide broadly accepted IPCC picture of the "background", frame-setting for the long-term development of the aviation system.

A preliminary set of four overall scenario families, comprising six individual scenarios were developed that bracket a range of important scenario drivers for the future of air transportation and related emissions. After the workshop draft storylines for these background scenarios were designed by IIASA.

These first results were subsequently reviewed by the CONSAVE partners. It was eventually agreed, that four development paths of three scenario families should be investigated. Each of them should focus on different constraints and challenges to allow a separate estimation and quantification (including sensitivity analyses) of possible constraints. This agreement underlined, that the CONSAVE project should focus on the elaboration of orientation knowledge – identifying the impact of special constraints/challenges and strategies, how to deal with them - instead of performing a forecast, which is based on the common consideration of all possible constraints.

The four selected CONSAVE scenarios of three scenario families were labelled as follows:

- "High Growth" scenario family with the two family members:
- **"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

Following the IPCC-SRES scenarios, a simplified taxonomy for the scenarios draws on two dimensions, which include the polarities of globalization-regionalization, as well as the emphasis on economic versus ecological development goals respectively. A combination of 2 x 2 = 4 scenarios describe the scenario space along these two dimensional axis (see figure 7). Three of the four original scenario families from the IPCC-SRES exercise were retained for the CONSAVE project. These scenarios represent extremes of possible developments rather than simple gradual variations along “business as usual” development pathways: In order to explore the long-term uncertainties and challenges surrounding air transportation,

CONSAVE 2050 considered it important to explore boundary conditions rather than intermediary scenarios. Thus, contrary to the IPCC-SRES scenarios, where one scenario family (IPCC-SRES B2) was designed to illustrate more gradual changes, the present CONSAVE scenario set contains no “middle-of-road”, “central tendency”, or “business as usual” scenario. Furthermore, the selection of just one scenario family for the description of non-global scenarios can be regarded as a consequence of the fact that in the scenario “Fractured World” more economy or more ecologic orientated societies can appear at the same time in different regions of the globe, filling the full half of the right hand side of the scenario space. Therefore, the altogether four scenarios of three scenario families represent a complete range of alternative future developments in terms of demographics, economy, geopolitics, as well as technology amongst other variables. The scenario storyline for “High Growth” is further differentiated to describe two subscenario developments that differ with respect to the regulatory framework under which future air transport could operate (ranging from few regulatory constraints to a multitude of stringent ones), in order to explore more explicitly the emergence of additional constraints on the future of air transportation, being a core objective of the CONSAVE 2050 project.

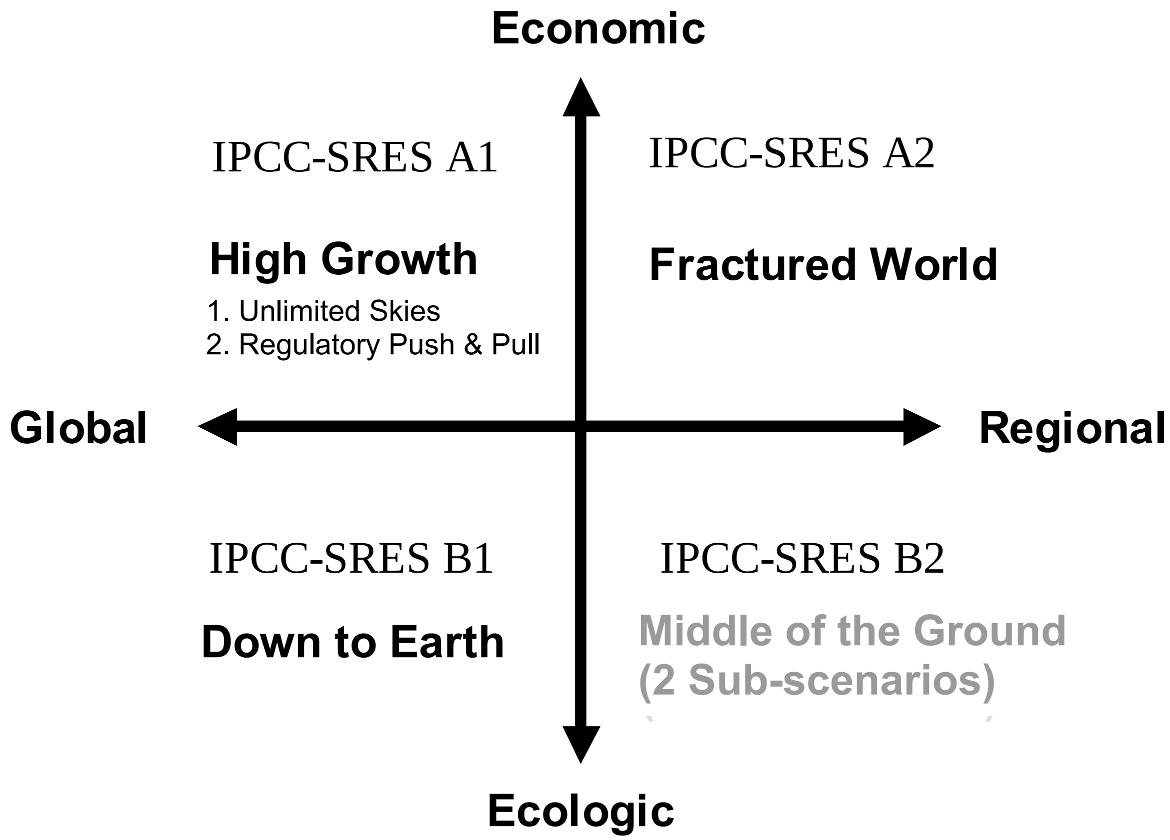


Figure 7: Taxonomy of the CONSAVE Scenarios and their relation to the IPCC-SRES Scenarios

Figure 7 provides an overview of the taxonomy of the CONSAVE scenarios and their relation to the IPCC-SRES scenarios (including as well as the original 6 scenarios developed within the CONSAVE workshop held at IIASA in January 2003). Scenarios no longer retained for the CONSAVE project are indicated by light-grey fonts.

Table 3 shows for the four selected CONSAVE scenarios their respective main assumptions, main character of challenges/constraints, relation to the IPCC/SRES scenarios, and the comparable scenarios with time horizon 2020 of ACARE/ASTERA and EUROCONTROL LTF as the most important actual external (long term) aviation scenario activities.

	Unlimited Skies (ULS)	**Regulatory Push & Pull (RPP)**	**Fractured World (FW)**	**Down to Earth (DtE)**
Main assumptions	Very High growth of demand: Ability to fit demand, new technologies	High growth of demand + Environmental problems + Introduction of Cryo-plane	Global conflicts, regionalisation, and fractured markets	Changing values, regional lifestyles and environmental conscious
Main character of challenges/ constraints	Need for large enhancement of aviation infrastructure and energy availability, landing charges	Regulations and increasing costs	Security problems, low demand, high costs (strong focus on regional resources, low standardisation)	Low demand, very high sensitivity to environmental impacts
IPCC/SRES related scenarios	SRES A1	SRES A1 -3%*	SRES A2	SRES B1
ACARE / ASTERA	Business Model	Constraint Growth	Block building	n. a.
EUROCONTROL LTF	Global Growth	Regulated Growth	Regional Concerns	n. a.

* For the RPP scenario there is no direct congruence with one of the IPCC/SRES scenarios, but the economic assumptions about the development of the World GDP were used from SRES A1 with a minus of 3% to ensure a consistent storyline.

Table 3: CONSAVE Scenarios - Main characteristics and comparison to external scenario work

Both, ACARE/ASTERA and EUROCONTROL LTF scenarios developed a very similar scenario structure, but do not have any equivalent to the fourth CONSAVE scenario “Down to Earth”. Related to their specific goals both activities preferred to develop a “base case” respectively a “Business as usual“-scenario.

5.4 Qualitative description of the four CONSAVE scenarios - Storylines of the overall scenarios and detailed features of the embedded aviation scenarios

5.4.1 Introduction

Each of the following scenario descriptions start with extensive qualitative scenario storylines to illustrate the character and philosophy of the development path. (These storylines were produced by the subcontractor IIASA, using the results of the CONSAVE scenario workshop for a first draft and later on integrating the proposals for modifications provided by the CONSAVE team.) They describe overall background scenarios for the development of “macro-trends” which are important for the future evolution of air transport demand, aircraft technologies and operations, and their combined impacts on the environment, via emissions. The storylines provide contextual information to guide the adoption of ranges of input variables in subsequent quantitative modelling with the AERO model. They were developed to be as consistent as possible with their equivalent scenario families developed within the IPCC-SRES exercise in order to enable to derive easily quantitative scenario macro-variables like population and economic growth, but were modified and adapted to reflect better air transport-related aspects, where necessary. The description starts with an overview on major qualitative (and quantitative) aspects of the Background Scenarios (see table 4).

In the second part for each scenario the elements of the storyline of the respective aviation scenario are described which are elaborated by DLR and the team to be in line with the characteristics of the storyline of the overall scenario: These aviation scenarios can be regarded as detailed “zoomed” parts of the respective overall scenarios storylines on communication/transport/air transport. The descriptions of the aviation scenarios include a catalogue of additional more detailed quantified assumptions on the long-term development in aviation technology developed by QinetiQ (used as input for the AERO-model) and - elaborated by NLR – a list of various quantified non-default assumptions for variables applied within the AERO-model to further characterize the CONSAVE aviation scenarios.

(While in the following the inputs for the AERO-model are described scenario-wise, within deliverable D9 respective characteristics for all scenarios are given in one table, to allow for direct comparisons of the scenario input assumptions (see Annex 9, Part II)).

5.4.2 The storylines of the CONSAVE Scenarios

A) “Unlimited Skies” (ULS) + B) “Regulatory Push & Pull” (RPP)

<u>Overview on the Background Scenarios ULS and RPP</u>

“Unlimited Skies” (ULS) and “**Regulatory Push & Pull”** (RPP) are both **“High Growth”** scenarios, largely following the “Western” model and having a similar development until 2020. Both scenarios describe a case of rapid and successful economic development worldwide driven by high human capital (education), innovation, technology diffusion, and free trade that are the main sources of productivity growth and modernization of social and economic structures. All parts of the world would achieve high levels of affluence by the end of the 21st century, even if disparities will not have disappeared entirely. In any case, the current distinction between "developed" and "developing" countries in any case will no longer be appropriate in this scenario.

For both “High Growth” scenarios the principal driver is *prosperity*. All major scenario driving forces are closely linked to prosperity levels, with actual causality links going both ways. For instance, demographic variables co-evolve with prosperity: mortality declines (life expectancy increases) as a function of higher incomes enabling better diets and affordable medical treatment. In turn, changes in social values and relations underlying the fertility transition along the historical European and Asian experience pave the way also for wider access to education, modernization of economic structures, market orientation, etc. that are a key for innovation and

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 catastrophic change
Technology development	Dynamism of technological innovation is broad-based; communication and transportation growth		Heterogeneous, partly incompatible, interchange problems	Rapid diffusion of post-fossil technologies
Political development	Market philosophy	Emission regulations	Regional differences	Pollution sources tightly controlled
Citizens' values	Global orientation, pragmatic solutions	Regulatory approach in environmental issues	Autarky, regional orientation	Environmental and safety concerns
Customer preferences	Convenient and flexible service and mobility	Cheap and environmentally okay	Security concerns	Stigmatisation of fast/international patterns
Aircraft technology	New very large aircraft available	Like ULS + hydrogen powered AC	Different standards	Introduction of hydrogen powered AC
Safety & Security	High standards	High standards (regulation)	High effort to ensure security	High standards
Market Development	Deregulation, strong competition	Controlled liberalisation, medium competition	Dominance of national carriers	Decrease in the number of airlines
Air transport supply&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 profitability
Aviation Costs	Lower specific costs	Lower specific costs	Higher (security & standards)	Higher specific costs

Table 4: Overview of the CONSAVE scenario storylines and major assumptions

diffusion of best practice technologies underlying the high productivity, and hence economic growth of the scenario. To summarize: High prosperity levels allow significant increases in investments into education, R&D, and the experimentation with new product and process innovations that in turn nurture high demand and productivity growth and hence, exert a powerful positive feedback mechanism on economic growth.

A corollary of the high economic growth via innovation and free trade logic of the scenario is that the mobility of people, ideas, and technologies co-evolves closely with the high economic growth rates of the scenario. Traditional, as well as novel (supersonic, maglev trains) transportation modes co-evolve with radical changes in ICT. Transport and communication are not only complementary in this scenario but enhance each other synergistically.

The core bifurcation of the scenario with respect to air transportation unfolds around alternative paths of addressing externalities of massive growth in transport and communication flows worldwide. These externalities include in particular congestion and local and regional environmental protection in case of transport, and issues of privacy and informational security in case of communication. Two sub-scenarios would gradually unfold after 2020.

In one, **"Unlimited Skies",** market forces address these externalities via vigorous technological innovation efforts, reviving the high experimentation rates and short innovation product life cycles, characteristic of the early pioneering days of air transportation and mobile telephones. Vigorous innovation is therefore the industry response in order to overcome potential barriers arising from the formidably high growth in air transport of this scenario. Safety, congestion, and local and regional environmental impacts (noise, emissions) are addressed successfully by introduction of advanced technology concepts. The motivation for these innovations is less environmental, but simply an economic innovation response to overcome bottlenecks, to avoid stringent regulation by the public sector, and to allow for sustained growth. In this scenario, global climate change impacts turn out to lower than previously anticipated and the high income societies of the future can adapt to it. Hence, also global environmental issues are comparably low on the priority list in this scenario.

In the second, **"Regulatory Push & Pull"** sub-scenario, strict governmental regulation provide for a regulatory "push and pull" on technology: "Pulling-in" desirable technologies and characteristics via regulation and incentives; "Pushing-out" undesirable ones. Initially, regulatory push and pull factors focus on rapid, incremental improvements of existing technologies (e.g. fuel efficient aircraft engines), but over the longer-term increasingly the focus shifts to radical technological solutions, e.g. banning progressively the use of kerosene in air transport in order to stimulate the market adoption of cryogenic hydrogen aircraft. Overall, technological change is less diverse and experimental than in the "Unlimited Skies" scenario, but more directed to rapidly respond to evolving environmental concerns, especially climate change, whose impacts turn out to be much larger than previously anticipated, unfolding rapidly already in the first decades of the 21st century. This leads to a frenzy regulatory effort of emission reduction and impact mitigation, while still maintaining the high economic growth priorities characteristic of this scenario family.

Key Scenario Drivers of the Background Scenarios ULS and RPP

Population, economic development, and regional disparities

The linkage between demographic and economic variables in the "High Growth" scenario is based on present empirical observations: The affluent live long and they have few children. High per capita incomes are thus associated with both low mortality and low fertility rates.

Causality links are bi-directional. For instance, increasing economic affluence and higher workforce participation of women may lower fertility rates. Alternatively, high education and resulting female empowerment result in modernization of traditional social structures, lowering fertility rates, and subsequently provide the social conditions for a "take-off" in accelerated economic development.

Combining low fertility and low mortality results in a rather low population projection, characterized in addition by a considerably "greying" of the population age structure. The analogous IPCC-SRES-A1 scenario suggests a quantification in which fertility rates could range between 1.3 to 1.7 children per women, replicating current sub-replacement fertility patterns of the affluent globally. Mortality rates would also be very low, with life expectancy approaching 100 years on average. In this scenario global population would peak below 9 billion by ca. 2050, in order to decline thereafter to some 7 billion by the end of the 21st century.

The economic growth scenario takes analogy to historical examples of most successful economic catch up, such as Scandinavia and Japan after WW II, to describe possible future development patterns of current low-income countries. The scenario is one of conditional convergence in which “the poor get richer, and the rich slow down”.

The global economy in the "High Growth" scenario expands at an average annual rate of 3 percent GDP growth per year to 2100, i.e. at the same rate as the average of the successful OECD countries since mid-19th century. Non-Annex-I[3] economies expand with an average annual growth rate of four percent per year twice as fast as Annex-I economies. Over time, growth rates decline as per capita incomes increasingly approach current OECD levels. Based on the quantification of the equivalent IPCC-SRES-A1 scenario the global economy could roughly triple each by 2020, 2050, and 2100; approaching 50, 150, and 500 trillion $ over these three time periods.

Equity is not a major concern in the scenario, but rather a "by-product" of the high rates of economic development. Existing per capita income gaps between regions close up (in a similar way as between Western Europe and Japan compared to the US in the 20th century). Approximately by 2030 Non-Annex-I GDP would surpass that of Annex-I economies. Per capita income level disparities are also reduced, but differences between regions are not entirely eliminated. Non-Annex-I per capita income could reach the 1990 Annex-I level (14,000 $/capita) by ca. 2040/2050. By 2100 per capita incomes would approach 100,000 $/capita in Annex-I countries, and could reach up to 70,000 $/capita in Non-Annex-I countries, making current distinctions between “poor” and “rich” obsolete.

Social Trends, Governance, Environment

Social Trends

The economic growth and conditional convergence focus of the “High Growth” scenario go hand in hand with an increasing convergence of social values and lifestyles along the “Western” hedonistic model, furthering emphasis on small family size, material well-being, and leisure. Increasing consumerism of the developing world is thus a central feature of this kind of scenario. *Ceteris paribus*, material demands would be similar to those of the affluent OECD countries at similar levels of per capita income, even if regional and cultural differences will not entirely disappear. Asians, for instance would continue “to eat rice” and still appreciate more collective leisure experiences in travelling together in groups and for shorter time periods, whereas Americans would ultimately adopt healthy Mediterranean diets and Western European recreational travel models of long summer vacations to coastal areas combined with more individualistic extensive “adventure” travel to far away destinations (even if those no longer would be “exotic” in the traditional, 20th century sense). Nonetheless, traditional consumerism might not grow linearly with affluence indefinitely. As evidenced in food habits and expenditures, saturation

[3] As defined in the UN FCCC (United Nations Framework Convention on Climate Change). Annex-I countries correspond to the industrialized countries, subject to the provisions of the UN FCCC. Non-Annex-I countries correspond to the developing countries.

phenomena might set in, furthering rather qualitative than quantitative growth, e.g. in high quality services, arts, and special, high value leisure activities. Thus, affluent consumers, instead of taking more single long-distance, low-budget trips would increasingly opt for fewer, but extreme high luxury "cruises" in which trips per se are more important than the destinations visited, combining sequences of "world around" interesting destinations much along the lines of current luxury ocean cruises. Thus, even with fewer trips, travel distances (and thus air travel demand, expressed in passenger-km) might continue to grow. With rising incomes, travel budgets would rise accordingly, approaching globally some 15 percent of available income, as is the case today in the most affluent societies, split however over a variety of different transport modes, with local and regional transport continuing to take the lion's share. However, ultimately travel time budget constraints (on average one hour per day spent travelling) might become dominant even in air transportation resulting in a revival of super- and hypersonic aircraft designs, including orbital flights. Such developments would unfold fist for the most affluent and powerful, e.g. in form of super-sonic executive jets, but would gradually become widely available also for the "everyday" consumer (e.g. post 2050) in form of family jets or scaled-up, spacious super- and hypersonic aircraft designs for hundreds of passengers. Consumers in such a scenario would therefore vigorously refuse current aircraft designs, combining slow subsonic speed with dense passenger "packing". Beyond 2070, even space travel might emerge as a small, extremely high value market niche.

Governance
Overall, the economic focus of the scenario presumes both "laissez-faire" as well as effective governance at the regional and international level. (The traditional small nation state would largely be gone, replaced instead by regional economic associations and trans-national companies.) Non-interventionist governance is the key concept for not intervening with the functioning of free markets, innovation experimentation, and economic growth. Governance would instead focus on a few key areas of public goods and externalities, such as knowledge (education and R&D), market failures (technological standards in order to reduce high costs of parallel standards and assuring market transparency), as well as environmental externalities.

Varying degrees of government intervention (regulation) provides for the core bifurcation into two sub-scenarios.

In **"Unlimited Skies"** governments serve primarily as "moderators" to raise awareness to industry and act as facilitators in R&D and technology development consortia. The traditional regulatory paradigm is replaced by "soft" (talk to) policy concepts, providing for few stringent regulatory constraints.

Conversely, in **"Regulatory Push & Pull"** industry recognizes the advantages of predictable regulatory environments and relies on regional and international institutions to provide equal level playing fields and common environmental standards for all market participants. Increasing attention for instance is devoted to preserve local air and water quality, which triggers both, conservation innovations and novel, close-to-zero-emission technologies, particularly in the transport sector. A new hydrogen infrastructure develops first incrementally along with natural gas pipeline systems to provide energy for fuel cell vehicles in mega-cities. First dedicated pipelines emerge by 2040 by which time also some aircraft start use hydrogen fuel. Effective governance is especially called for in addressing climate change, especially after its effects assume dramatic proportions in the near-collapse of the North Atlantic thermohaline circulation and the Asian Monsoon between 2052 and 2058. An ambitious target of a zero-carbon global economy by 2100 is agreed by 2060, and great structural shifts begin to take place after 2075 and yield substantial emission reductions by 2100, even if it takes yet another 40 years to fully phase out carbon emissions. In such a scenario zero-carbon energy sources could account for up to 85 percent of global energy supply by 2100.

Environment

By assumption (and cultural Western development model bias) the ecological resilience in the scenario is assumed to be high. Ecological concerns are also low in their own right. Instead the valuation of environmental amenities is strictly valued in monetary terms, with the valuation closely linked to rising income levels. Non-congestion, clean water and air, avoidance of nuisance by traffic noise, recreational possibilities in nature, etc. all assume increasing importance with rising affluence, albeit preferences for environmental amenities may remain different across regions and income levels. For instance urban air quality and human health would be valued highly even at income levels lower than those prevailing in England where stringent air quality measures were introduced after the "killer smog" of 1952. Reduced particulate and sulphur air pollution are assumed to become a matter of major consumer preference at levels of 2,000 to 3,000 $/capita income in Asia. Altogether, the concept of environmental quality might change in this scenario from "conservation" of nature to active "management" (and marketing) of natural and environmental amenities and services. Because environmental quality can be marketed for products and services, there is little need for government regulation *per se*, as polluting producers and products are essentially driven out of the market. “Life cycle semiconductors” are attached to any product/service sold recording and communicating all externalities associated and providing complete market transparency. Product responsibility is also valued high, litigation and compensation for externalities imposed being the norm in this affluent world. For instance, already by 2020, compensation schemes (1000 $ per capita for each exposure to above 75 dB) are established by court ruling in the US to compensate for aircraft noise, a trend that spreads also to Europe and Asia, especially in high density urban corridors by 2050.

In a sub-scenario variant, above “free market” philosophy for the environment is contrasted by a strict regulatory approach. Instead allowing for market compensation of environmental damages, environmental externalities are aimed to be “regulated away” altogether, especially after it became apparent that the scale of climate change damages would exceed any reasonable financial compensation even in a 150 Trillion $ GDP world economy of 2050. This “Regulatory Push & Pull” scenario would gradually branch out from the “High Growth” world after 2020, including first local and regional environmental issues, and after 2060 also a strict global climate change regulatory regime.

Resources/Technology

Resource availability and technology are tightly interrelated in this High Growth, “high tech” scenario. High productivity growth results from substantial technological innovation and both contribute to economic growth, expansion of accessible resources, and improved efficiency in resource use. Resource availability is largely technology driven, rather than the other way around. For instance, new non-fossil technologies like hydrogen emerge out from supply push factors related to technological innovations in fuel cell vehicles rather than being “forced” by increasing resource scarcity. As a result the call on fossil resources which is comparatively high in this High Growth world is mitigated by continuous innovation and structural change. For instance, by 2020 zero-carbon energy sources could contribute some 15 percent of global energy, a share that would expand to roughly one third by 2050, perhaps approaching two thirds by 2100 (as illustrated in the comparable IPCC-SRES-A1B scenario).

In domains of significance for environmental regulation in the **“Regulatory Push & Pull”** sub-scenario, this progress would even be faster: reaching some 20% global market share by 2020, 40% by 2050, even 85% by 2100 (as illustrated in the IPCC-SRES-A1T scenario).

Overall, the dynamism of technological innovation is broad-based, including many radical solutions, from “engineered” human health, landless farming, bio-engineered renewable feedstock and structural materials. High rates of experimentation and a free market orientation provide evidently for numerous negative surprises, which are however addressed by compensatory and adaptive mechanisms rather than by traditional regulatory banning regimes. The latter option would however be considered for key strategic areas such as climate change, assumed to be significant in the “Regulatory Push & Pull” sub-scenario.

Communication/Transport/Air Transport

Communication and transportation technologies and styles are highly homogeneous and extremely developed in this “High Growth” world, extending current virtual and physical communication patterns of urban elites to a global phenomenon, driven by the twin driving forces of income growth, and continuous cost reductions, particularly in communication technology. Information and data transmissions finally really become “too cheap to meter” and as of 2020 communication costs for all modes drop to close to zero globally. On the one hand this new economic balance shifts emphasis from physical, “batch” travel to instantaneous mobility, especially after virtual realty avatars and sensuality robots available for transmitting a wide range of sensual experiences (vision, sound, smell, texture) become widely available after 2040. On the other hand, vastly increased communication flows also induce additional travel. The end result might simply be “dynamics as usual” from a long-run historical perspective, where communication and transport flows have roughly grown at 2 percentage points faster than GDP (translating to a 5 percent annual growth rate globally for the average 2.9%/yr GDP assumed for Unlimited Skies” and 2.7%/yr for “Regulatory Push & Pull”).

Rather than a "global village" future this is however rather one of "global cities" because existing trends towards even higher urbanization continue in this scenario as cities provide the highest "network externalities" for the educational and R&D intensive economic development pattern underlying the scenario. Regional differences in settlement patterns however persist ranging from fragmented "compact" (but large, i.e. 20+ million inhabitants) cities that draw on (and depopulate) their respective rural hinterlands in Latin America (e.g. Sao Paulo) to urban "corridors" connected by high capacity communication and transport networks in Asia, Europe and in the coastal areas of North Africa and North America. Regional transport networks include high speed and maglev trains, ultimately fusing short- and long-distance transport technologies (metro's) into single interconnected infrastructures making current distinctions between short- and long-distance travels increasingly blurred. Air transportation would focus on intercontinental travel and some feeder functions to smaller urban areas, but is unlikely to provide for the vast amounts of passenger flows travelling *within* the regional urban clusters as daily commuters.

The large urban agglomerates and the high transport demands of a high material growth economy generate potentially vast congestion constraints, solved by applying either market based instruments (prices) as in “Unlimited Skies” or by governmental regulation as in “Regulatory Push & Pull”. Market based instruments would include for instance systematic “just-in-time” access and parking fees, auctioning of (the limited number) of new car and truck registrations in mega-cities, etc. much along the (stringent) Singapore model. Therefore even at very high income levels, car ownership rates could be comparatively low, and in extremely densely populated areas rather a luxury than a means of mass-transport (cf. Hongkong). In lower density areas car densities are high (+1 car per inhabitant); their fuel systems oil versus electricity or hydrogen being varied regionally. Furthermore, intercontinental transport could well be provided by (energy and GHG intensive) hypersonic aircraft fuelled by methane or hydrogen. Hypersonic transport would be the physical transport equivalent of the high capacity virtual communication “backbones” of a truly global economy, paving the way for space travel that could emerge towards the end of the 21st century (post 2070).

Embedded Aviation Storyline "Unlimited Skies" (ULS)

Main challenges, bottlenecks, constraints

Very high challenges were assumed to keep airport capacities in line with the requirements of the huge demand, especially for Europe and the United States. The high challenges to fit demand are addressed and overcome by reacting in time, applying market forces.

Mobility Patterns and Transport Development

- High requirements for physical and virtual mobility
- High increase in average trip distance
- High increase in transport demand overall
- High enhancement of intermodal transport
- Telematics and new transport technologies are very important
- High increase of technology development in all transport modes

Air Transport Supply and Demand

- Very high increase in air transport demand due to the high economic growth and the convergence of social values and lifestyles along the western hedonistic model
- High increase in air trips per capita
- High increase in air transport supply, both hub & spoke flights and point to point flights
- High comfort standards
- Increase in all trip purposes (vacation, leisure and business), highest growth in leisure trips, higher growth in vacation trips than in business trips
- Demand peaks caused by mega events like Olympic Games, World Exhibitions and Championships
- High increase in air cargo demand and supply
- Decrease of military movements in relation to the total number of flights

Airport and Air Traffic Management Capacity

- Many new airports, most notably in Asia
- New Airports financed without public capital
- High constraints in the availability of airport capacity, in particular in conurbations like New York, London and Tokyo
- New technologies in Air Traffic Management, enhancement of productivity
- In spite of high increase of aircraft movements, no serious problems with delays
- Mega Airports with very high capacity

Safety & Security

- High safety and security standards, paid from fares
- Low specific accident rate
- Low security problems

Air Transport Market Development

- Deregulation
- Strong competition
- Building of alliances as a transitional stage toward global fusions
- No more differentiation between Network Carriers and Low Fare Carriers because of the low level of air transport fares in general. Low Fare Carries are part of global aviation groups. Differentiation of aviation companies oriented at the operating range long, middle and short.
- Number of global players decreases, however many regional airlines
- Specific profits decrease

Aviation Costs

- Higher personnel costs in general, but lower specific costs because of higher productivity
- Lower specific costs for maintenance because of higher productivity
- Higher costs for new aircraft, but lower costs per seat, because of low personnel costs from employees from developing countries
- Higher costs for airport usage because of high demand for airport capacity
- Lower specific costs for ATM services
- Costs for aircraft fuel increasing
- Decrease of fares in air transport because of high competition

Environmental Impacts of Air Transport

- Decrease of specific emissions (gaseous, noise) because of technological development
- High increase of emissions (gaseous and noise) overall because of high increase in numbers of flights, but noise problems for sleepers decreased
- No major problems with the increase in emission because impacts of emissions are shown to be less dangerous than originally thought and therefore the environmental consciousness is reduced. Noise molestations are compensated.

Aircraft Technology

- Aircraft size increase, new very large aircraft available
- High dynamism in the development of propulsion technology
- Lower specific fuel consumption and decrease in aircraft noise
- Major introduction of Cryoplane from 2060 (start in 2045)
- Very fast innovation cycles in new technologies
- After 2050: automatic controlled aircraft and therefore lower personnel costs

Detailed Technical Assumptions

- (1) New aircraft:
  Late but quicker LH2 fleet introduction based on input from Airbus.
  2020: ongoing evolutionary improvements in conventional a/c and propulsion. Intense R&D to resolve environmental impacts.
  2050: kerosene power still widespread with ongoing gradual performance improvement. As aviation begins to exceed 5% of total CO2 emissions, start to see introduction of an alternative low emission fuel (e.g. hydrogen see below), fuel cell, dense safe energy storage devices) in 2045. Very slow growth until major changeover to LH2 starting in 2060. Supersonic travel restarts in 2020 for business and luxury travel with a fleet growing to 1000 small aircraft by 2050. Utilisation and size of the aircraft mean actual impact is small. Hypersonic travel exists after 2050 but does not become a regular means of travel until the end of the century.
  2100: Speculatively, "close-to-zero emissions" air vehicles entering fleet from 2075, including hypersonic and space travel (e.g. EM launcher)

- (2) Liquid Hydrogen Aircraft (LH2) storylines:
  LH2 is an example of a lower emissions fuel for aviation. Initial introduction in 2045 for a few small aircraft types. Major introduction from 2060. Aircraft fly lower to avoid climate impact from H2O (and particulate) emissions. Fuel cost, ground emissions and altitude NOx emissions still an issue. In this scenario, LH2 may be overtaken by other technologies with lower emissions.
- (3) Aviation emissions types
  2020: Current emissions mix
  2050: Current emissions mix
  2100: all flight is low or "close-to-zero" emission through technology insertion

- (4) Proportion of fleet kerosene fuelled
  100% in 2020; perhaps10 year rollover starting 2060 to 95% LH2; 0% kerosene in 2100

- (5) Emissions technology improvement assumption
  balanced NOx and CO2 reductions
- (6) Reduction of NOx emissions for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *constant percentage point reductions per year* (not cumulative year-on-year).
  1992: LTO Dp/Foo = 62. Reductions compared to 2000 data: (- 2000: +0.12% p.a.)
  2020: -50 to -60% below 2000 level (-2.25% p.a.) = 55% of 2000
  2050: -60 to -70% below 2000 level (-1.2% p.a.) = 35% of 2000
  Until 2100: CAEP/2 -95% (approx -1.4% p.a.) = 10% of 2000
- (7) Fuel efficiency change for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *cumulative year-on-year*. Reductions compared to year 2000 data.
  1992: tsfc at SLS TO = 0.34 kg/hr/kg
  2020: -10 to -15% below 2000 level (-0.64% p.a.)
  2050: -1.23% p.a. after 2020; 2100: -1.07% p.a. after 2050
- (8) Hydrogen fuelled vehicles - Emission change (NOx) over time:
  Until 2050: N/A; Post 2050 Introduction:15% less NOx than equivalent technology kerosene aircraft; 2100: 25% less NOx than equivalent technology kerosene aircraft
- (9) Hydrogen fuelled vehicles - Fuel efficiency change over time: +15% compared to equivalent technology kerosene aircraft
- (10) Emission change - post LH2 "close-to-zero" emissions vehicle: NOx: small, CO2: small, Energy (heat): 500%
- (11) Fleet lifespan (mid-range scenario possibility: 90% of fleet survive to 25 years old in 2000 (approx), 90% survive to 35 in 2050): medium (<30 years).
- (12) Aircraft size growth (mid-range scenario possibility: 0.53% per year growth, 220 seats average in 2000, up to 287 by 2050): large
- (13) Utilisation rate (relative to 2000): 1,124
- (14) New Large Aircraft (BWB) EIS: 2025
- (15) Noise: Refers to best available technology: 10 dB reduction by 2020; further 8 dB by 2050

Embedded Aviation Storyline “Regulatory Push & Pull” (RPP)

Main challenges, bottlenecks, constraints

Nuisances of noise (especially during the first decades of the century) and emissions (near airports, climate change) are predominantly addressed by frame-setting policy measures, which require high costs and adaptation phases for aviation stakeholders.

Mobility Patterns and Transport Development

- High significance of physical mobility
- High importance of virtual mobility
- Increase in average trip distance
- Increase in transport demand in general, not so strong as in “Unlimited Skies”
- High enhancement of intermodal transport caused by regulation
- Higher regulation of leisure trips than of business trips
- New technologies in all transport modes pushed by regulations
- Telematic technologies used for road pricing

Air Transport Supply and Demand

- High increase in air transport demand depending on the high economic growth and the conditional convergence
- High increase in air transport supply, both hub & spoke flights and point to point flights
- Increase in air trips per capita
- Business trips with high importance and high growth rates, but vacation and leisure trips with higher growth rates
- Demand peaks caused by mega events like Olympic Games, World Exhibitions and World Championships
- High increase in air cargo demand and supply, but not so strong as in US
- Decrease of the share of military movements on the total number of flights
- Political restrictions, like environmental tax and noise contingents, damp the demand

Airport and Air Traffic Management Capacity

- Some new airports, most notable in Asia
- Airport capacity regulated by government
- New airports financed by government, but managed by private sector
- Constraints in the availability of airport capacity and thus delays on many airports
- New technologies in Air Traffic Management, enhancement of productivity, regulation of ATM services

Safety & Security

- High safety standards defined by government and paid from fares
- Low specific accident rate
- High security standards ensured by government
- Low security problems

Air Transport Market Development

- Liberalisation in transport markets in general, but many detailed regulations, like air transport conventions between countries, labour time regulation and salary regulation
- Many airlines, but medium competition because of competition regulations
- High profits protected by regulation of ticket prices
- High importance for airline alliances. No fusion possibilities because of high competition regulations
- Low Fare Carriers are complementary to Network Carriers, limited proportion of Low Fare Carriers because of high regulation
- Subsidies for unprofitable connections to keep rural regions alive

Aviation Costs

- Higher personnel costs in general, but lower specific costs because of higher productivity
- Higher specific costs for maintenance in comparison to “Unlimited Skies” because of higher regulation standards
- Lower specific costs for new aircraft than in “Unlimited Skies”
- Higher purchase costs for new aircraft caused by regulation of aircraft prices
- High costs for airport usage because of regulation
- High start-up costs for ATM-Systems, but also high benefits in the long-term
- Lower specific costs for ATM services
- High costs for aircraft fuel (including the infrastructure roll-over costs for introduction of hydrogen as fuel)
- Decrease of fares in air transport, but not so strong as in “Unlimited Skies”

Environmental Impacts of Air Transport

- Decrease in specific gaseous emissions because of regulation
- Increase in gaseous emissions overall because of increase in numbers of flights
- Increase in contrails and cirrus clouds because of the introduction of hydrogen powered aircraft
- Decrease in specific noise emissions because of regulation
- Increase in noise emissions overall because of high increase in numbers of flights
- As response of the emission increase regulations are tightened.

Aircraft Technology

- Aircraft size increase, new very large aircraft available
- High dynamism in the development of propulsion technology
- Lower specific fuel consumption and decrease of aircraft noise, pushed by governmental regulations
- Introduction of Cryoplane starts 2035 [check final decision]
- Innovation cycles for aviation technology driven by regulation

Detailed Technical Assumptions

- (1) New aircraft:
  Late but quicker LH2 fleet introduction based on input from Airbus
  RP&P (LH2) - same as in "Unlimited Skies" except quicker introduction of lower emissions technology into fleets from 2040, 95% complete by 2050. Supersonic travel restarts later than "Unlimited Skies" due to environmental regulation (2030) for business/luxury travel with a fleet growing to 500 small aircraft by 2050. Utilisation and size of the aircraft mean actual impact is small. Hypersonic and space travel further limited by pollution impact until beyond 2075.
  RP&P(No LH2) - same as above except no lower emissions technology (e.g. LH2) is introduced until after 2050 (due to lack of demonstrated environmental impact improvement)
- (2) Liquid Hydrogen Aircraft (LH2) storylines:
  RP&P(LH2) - as for "Unlimited Skies " except introduction starts in 2035 with rapid rollover starting in 2040; RP&P(No LH2) - As for "Unlimited Skies"
- (3) Aviation emissions types
  2020: Current emissions mix
  2050: RP&P(LH2) - some kerosene power with current mix. Most replaced with "lower emissions technology". Exact emissions depend on which technology. If hydrogen, then altitude CO2 eliminated , replaced with increased hydrogen generation CO2 emissions. Problems of fugitive hydrogen emissions resolved by innovation.
  RP&P(No LH2) - Current emissions mix
  2100: all flight is low or "close-to-zero" emission through technology insertion
- (4) Proportion of fleet kerosene fuelled
  100% in 2020
  RP&P(LH2) - 10 year rollover starting 2040 to 95% LH2,
  RP&P(No LH2) - as for "Unlimited Skies"
  0% in 2100
- (5) Emissions technology improvement assumption
  balanced NOx and CO2 reductions
- (6) Emission change (NOx) for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *constant percentage point reductions per year* (not cumulative year-on-year).
  1992: LTO Dp/Foo = 62. Reductions compared to 2000 data (- 2000: +0.12% p.a.):
  2020: -50 to -60% below 2000 level (-2.75% p.a.) = 45% of 2000
  2050: -60 to -70% below 2000 level (-0.74% p.a.) = 35% of 2000
  until 2100: CAEP/2 -95% (approx 1.6% p.a.) = 7% of 2000

- (7) Fuel efficiency change for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *cumulative year-on-year*. Reductions compared to year 2000 data. 1992: tsfc at SLS TO = 0.34 kg/hr/kg; 2020: -10 to -20% below 2000 level (-0.75% p.a.); 2050: -1.5% p.a. after 2020; 2100: -1.07% p.a. after 2050
- (8) Hydrogen fuelled vehicles - Emission change (NOx) over time
  RP&P(LH2) only - Introduction:15% less NOx than equivalent technology kerosene aircraft;
  2050: 20% less NOx than equivalent technology kerosene aircraft
  2100: 25% less NOx than equivalent technology kerosene aircraft
- (9) Hydrogen fuelled vehicles - Fuel efficiency change over time
  +15% compared to equivalent technology kerosene aircraft
- (10) Emission change - post LH2 "close-to-zero" emissions vehicle
  NOx: small, CO2: small, Energy (heat): 500%
- (11) Fleet lifespan (mid-range scenario possibility: 90% of fleet survive to 25 years old in 2000 (approx), 90% survive to 35 in 2050): short (<25 years)
  Late but quicker LH2 fleet introduction based on input from Airbus except for 10 year LH2 rollover period
- (12) Aircraft size growth (mid-range scenario possibility: 0.53% per year growth, 220 seats average in 2000, up to 287 by 2050): large
- (13) Utilisation rate (relative to 2000): 1,124
- (14) New Large Aircraft (BWB) EIS: 2020
- (15) Noise: Refers to best available technology:
  10 dB reduction by 2020; further 8 dB by 2050

C) "Fractured World" (FW)

Overview on the Background Scenario

The scenario describes a heterogeneous world that becomes increasingly fragmented, consolidating into a number of "inwards-looking" regions that share similar political, cultural, and economic characteristics and priorities. Self-reliance in terms of resources and cultural/religious identities takes precedence over economic, social, and cultural interactions and integration between regions. A definitive "anti-globalization" stance, spanning a wide spectrum from isolationist tendencies to recurrent conflicts, hampers international trade, communication, and capital flows, resulting in slower diffusion of ideas, knowledge and technologies internationally, but results in more diverse experimentation and implementation of varied solutions at regional levels. Economic growth is uneven in this scenario and the income gap between now-industrialized and developing parts of the world narrows more slowly and gradually as regions pursue diverse development paths reflecting their diverse economic, political, and cultural priorities.

The principal scenario driver is *geopolitics* and the *preservation of regional cultural identity* and *political and economic autarky.* In a reversal of the globalization trends of the previous century, the world "consolidates" into a series of roughly continental regions that globally coexist with comparatively little interchange, sometimes even with conflicts, particularly for access to resources (water, food, energy) critical for feeding growing populations, particularly in the "South".

Two developments are possible: one is an almost "autistic" coexistence of these different regional blocks that minimize exchanges, but otherwise aim to co-exist more or less peacefully (as for instance described in the IPCC-SRES A2 scenario). In another *mean* scenario (explored for this CONSAVE exercise) regional fragmentation is consolidated by continued conflict between regions. In this multi-polar world the "cold war" coexistence model between the USA and the USSR becomes a global characteristic feature with regularly recurring conflicts between regions. These could take the form of confined, regional wars in which the use of widespread available bio-chemical and nuclear weapons is only mitigated by the fear to draw into the conflict other regions fearing negative impacts on their own territories akin to the nuclear mutual deterrence model of the cold war. Thus, conventional warfare continues throughout the 21st century, complemented by elements of "state-induced terrorism", in which governments would induce extremist groups to attack private and business entities of adversarial regions. For instance, instead of terrorist hijacking of aircraft, "downing" of civilian aircraft by missiles or hijacked military jets becomes widespread by 2010-2020, further reducing the willingness of passengers to travel intercontinental and for airlines to serve inter-regional destinations.

Regions pursue different economic strategies based on the resources and technological options available to them. Trade within economic regions increases, while trade between regions is strictly controlled by tariff and non-tariff barriers and high prices dictated by numerous regional resource monopolies along the OPEC model of the 1970s. High income regions restrict immigration and impose selective controls on technology transfer to maintain their income differential. But as markets for exports to the OECD countries decline, and perceiving the free market system and "modernization" to have failed, communities everywhere retreat into traditional cultural models and strive for political and economic independence from globalization forces. While many heed this as a positive period of cultural reaffirmation and of harnessing of indigenous resources and technological solutions applied to local conditions, the return to traditional values also leads to an increased emphasis on the local community and family, tending to maintain high fertility levels and thus population growth.

The CONSAVE "Fractured World" is fragmented into 4 major blocks: *NAFT* (North America, Central America), *Eurasia* (EU, Former Eastern Block), 東国 *Tō Goku* (Far East North), *Sub-Himalayas* (Far East South) and the "peripheral" regions Latin America (South America northern and southern parts), Africa (Non-aligned Europe, Eastern Africa, Western Africa, Southern Africa), Middle East, Oceania (Southwest pacific).

Interestingly enough, the regional blocks characterizing this "Fractured World" scenario emerge along *natural* barriers as political/cultural/economic "divides". These include the "North Atlantic" (between North and Central America, and Eurasia [i.e. Europe and Russia]), the "Pacific" (between America and Asia), the "Mediterranean" (between Eurasia and the Islamic world), and the "Himalayan divide" between the Indian subcontinent (Far East South) and China, Japan and the rest of Asia (Far East North). Countries/regions left outside these regional blocks (Latin America, Sub-Saharan Africa, and Oceania) either regress to a status of economic hinterland of their respective neighbouring regional block, or pursue opportunistic survival strategies of changing coalitions in this multi-polar world.

A series of conflicts originating in the Middle East results in a period of extreme high volatility of oil prices in the decade 2005-2015 and again during 2020-2030. Attempts of large oil importing countries to assume control over critical oil suppliers outside the instable Middle East (Latin America, the Caspian, and Africa) is met with fierce opposition triggering conflicts and a spiral of reciprocal trade restrictions and product boycotts, first between the "South" and the "North", but increasingly also within the OECD countries (in particular between North America on one side, and Europe and Russia, as well as China and Japan, on the other) amplifying further oil price volatilities. By 2020, the WTO regime of trade liberalization collapses and after 2040 the efforts of the Organization of Petroleum Non-exporter Countries (OPNEC) gain momentum, resulting in an almost ceasing of interregional oil trade by 2050. International trade retreats into a strict *quid pro quo* mode, largely based on barter trade of surplus production, with little regard to international division of labour or relative comparative advantage. Products and technologies (such as aircraft) are no longer purchased on economic criteria but rather based on political and autarky considerations, raising prices considerably.

This "Fractured World" is first felt for international tourism and business travel as well as intercontinental (voice and data) communication ("ad hoc" exchanges) and later-on also in the longer-term mobility of people (migration) and goods (trade). Transcontinental passenger and communication traffic peaks around 2010, declines to present values by 2020, and by 2050 is at a mere 10 percent of current levels. Trade flows follow a similar pattern, albeit lagged by some 2 decades, as despite emphasis on regional autarky it takes considerable time to develop regionally self-sufficient agricultural and energy systems.

Key Scenario Drivers of the Background Scenario

Population, economic development, and regional disparities

With the regional emphasis on "indigenous" development priorities and a return to traditional values in this scenario, there is increased emphasis on family and community life and less on exchange, implying lower mobility. In some, but not all regions, increased emphasis of family values translates into large families. Fertility rates vary thus widely among regions, and there is little global convergence in demographic patterns. Presently developed countries would see rising fertility levels, as continued in-migration is considered culturally and politically unacceptable. Fertility rates would reach replacement levels (2.1) again in Europe or in Japan, or being even slightly above it (North America). Fertility rates in developing countries would slightly decrease but remain high and heterogeneous typically ranging at 3-4 children per mother. Mortality patterns would also be heterogeneous, ranging from low mortality (increasing life expectancy to some 90 years in the Industrialized Countries) to high mortality (actual declining life expectancy in Africa). Based on the equivalent IPCC-SRES-A2 scenario, global population could reach some 11 billion by 2050 and further increase to some 15 billions by 2100, making this scenario an upper bound case based on current understanding of possible future demographic trends.

The slower development in technology, and the retreat from globalization with its resulting diffusion and trade barriers, implies that international disparities in productivity levels persist and productivity growth remains uneven, in some regions even painfully slow. Economic development takes place largely along conventional industrialization lines. There is no "fifth Kondratieff", i.e. emerging new dominant growth sectors in ICT and biotechnology. Development in medium-income regions can be seen as a process of gradual catch-up with the wealthier regions. Technology transfer is limited so that the catch-up process is slow, in many cases requiring reinvention of technologies. Technological innovation does not cease in this "Fractured World" as performed in all regions, but market fragmentation limits export possibilities and technology diffusion consequently remains fragmented at the regional level and costs remain high. In the poorest regions, high population growth and a minimal capacity for technology development means that per capita income growth is slow. The richest regions see some continuing economic growth, but with only incremental changes in technology, productivity and economic structure, per capita income increases only by about 1% per year. While science is conducted in all regions and information about scientific developments is available world-wide language as well as political barriers restrict communication and diffusion of innovations at a global scale. Meanwhile, consumption and production patterns and hence, technology and practices, are determined by local circumstances.

As a result, GDP per capita grows only slowly, but because of high population growth, aggregate GDP growth remains comparatively robust. For instance in the comparable IPCC-SRES-A2 scenario world GDP could increase by a factor of 2 until the year 2020, and by a factor of 4 by 2050, ultimately reaching a 10-fold increase by 2100. However, international disparities in productivity, and hence income *per capita*, are largely maintained or increased in absolute terms in such a scenario.

One significant implication of above described "fractured" demographic and economic development pattern is that there is little convergence in consumption patterns worldwide. In addition, because much of GDP growth is actually driven by demographics rather than by productivity advances (growth in population, but much less growth in per capita income), traditional models of income elasticities of consumption no longer apply, particularly for non-basic consumption items such as communication and motorized mobility. Thus, whereas basic human needs and services (food, housing, residential energy) roughly continue to growth in line with population growth as in the past, "luxury" goods and services see much lower growth than over the past decades, being increasingly decoupled from aggregate GDP growth, in some regions even below per capita income growth rates, if perceived as being either inconsistent with prevailing cultural values or simply as too risky. Examples for this include meat consumption in South Asia, "Western" media and trans-continental telecommunication in the Islamic world, or intercontinental leisure travel in the case of Eurasia.

Social Trends, Governance, Environment

Social trends are highly heterogeneous in "Fractured World". Overall there is a general renaissance of traditional social, cultural, and political values ranging all the way from pluralistic, secular societies, to more homogeneous societies emphasizing their respective common cultural and religious heritage. An increasing tendency toward cultural pluralism with mutual acceptance of diversity and fundamental differences limits the desire to explore different socio-cultural environments as part of every day life (i.e. tourism), even high-level "dialogue" between civilizations.

Social and political structures diversify; some regions move toward stronger welfare systems and reduced income inequality, while others move toward "leaner" government and more heterogeneous income distributions. A unifying theme of governance in this scenario is the emphasis on self-sufficiency, import substitution and avoidance of exposure to perceived cultural hegemony. In some regions, governments regulate imports of goods and information strictly in quantitative terms. For instance, oil imports would be rationed and conserved for strategic sectors such as pharmaceuticals, fertilizers, and fuels for agriculture. In others, regulatory frameworks would rely more on traditional market mechanisms, such as taxes, which would be particularly high for all domains considered as excessive "luxury" consumption, such as intercontinental voice and data communication, aircraft fuel for tourism, or imported exotic food items.

A key feature of this scenario is a retreat from globalization, with consolidation of governance and markets at the regional level. Global institutions such as those in the United Nations system become increasingly ineffective, so that environmental, economic and social issues are subject to relatively weak governance at the global level. Regional institutions and governments are strengthened. The growing role of the economic regions, and their competing economic interests, lead to reduced inter-regional co-operation, increasing protectionism, and tight constraints on migration.

With substantial food requirements for rapidly growing populations, agricultural production and food distribution is one of the main focus areas for innovation and research, development, and deployment (RD&D) efforts, and environmental concerns. Initial high levels of soil erosion and water pollution are eventually eased through the local development of more sustainable high-yield agriculture. Although attention is given to potential local and regional environmental damage, it is not uniform across regions. If required, human health and environmental concerns are also ranked second after self-sufficiency considerations, for instance considering air pollution from synfuel production from coal or unconventional oil. Global environmental concerns such as climate change are weak – and independent from the actual scale of realized climate change damages --, not at least because the prevailing geopolitical setting provides for few possibilities to arrive at any global solution of mitigating or adapting to global climate change.

Resources/Technology

Resource availability is a key concern in this scenario. With the gradual collapse of international trade in energy and food, which are considered key regional resources to be conserved for "domestic" consumption, efforts focus on developing sustainable "domestic" supplies at a regional level. Resource availability in this scenario is initially less constrained by geology but rather by geopolitical and security considerations. Over the longer-term (2050 and beyond) however, actual physical scarcities could emerge, as the historical model of international oil companies financing and performing elaborate hydrocarbon exploration efforts for subsequent production and exports no longer proves feasible already by ca. 2020. As a result, resource "replenishments" fall increasingly short of demand, increasing the risks of physical imbalances between supply and demand in the post-2050 period, adding to political and autarky driven supply/demand imbalances of the earlier periods.

Agricultural production is highly regulated and subsidized. In regions with abundance of agricultural land (e.g. North America, Australia) agricultural production remains largely along traditional lines, and excess agricultural land, previously devoted to food exports, is reallocated to biofuel production to substitute for energy imports. Perishable food continues to be transported by cargo aircrafts. In land scarce regions (particularly in Asia), the focus is on high-yield agriculture with genetically modified crops and intensive coastal aquaculture, focusing on regional food supply chains.

Regions also pursue different resource exploitation strategies with respect to energy, focusing on regional resource endowments. Synthetic fuels from coal are dominant in Asia, fuels from unconventional oil (shales and tarsand) are harnessed on a large scale in North America. Latin America and Africa focus on biomass fuels. Conversely, the Middle East continues to rely on conventional oil and gas throughout the 21st century. Regions poorly endowed with fossil fuels rely on vigorous conservation efforts and new, unconventional supplies. Eurasia for instance pursues aggressively a "bio-nuclear" resource strategy in which the twin energy currencies electricity and hydrogen are produced from nuclear and renewable resources in Europe, with gas from Russia (having joined the European Union by 2020) as important transitional fuel. In Japan, emphasis is more on nuclear generated electricity with an increasingly important supply from off-shore wind and photovoltaics after 2050. Electricity also is the dominant transportation fuel powering trains and urban electric cars in Japan. Overall by 2050, all regions are energy self-sufficient, albeit drawing on diverse regionally available resources.

Overall, technological change in the "Fractured World" scenario is highly heterogeneous both across technologies and across regions. It is more rapid than average in some regions and slower in others, as industry adjusts to local resource endowments, culture, and education levels. Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor in resources place a very high priority on minimizing import dependence through technological innovation to improve resource efficiency and make use of substitute inputs. In agriculture and energy many high-tech solutions are devised to respond to the quest for regional self-sufficiency. But in other technologies, the picture is less progressive due to fragmentation of R&D and more limited market sizes for new technologies. There is also a substantial increase in the public and private sector bureaucracy needed to maintain basic social and economic functions. In this scenario, the weight of the complexity and the bureaucracy leads to innovation stagnation.

Communication/Transport/Air Transport

Some of the main promises for technological advance in the 21st century, information and communication technology, biotechnology and other advanced technologies, fail to emerge a new global carrier branches and to increase economic productivity. The Internet and related technologies such as virtual reality systems are used mainly as commercial entertainment media, generating new industries and replacing traditional channels of entertainment, but having little spin-offs elsewhere in the economy. Networks function mainly on a regional basis and there are persistent incompatibility and interchange problems across different regional infrastructure systems, particularly in communication, but also for intercontinental air transport.

Whereas intra-regional communication and transport exchanges roughly grow along historical rates – moderated however by the substantially slower per capita income growth – inter-regional communication and transport flows stagnate, even are reduced in absolute amounts. There is no market demand for air travel beyond the sound barrier. Because of the critical importance of energy availability, regional transport systems diverge greatly among regions. In regions like the Middle East with large availability of conventional oil, mass motorization continues, and conventional aircraft designs dominate. The region could even become the major hub for the (comparatively modest) inter-continental air travel as regional air carriers have a decisive comparative fuel cost advantages over traditional, OECD based global airlines.

In other regions, transportation demand growth is hampered by the twin effects of high energy price increases, compounded by additional high price volatility. Regional response strategies are varied. For instance, North America would largely rely on unconventional oil supplies from tar sands and oil shales as source for automobile and aircraft fuel, largely preserving the technological dominance of the internal combustion engine and classical aero-engines. In order to maximize fuel efficiency and minimize costs, aircraft sizes would be stretched to giant super jumbos with a few thousand passengers crowded together but travelling only within North America (much along the current model of using B-747s along the Shinkansen corridor in Japan). Air transportation, finally becomes a low value commodity, tightly regulated by governments and organizationally the industry resembles increasingly the railways at the end of the 20th century with striking similarities to the "British Rail disease". For the few remaining inter-continental connections, market demand is too low to justify the use of "super-jumbos." Small- to medium sized aircraft dominate, but equipped with elaborate systems of self-defence against potential terrorist attacks.

In the densely populated urban corridors of Asia, public transport systems with maglev's and inner-city metro lines predominate. Goods transport also increasingly returns to railways; only local distribution would be assured by classical trucks either running on synfuel derived from coal, and in some regions also by bio-diesel. Private transportation is limited to the extremely rich, as highly taxed, and essentially confined to local, high status electric vehicles ("E-Lexus"). As a result, air transportation demand is very small.

Eurasia would take a somewhat intermediate position with respect to public/private transport modes, relying on both electricity (for high speed trains and maglev's) as well as hydrogen for fuel cell cars and aircraft. But as the market for these high-technology transport vehicles is essentially confined to Western Europe (with Russia continuing to rely on conventional transport technologies), they remain expensive and diffusion is significantly below the levels of the cheap oil automobile dependence period. Air transportation demand is also much more limited, essentially for travelling to Siberia and the Southern European rim, as for shorter distances rapid rail systems are favoured by both policy and consumer demand.

Embedded Aviation Storyline

Main challenges, bottlenecks, constraints

Due to political, religious and social divergences, the world is divided into blocks with high tensions, occasional confrontations, terrorism, causing high security and standardisation problems/costs.

Mobility Patterns and Transport Development

- The importance of physical mobility differs between world regions
- High importance of virtual mobility in a few world regions, like NA, Europe, Asia
- Long-distance travel only to friendly regions
- Development in transport demand inhomogeneous among world regions
- Enhancement of intermodal transport in a few world regions, like NA, Europe, Asia
- High importance of new transport technologies in NA, Europe and Asia
- More efficient transport because of telematic technologies in NA, Europe and Asia

Air Transport Supply and Demand

- Different development of the air transport supply and demand in different world regions
- High growth in domestic air transport demand in North America, Europe and Asia
- Low growth in interregional air transport demand with large fluctuations due to occasional improvements in the relationships between blocks or on account of economic and military conflicts
- Different comfort standards in aviation between the world regions
- Different development in trip purposes: very high growth of vacation and leisure trips and high growth of business trips in western regions, only growth of business trips in poor regions
- Different development of air freight growth, low growth in long distance air cargo demand
- Comparably high level of military movements
- Political restrictions, like environmental tax and noise contingents, damp the demand in a few world regions like North America and Europe

Airport and Air Traffic Management Capacity

- Airport capacity availability is inhomogeneous
- Significant infrastructure constraints in Europe and North America
- Private financing of airports in western regions (NA, Europe, Far East), public finance of airports in other regions
- Low efficiency of the ATM-System overall because of many different technical solutions
- Efficiency problems in interregional flights because of different standards in ATC

Safety & Security

- Different standards in safety between the world regions
- High safety standards in North America, Europe and Southwest Pacific
- Safety problems in a few world regions like Africa and South America
- High effort to ensure security all over the world, with high costs
- Different guarantees for security between the world regions
- During conflicts, occasionally high security problems, especially affecting the interregional air traffic between hostile regions.
- Phases with terrorism

Air Transport Market Development

- Liberalisation in a few world regions, but still dominance by national carriers
- Different competition in the different world regions
- High profit for airlines in world regions with high air transport demand
- Airline alliances only inside individual regions, high importance for alliances in regions of high air transport growth, less global alliances and more regional airlines
- High relevance of Low Fare Carriers in regions with high air transport growth

Aviation Costs

- Heterogeneous personnel costs in different world regions
- Higher specific costs for maintenance because of different regulation standards
- High specific costs for new aircraft because of small volume of aircraft ordering
- Varying costs for airport usage
- High specific costs for ATM services because of low efficiency
- Varying costs for aircraft fuel, high costs in North America and Europe
- Increase in fares for air transport
- Additional costs for technical solutions related to security

Environmental Impacts of Air Transport

- Heterogeneous development of specific gaseous/noise emissions in the world regions
- Heterogeneous development of gaseous/noise emissions overall in the world regions
- Heterogeneous environmental regulations for aviation in the world regions

Aircraft Technology

- Different standards in different word regions
- High technology development in North America, Europe and Asia with new fuels (syn-fuel, hydrogen), new propulsion technologies
- Lower specific fuel consumption and decrease of aircraft noise in North America, Eurasia and Far East
- High specific fuel consumption in Middle East because of high oil availability
- Introduction of Cryoplane only in Eurasia
- Different diffusion of new aviation technologies: high introduction of innovation in the western regions

Detailed Technical Assumptions

- (1) New aircraft:
  Late but quicker LH2 fleet introduction. Different standards with regional available fuels, raising prices, "risky" technologies not accepted; From 2020, NAmerica starts to use a range of fuel efficient aircraft, including large aircraft (super-jumbos in 2050) with kerosene-like fuels synthesised from shales and tars. By contrast, Eurasia uses advanced, fuel efficient aircraft. From 2015 these start to use hydrocarbon fuel made by alkylation from methane. From 2050, LH2, light recuperated gts or fuel cell aircraft start to replace hydrocarbon-fuelled aircraft as feedstocks run down. Mid-East: conventional aircraft (future major hub?). Very limited development toward fuel efficiency or cleaner transport. Sub-Himalayas: Conventional aircraft used with kerosene-like fuels from coal. Slow fleet roll-over and development. Far East North: Synthesised kerosene fuels increasingly fuel-efficient aircraft. Unaligned Regions: primarily use aircraft obtained from other regions, fuelled by kerosene-like fuel from biomass.
- (2) Liquid Hydrogen Aircraft (LH2) storylines:
  Limited application (Eurasia only). It is worth noting that with the lack of emphasis on climate forcing, LH2 aircraft may never be developed as they are overtaken in fuel efficiency terms by other emerging technologies (e.g. light recuperated thermodynamic

cycles, light fuel cells)

- (3) Aviation emissions types
  Drive for reduced fuel consumption (high OPR) and synthesis of fuels from coal and shales causes substantially increased NOx except in Europe, where LAQ concerns mitigate this. Parasitic emissions e.g. SOx heavy and alkaline metals, aromatics (LAQ) also increase, affecting climate change.
- (4) Proportion of fleet kerosene fuelled:
  100% in 2020, 90% in 2050, 75% in 2100
- (5) Emissions technology improvement assumption:
  aggressive CO2 reduction (regional) for economic reasons
- (6) Emission change (NOx) for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *constant percentage point reductions per year* (not cumulative year-on-year).
  1992: LTO Dp/Foo = 62. Reductions compared to year 2000 data (- 2000:+0.12% p.a.): 2020: -50 to -60% below 2000 level (-2.75% p.a.) = 45% of 2000.
  2050: regional: N.America - gradual increase to 2x 2000 levels (+11.5% p.a. average); Eurasia, Far East - maintain 2020 tech levels; Middle East - 2010 to 2020 aircraft mean levels; Sub-Himalayas, Unaligned Regions - post-2000 aircraft mean levels - until 2100: no further change
- (7) Fuel efficiency change for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *cumulative year-on-year*. Reductions compared to year 2000 data. 1992: tsfc at SLS TO = 0.34 kg/hr/kg. 2020: -10 to -20% below 2000 level (-0.75% p.a.). 2050: regional: N.America: -1.87% p.a. after 2020; Eurasia, Far East North: -0.76% p.a.; Other regions, use same assumptions as described above for NOx; 2100: N.America: -1.02% p.a. after 2020; Eurasia, Far East North: -0.886% p.a.; Other regions -1% p.a.
- (8) Hydrogen fuelled vehicles - Emission change (NOx) over time
  2020: N/A; 2050: 20% less NOx than equivalent technology kerosene aircraft (Eurasia only); 2100: 25% less NOx than equivalent technology kerosene aircraft (Eurasia only)
- (9) Hydrogen fuelled vehicles - Fuel efficiency change over time
  +10% compared to equivalent technology kerosene aircraft
- (10) Emission change - post LH2 "close-to-zero" emissions vehicle
  NOx: n/a; CO2: n/a; Energy (heat): n/a
- (11) Fleet lifespan
  (mid-range scenario possibility: 90% of fleet survive to 25 years old in 2000 (approx), 90% survive to 35 in 2050); 2050: regional: N.America, Eurasia, Far East North - short (<20 years); All other regions - long (30+ years) Late but quicker LH2 fleet introduction based on input from Airbus depending upon region
- (12) Aircraft size growth
  (mid-range scenario possibility: 0.53% per year growth, 220 seats average in 2000, up to 287 by 2050); 2050: regional: North America, Eurasia - large growth; Middle East, Sub-Himalayas, Far East North, Unaligned Regions - no change
- (13) Utilisation rate (relative to 2000): 1,124
- (14) New Large Aircraft (BWB) EIS: 2040
- (15) Noise: Refers to best available technology
  10 dB reduction by 2020; N America and Mid-East further 5dB by 2050, Sub-Himalayas and Unaligned Regions further 3dB by 2050, Eurasia and Far East North, further 8dB by 2050.

Region	Resource Availability	Aircraft fuels	Aircraft size
North + Central America	low quality fossil fuels	manufactured kerosene from low quality fossil fuels, e.g. tarsands etc	large
Eurasia	renewables and Russian gas	kerosene alternatives such as LH2, Russian gas	large
Middle East	abundant oil reserves	Kerosene	medium (no change)
Sub-Himalayas	Coal	manufactured kerosene from coal	medium (no change)
Far East North	Nuclear	manufactured kerosene and kerosene alternatives such as LH2	large
Other (Southern Africa, Oceania, Latin America)	coal and biomass	manufactured kerosene from coal and biomass	medium (no change)

Region	Fleet roll-over	Other characteristics	Technology / manufacturing capability
North + Central America	High	high efficiency new aircraft types, designed for continental travel (<3k miles)	very high technology for conventional aircraft designs
Eurasia	High	high efficiency new aircraft types running on alternative fuels, designed for continental travel (<2k miles)	very high technology, new aircraft designs and concepts (LH2, gas)
Middle East	very low	current aircraft stock (post 2010 aircraft) used for intercontinental travel	none, use existing stock
Sub-Himalayas	very low	continued use of old aircraft stock (post 2000 aircraft), continental travel	none, use existing stock
Far East North	High	replacement with new high efficiency/ high technology, continental travel	very high technology, new aircraft designs and concepts (LH2, nuclear?)
Other (Southern Africa, Oceania, Latin America)	very low	continued use of old aircraft stock (post 2000 aircraft), continental and intercontinental travel	none, use existing stock

Table 5: Overview of specific assumptions for regional fuel availability and technology in the Fractured World scenario after 2020

D) "Down to Earth" (DtE)

Overview on the Background Scenario

The central elements of this scenario storyline are a high level of environmental and social consciousness combined with globally coherent approach to sustainability based on a combination of lifestyle changes favouring quality over quantity and the development of "appropriate" environmentally friendly technologies. Heightened environmental consciousness might be brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, over-fishing, acidification, and climate change pose a serious threat to the continuation of human life on Earth. Likewise, continued economic disparities across and within regions are increasingly recognized as a threat to the sustainability of political and social structures as contributing to conflicts, unrest, and vulnerability of societies and economies. Governments, businesses, the media, and the public pay increased attention to the environmental and social aspects of development. These changes in the ideation of the dominant development paradigm of the 20th century translate into changing perceptions, values, and preferences of private citizens and the public sector alike. The "slow food" movement, emerging at the end of the 20th century, serves as a guide for the global diffusion of "slow" lifestyles, in terms of diets, consumption and transport patterns, as well as attitudes towards the acceptability of new technologies.

The principal scenario driver is changing *perceptions, attitudes and lifestyles*, complemented by new models of international *policy coordination and cooperation*. Contrary to the prevailing trends towards consumerism and hedonistic lifestyles, "slow" and "smart" become the dominant metaphors for desirable lifestyles and technologies and are continuously critically evaluated and modified in view of a gradually evolving ideology of sustainability. While local and regional interpretations of sustainability vary, reflecting varied conditions, a widespread consensus on the imperative of sustainable development emerges across all societies and cultures. Sustainability fora and solidarity movements favouring the de-privileged proliferate, enabled by rapidly expanding global communication networks and recast traditional "top-down" policy frameworks by "bottom-up" citizen movements. Talk is followed by action, initially based on grass-roots movements like NHI (No Hunger International) or HfA (Health for All), the objectives of which are increasingly adapted by national and international policy bodies translating into new models of international cooperation aiming at building the three pillars of sustainable development: eradication of poverty, social and economic equity, and environmental protection.

Innovation and productivity gains are increasingly invested no longer in increasing consumption of the affluent but rather in improved efficiency of resource use ("dematerialization"), economic equity, building of social institutions, and environmental protection. Approaches are pragmatic and results oriented aiming at reconciling man and nature, i.e. means and ends are "Down to Earth". A strong welfare net prevents social exclusion on the basis of poverty within regions. An increasingly widespread social stigmatization of conspicuous consumption patterns results in rapidly changing lifestyles and increasing public support for stepped-up resource transfers from "rich" to "poor" also at the international level. Preservation and remediation become core themes of environmental governance, increasingly involving voluntary agreements, self-restraint, and "smart" technological solutions in addition to traditional command and control public policies. In a world of "global villages" values and lifestyles converge, whereas instruments (social and technological solutions) are increasingly varied to best reflect local circumstances. Despite globalization of values and lifestyles, the focus of everyday life increasingly revolves around local communities. Whereas ideas are exchanged globally through increasingly sophisticated and cheap communication means, social contacts remain firmly rooted in local communities. "Down to Earth" citizens communicate and think globally, but live and act locally. For many, long-distance travel to remote destinations looses its traditional appeal, at best being an once-in-a-lifetime experience. However, counter-currents may develop and in some places people may not conform to the main social and environmental intentions of the mainstream as described in this scenario. Massive income redistribution nationally and internationally and presumably high taxation levels may also adversely affect the economic efficiency and functioning of world markets. The paramount importance given to "appropriate" technologies may hinder the diffusion of advanced technology concepts such as fuel cell cars that might be objected in favour of environmentally benign bicycles in some places. The quest for "sustainability correctness" may provoke counter-reactions, e.g. in form of "spring breaks" of students travelling 5,000 miles to distant holiday destinations. But despite these counter-currents, the sustainability paradigm gets established firmly and "think slow and "smart" increasingly replaces "think big" as desirable goals for the material culture of societies.

Particular efforts are devoted to increases in resource efficiency to achieve the sustainability goals stated above. Incentive systems, combined with advances in international institutions, permit the rapid diffusion of cleaner technology. To this end, R&D is also enhanced, together with education and the capacity building for clean and equitable development. Organizational measures are adopted to reduce material wastage by maximizing reuse and recycling. The combination of technical and organizational change yields high levels of material and energy saving, as well as reductions in pollution. Labour productivity also improves as a by-product of these efforts. Combined with the quest for high quality of product and services this translates into high productivity gains and into hefty increases in high value added activities and products, yielding high economic growth.

Key Scenario Drivers

Population, economic development, and regional disparities

The demographic transition to low mortality and fertility occurs rapidly, incidentally at the same rate as in high economic growth scenario presented above, but for different reasons as it is motivated partly by social and environmental concerns. For instance, reducing the environmental "footprint" of humanity is increasingly stated as reason for low fertility levels. Sub-replacement fertility levels ranging between 1.3 to 1.7 children per woman are a globally pervasive phenomenon. Global population reaches nine billion by 2050 and declines to about seven billion by 2100.

"Down to Earth" is a world with high levels of economic activity. The corresponding IPCC-SRES-B1 scenario describes a development pattern in which global GDP would increase to some 50 Trillion by 2020, 140 Trillion by 2050, eventually multiplying by a factor close to 20 by the end of the 21st century (350 Trillion $). But nature of economic activities and especially its distribution are radically different from conventional high economic growth scenarios. High value added increasingly does not rely on resource consumption as a high proportion of income is spent on services rather than on material goods, and on quality rather than quantity. Personalized services, revival of (expensive) arts and craft custom-made objects, cultural activities all add high value to the "green" GDP in "Down to Earth", without however requiring large natural resource inputs. The emphasis on material goods is also less as resource prices are increased by environmental taxation.

Another important difference is in the more equitable income distribution characteristic for "Down to Earth", both domestically as well as internationally. Global income disparities when measured by per capita income differences between "North" and "South" were approximately 16:1 in 1990 when incomes are compared at market exchange rates, and still a factor close to 6 when incomes are compared at purchasing power parities. These income disparities are significantly reduced in the "Down to Earth" scenario as a result of deliberate progress toward international and national income equality. North-South income disparities (expressed at market exchange rates) would be reduced to a factor of 4:1 by 2050 and a factor 3:1 by 2100 (and to a factor of 1.5 when incomes are compared at purchasing power parities) as suggested in the corresponding IPCC-SRES-B1 scenario.

Social Trends, Governance, Environment

Social Trends

As mentioned above, *social change* is the principle characteristic and main driver of this scenario. Trans-material values and lifestyles become a global phenomenon, but unlike the traditional Western consumerism model these new lifestyles emerge out of a multitude of sources and in a polycentric structure, drawing inspiration from a wide variety of experiences from religion, philosophy, as well as concrete life biographies from all over the world. From this perspective, the "slow" movement is different from the "green" movement of the 20th century and hence might find much wider adoption.

The material culture of people is not necessarily frugal, as people continue to value highly their indoor and outdoor environments, albeit always emphasizing quality over quantity. Instead of "throw-away" products, longevity, repair capability, and perfect functional and artistic design become the dominant purchase criteria. Minimization of up-front expenditures (e.g. in housing) gives way to a systematic life-cycle economic perspective, fully considering externalities and placing paramount priority on environmental performance. With the exception of demonstrative, conspicuous consumption products such as luxury cars or private jets which are considered undesirable, material consumption patterns allow for plenty of choice. Lifestyles emphasize *ludique* over social status via demonstrative consumption. Fashion designers, ebonists, even builders of wooden sailing boats are all professions that see a vigorous revival as consumer demands and lifestyles change.

Also the spatial context in which people's lifestyles take place changes significantly. Instead of spatially separated activities, collocation and "community" become important spatial foci of every day life, significantly promoting "soft" mobility and reducing long-distance travel demand. The "think globally, act locally" philosophy is applied in a system of electronically interconnected "global villages", in which both traditional rural and suburban villages coexist with "urban villages", that have high population densities, but otherwise function economically and socially like traditional village communities (a contemporary example being Greenwich Village in New York).

Governance

Governance structures are effective in this scenario at all levels from the local up to the global. Regulatory modes are diverse and generally take considerable amount of time, coordination, and approval seeking, not at least because of the grassroots type nature of many social movements involved as stakeholders. However, whatever time is lost in the policy formulation process, is quickly gained subsequently by wide social "buy-in", fast implementation and limited obstruction to regulatory rules.

A distinguishing feature of "Down to Earth" (as well as similar scenarios portrayed in the scenario literature) is the emergence of effective international governance. Originally emerging out of the environmental field, global governance structures and institutions progressively extend their reach to include for instance, technology policy (R&D and standard setting), IP rights, education, even media control. These tendencies materialize first in highly concentrated sectors, such as aviation or the automobile industry. For instance, the Global Aviation Advisory Board (GAAB) is instituted by a UN resolution in 2015 and as of 2020 sets global standards for the safety, fuel efficiency, and emission performance of all aircraft designed and operated. GAAB also has to power to "ban" outdated technological vintages, accelerating the turnover of capital stock and thus the diffusion of new types of aircraft. Yet, by 2050, environmental pressures, especially in connection to climate change trigger even stiffer regulation affecting also consumer choice through the introduction of air ticket quotas that are originally auctioned-off, but subsequently allocated on a per-capita basis.

In the "Down to Earth" scenario, a re-appraisal of the global and local air quality impact of aviation is made. By 2010, it is recognised that the trade-offs available in engine design deliver a minimum environmental impact if NOx is minimised, even at the expense of slightly higher fuel consumption (and hence CO2). Environmental concern allows widespread implementation of this NOx-focussed approach and a range of lower pressure ratio engines delivering increasingly lower NOx becomes widespread through the fleet.

Regulation deepens in all aspects concerning social equity and environmental protection. Even if benign in intent, the consequences of this “Big Sister” state are perceived by many as overly patronizing and jeopardizing civil liberties. Thus all governance institutions are continuously challenged and are in permanent need for justification and seeking wide stakeholder consensus. This is the necessary price to pay to get wide approval of the ambitious projects of international resource transfers (reaching up to 5 percent of GDP of the donor countries) being part of the global war on poverty or for the exorbitant carbon taxes introduced to combat climate change (rising from around 50-100$/ton carbon in 2010/2020 to some 2000 $/ton towards the end of the 21st century).

Environment

Given the high environmental consciousness and institutional effectiveness assumed for this scenario, environmental quality is high, as most potentially negative environmental aspects of rapid development are anticipated and effectively dealt with locally, nationally, and internationally. Clean local water and air are first policy priorities and an almost universal global provision is achieved by 2030. Trans-boundary air pollution (acid rain) is also basically eliminated in the long term. Land use is managed carefully to counteract the impacts of activities potentially damaging to the environment. Cities are compact and designed for public and non-motorized transport, with suburban developments tightly controlled. Strong incentives for low-input, low-impact agriculture, along with maintenance of large areas of wilderness, contribute to high food prices with much lower levels of meat consumption.

Overall, all negative impacts of an industrial society are at the focus of public and citizens attention. If technological solutions can solve the problem they are adopted, assuming they meet the criterion of local social appropriateness (e.g. close-to-zero-emission vehicles in industrialized countries). If no technological fix can be devised or the technological solutions are deemed insufficient (like for measures reducing aircraft noise) the answer is a strict ban on activities or technologies deemed socially or environmentally undesirable. One notable exception to this approach is in the efforts to combat[4] climate change. Avoiding climate change impacts in promoting a vigorous move towards a carbon-free energy system is recognized to be feasible only over the long-term. Because of the pervasiveness of energy use activities the simplistic “ban away” approach is simply not feasible, requiring instead a whole host of positive and negative incentives in terms of R&D subsidies, clean technology and clean development funding as well as taxation of emissions, which are gradually, but persistently stepped up reaching 2000 $/ton carbon. As a result, towards the end of the 21st century the task of phasing out fossil fuels is well underway and atmospheric concentrations of CO_2 are stabilized at below 450 ppmv.

Resources/Technology

With the exception of a few environmentally critically raw materials, resource availability becomes progressively decoupled from geology. In other words, not geological availability determines resource availability, but rather *social choice*. Despite continued abundance of coal and unconventional oil, few deposits are explored and even fewer exploited as efforts concentrate to achieve a smooth transition to alternative energy systems. There is extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition (also used as transitional fuel for cars, buses, and aircraft), but the major push is toward post-fossil technologies centring round the twin energy carriers electricity and hydrogen, driven in large part by environmental concerns. This transition is made the easier, because demand remains relatively low, reflecting pronounced dematerialization of economic activities, changing consumer

[4] This is a notable difference to the IPCC-SRES-B1 scenario that assumed no explicit climate policies.

choices, as well as high prices. As a result global energy use only grows slowly, roughly doubling by 2050 and quadrupling by 2100 -- for an almost 20 times increase in the size of the global economy. Energy systems diversify out from the use of fossil fuels. By 2020 close to 20 percent of global energy supply are derived from zero-carbon energy sources, a share that increases to 30 percent by 2050 and well over 50 percent by 2100 alleviating both pressures on depletable resources as well as on the environment.

Technologically, the scenario is characterized by high levels of technological development in the domains of material and energy saving, emissions control technology, as well as labour productivity. The latter is essential to support the rapid growth in personal income, given that a major increase in labour force participation is implicit in the equity assumptions of rapid economic growth in the "South". Technologies tend to be implemented in a pollution prevention mode, implying a much more highly integrated form of production than industry practices today. The traditional competitive model of technological innovation also gives gradually way to elaborate schemes of informal and formal coordination of R&D activities. Overall, both public and private sector R&D expenditures are significantly stepped up (reaching up to 5 percent of GDP), but increasingly targeted to environmentally desirable technologies in the domains of pollution prevention and environmental restoration but always being anxious about unintended side-effects. As a result, technology and risk assessment become dominant professions, not unlike lawyers in the contemporary US.

Communication/Transport/Air Transport

Communication and transport act as substitutes especially after the emergence of full virtual reality (VR) personal communicators that manipulate brain functions for a perfect multimedia experience, including sound, vision, smell, tastes, and tactile experiences. The phenomenal corresponding growth in bandwidth is managed via new carbon nanotube cables and ubiquitous satellite connections. These advanced information technologies achieve a global spread quickly, and are fully integrated into all economic and social activities. Much like the almost universal and 100% adoption of mobile phones among the youngsters in Europe, VR personal communicators and their early precursors are globally adopted. The global communication panel report of 2050 identifies that out of the 9 billion people inhabiting the planet in 2050, less than 500,000 refuse the use of a VR communicator out of privacy concerns. Even the most critical technology luddists embrace fully the increasingly wide range of advanced electronic communication technologies and infrastructures, as they epitomize dematerialization and "smart" use of resources. Electronic communication also provide for the only technological mean to cope with the complexities of participatory decision making processes. Cynics postulate a "law of constant voting time" of approximately two hours a day which many consider as taxing and ineffective. Conversely, electronic communication turns out to be quite effective in substituting for travel demand. As a result both travel time and money budgets get significantly reduced.

Transportation demand grows only slowly with air transport being the most hit by "Down to Earth" consumers. In the near-to medium term there remains some room for modest growth particularly in developing countries (perhaps a factor two growth to 2020 and a stabilization at that level to 2050), but over the long-term air transport volume declines in absolute amounts compared to present day levels. Other long-distance transport modes fare only somewhat better, especially when perceived as environmentally less obtrusive, such as conventional rail. Under a general "slow" movement philosophy the market potential for high-speed ground transportation (Maglev's) remains low: a few isolated lines are built in particularly dense urban corridors (Shinkansen, Beijing-Shanghai, BosWash, Rio-Sao Paulo), but these remain isolated infrastructures and see no pervasive diffusion. Local transport modes emphasize "soft" mobility concepts by public transport and bicycles (many of them fuel cell powered) and by small fuel cell carts in suburban settings. Traditional cars survive only in truly rural areas, continuing to rely on gasoline for many decades, especially in developing countries. However, over the long-term also rural vehicles become hydrogen powered, produced de-centrally to avoid obtrusive large energy infrastructures.

Embedded Aviation Storyline

Main challenges, bottlenecks, constraints

The problem to achieve sustainability is addressed by uncompromising changes in lifestyles. Air transport, especially long distance trips regarded very critically for the mainstream, the demand is low. In addition customers require high security, safety and comfort levels.

Mobility Patterns and Transport Development

- Low importance of physical mobility
- High importance of virtual mobility
- Decrease in average trip distance
- Sparse long-distance travel, in particular for vacation trips
- Low increase in transport demand overall
- High importance of intermodal transport in conurbations
- Telematic and transport management systems reduce transport emissions
- Many innovations in vehicle technologies for emission reduction

Air Transport Supply and Demand

- Decrease in demand for air transport because of ecological awareness
- Decrease in air transport supply, mainly point to point flights
- Low growth of vacation and leisure trips, medium growth of business trips, business most important reason for air transport demand
- Low air freight demand growth

Airport and Air Traffic Management Capacity

- Few new airports necessary within the first three decades, afterwards decrease in demand and no new airports needed
- Airports managed by the government because of low profitability
- No constraints in airport and ATM capacity

Safety & Security

- High safety and security standards
- No safety or security problems

Air Transport Market Development

- High regulation in transport markets
- Decrease in the number of airlines and low competition between airlines
- High importance of airline alliances but also of fusions to limit/reduce declining profitability of airlines
- No relevance for Low Fare Carriers because of high environmental costs and low demand
- Strong decrease in military movements
- Strong local policies and regulations to limit the extension of large polluting cities

Aviation Costs

- Higher personnel costs, in general and specifically
- Higher specific costs for maintenance because of high regulatory standards
- High specific costs for new aircraft because of small volume of aircraft orders
- High costs for airport usage because of high cost of environmental taxes
- High specific costs for ATM services because of lower flight demand
- High costs for aircraft fuel because of high cost of environmental taxes
- High increase in fares for air transport

Environmental Impacts of Air Transport

- Decrease of specific gaseous emissions because of regulation
- Decrease of gaseous emissions overall because of decrease in numbers of flights
- Decrease of specific noise emissions because of regulation
- Decrease of noise emissions overall because of decrease in numbers of flights
- In spite of decrease in noise and the emissions, most people think that aviation is a burden because of high environmental consciousness.

Aircraft Technology

- Introduction of Cryoplane starts in 2030
- In 2040 95% of all aircraft are powered by hydrogen.
- Lower specific fuel consumption and decrease of aircraft noise because of high environmental standards
- Innovation in aircraft technologies driven by environmental regulations

Detailed Technical Assumptions

- (1) New aircraft :
  As soon as the Down-to-Earth philosophy becomes established, measures are taken to minimise environmental impact. Typical flight leg becomes 4000km. R&D effort increases hugely to provide short term environmental improvements (e.g. aggressive NOx reduction for conventionally fuelled aircraft). Intense climate and research shows no environmental benefit from LH2 fuel even with operational changes (due to holistic impacts of production and fugitive emissions). No other environmentally-beneficial fuel emerges for aviation. Speculatively, "Close-to-zero" emissions propulsion technology begins to emerge around 2050 and starts to enter fleet from 2085 (later than unlimited skies due to lower emphasis on air travel technologies within the economy).
- (2) Liquid Hydrogen Aircraft (LH2) Storylines
  LH2 fuelling not introduced due to lack of overall climate impact benefits
- (3) Aviation Emissions Types
  2020: Current emissions mix; 2050: Current emissions mix
  2100: all flight is low or "close-to-zero" emission through technology insertion
- (4) Proportion of fleet kerosene fuelled: 100% in 2020, 100% in 2050, 0% in 2100
- (5) Emissions technology improvement assumption: aggressive NOx reduction
- (6) Emission change (NOx) for kerosene fuelled aircraft over time (new technology)
  Note: reductions are *constant percentage point reductions per year* (not cumulative year-on-year). 1992: LTO Dp/Foo = 62; Reductions compared to year 2000 data: 2000: +0.12% p.a.; 2020: -30 to -40% below 2000 level (-3.25% p.a.) = 35% of 2000; 2050: % -80 below 2000 level (-1.43% p.a.) = 20% of 2000; until 2100: CAEP/2 -95% (approx 1.3% p.a.) = 7% of 2000
- (7) Fuel efficiency change for kerosene fuelled aircraft over time (new technology):
  Note: reductions are *cumulative year-on-year*. Reductions compared to year 2000 data. 1992: tsfc at SLS TO = 0.34 kg/hr/kg; 2020: -10 to -20% below 2000 level (-0.75% p.a.); 2050: regional: N.America: -1.87% p.a. after 2020; Eurasia, Far East: -0.76% p.a.; Other regions, use same assumptions as described above for NOx; 2100: N.America: -1.02% p.a. after 2020; Eurasia, Far East: -0.886% p.a.; Other regions -1% p.a.
- (8) Hydrogen fuelled vehicles - Emission change (NOx) over time:
  2020: N/A; 2050: 20% less NOx than equivalent technology kerosene aircraft (Eurasia only); 2100: 25% less NOx than equivalent technology kerosene aircraft (Eurasia only)
- (9) Hydrogen fuelled vehicles - Fuel efficiency change over time
  +10% compared to equivalent technology kerosene aircraft
- (10) Emission change - post LH2 "close-to-zero" emissions vehicle
  NOx: n/a; CO2: n/a; Energy (heat): n/a
- (11) Fleet lifespan

(mid-range scenario possibility: 90% of fleet survive to 25 years old in 2000 (approx), 90% survive to 35 in 2050) 2050: regional: N.America, Eurasia, Far East - short (<20 years); All other regions - long (30+ years)

- (12) Aircraft size growth
  (mid-range scenario possibility: 0.53% per year growth, 220 seats average in 2000, up to 287 by 2050); 2050: regional: North America, Eurasia - large growth; Middle East, Subcontinent, Far East, Unaligned Regions - no change
- (13) Utilisation rate (relative to 2000): 1,124
- (14) New Large Aircraft (BWB) EIS: 2040
- (15) Noise: Refers to best available technology
  10 dB reduction by 2020; N America and Mid-East further 5dB by 2050; Sub-Continent and Unaligned Regions further 3dB by 2050, Eurasia and Far East, further 8dB by 2050.

5.5 Further input assumptions for the AERO-model

For calculations with the AERO-model the determination of ca. 70 assumption variables for system parameters, 50 scenario variables, and 50 policy variables is required (see D5). Only a subset of these input assumptions is needed to characterize the CONSAVE Scenarios. For the remaining variables historically observed (default) values were used.

The (quantified) macro economic and demographic model inputs are taken directly from the Background Scenarios (see following section (5.6)). The needed quantitative input assumptions on the long-term development of the aircraft technology and the fleet, described in the previous section, were developed by QinetiQ. The following catalogue of further scenario dependent input assumptions required to be defined for the AERO-model were derived consistently from storylines of the CONSAVE Scenarios (see previous section), and from proposal for quantifications of exogenous inputs elaborated in WP 2 from IIASA (see next section (5.6)):

- Assumptions on saturation effects
- GDP – elasticities
- Energy scarcity and kerosene prices / oil price development
- Cost developments

- **Saturation of demand for air transport**

In history demand in the long-term development of many markets has followed S-shaped logistic functions. Growth in air transport demand is assumed to follow a similar function, mainly dependent on GDP and – until markets start to be saturated - with higher growth rates than GDP. A wide-spread definition of maturity of air transport markets is that a market is called saturated if demand increases with the same growth rate as GDP. (That means, that even in an mature market air transport demand can still grow, but no longer with higher rates than GDP.) The level of the saturation effect for air transport demand is part of the travelling behaviour and included and estimated from the CONSAVE storylines. Because of the constrained nature of the CONSAVE scenarios, the saturation effects are considered low, resulting in an only relatively low dampening effect for demand for air transport. For the purpose of this study, saturation of air transport is estimated at 15% in (AERO-model base) year 1992 for the business and leisure travelling for the North American market. For cargo, until 2050 no saturation is expected.

- **Demand - elasticities**

For scenario developments that more or less represent a business as usual case, the observed, historic elasticities are a good measure for forecasting demand for air transport. In case the society changes course with respect to travelling behaviour or technology developments, elasticities need adjustment. IIASA (documented in deliverable D7) has provided guidelines for the adjustments. Eventually the GDP-elasticities for air transport demand described in table 6 were assumed:

		ULS	RPP	FW*	DtE
Leisure	2000	1,5	1,5	1,5	1,5
	2005	1,5	1,5	1,5	1,5
	2010	1,42	1,35	1,35	1,2
	2020	1,25	1,15	1,15	0,6
	2030	1,1	1,05	1,05	0,4
	2040	1,0	1,0	1,0	0,25
	2050	1,0	0,95	0,95	0,1
Business	2000	1,3	1,3	1,3	1,3
	2005	1,3	1,3	1,3	1,3
	2010	1,3	1,17	1,17	1,05
	2020	1,2	1,11	1,11	0,5
	2030	1,1	1,05	1,05	0,45
	2040	1,0	1,0	1,0	0,4
	2050	1,0	0,95	0,95	0,3
Freight	2000	2,25	2,25	2,25	2,25
	2005	2,0	2,0	2,0	2,0
	2010	1,9	1,8	1,8	1,55
	2020	1,65	1,52	1,52	0,65
	2030	1,4	1,23	1,23	0,55
	2040	1,2	1,1	1,1	0,45
	2050	1,0	0,97	0,97	0,35

* Influences of decrease in traffic between the regions of the Fractured World are not included; these are taken into account via cost modelling

Table 6: GDP- Elasticities

- **Regional differentiation of energy scarcity and kerosene prices**

The cost of fuel is very much sensitive to the availability of crude oil, even if alternative fuels are available, as alternative fuels become economically viable only if the price of crude oil is high enough or has been high enough in the past. For the Fractured World scenario, the unfolding storylines suggest a (fractured) world where in some regions, oil has become a scarce commodity, whereas in other regions, there is either plenty of oil, or some other form of energy carrier has replaced conventional fuels for aviation.

In order to include a regional differentiation that is in line with the storylines as well as in line with the global fuel price development, IIASA has suggested, that the price development is a function of the Resource/Production (R/P) ratio, plus an autonomous yearly increase. The R/P ratio is the ratio of proven Reserves to annual Production. An R/P ratio of 45 implies that given the actual annual oil production, the proven reserves are exhausted in 45 years. The proven reserves may increase in the course of time changing the R/P ratios for a given production rate. The underlying mechanism of R/P ratios and crude oil prices is explained and elaborated upon in Appendix D of Deliverable D9.

The crude oil price is a mix of local oil extraction and global oil extraction, depending on the level of coherence or isolation between economic blocks world. The following table 7 and graphs will show the development of crude oil prices and the contributions of the local and global Resource/Production ratios.

	Unlimited Skies	Reg. Push & Pull	Fractured World	Down to Earth
Until 2020	Uniform oil price	Uniform oil price	Uniform oil price	Uniform oil price 100% world
In 2030	Uniform oil price 100% world	90% world 10% local	70% world 30% local	Uniform oil price 100% world
In 2040	Uniform oil price 100% world	80% world 20% local	50% world 50% local	Uniform oil price 100% world
In 2050 and after	Uniform oil price 100% world	70% world 30% local	30% world 70% local	Uniform oil price 100% world

Table 7: Oil price development

For interpretation of the results, the GDP/capita as a measure for buying power should be compared to the actual price levels. Price levels are quoted in 1992$ and hence do not include the inflation effects (see figures 8-11).

The kerosene prices are linked to the crude oil prices using a kerosene – crude oil ratio that is derived from historical data, with an approximately world oil price, with small regional variations. This link ensures that effects local circumstances, e.g. production facilities and airport infrastructure are included in the regional pricing.

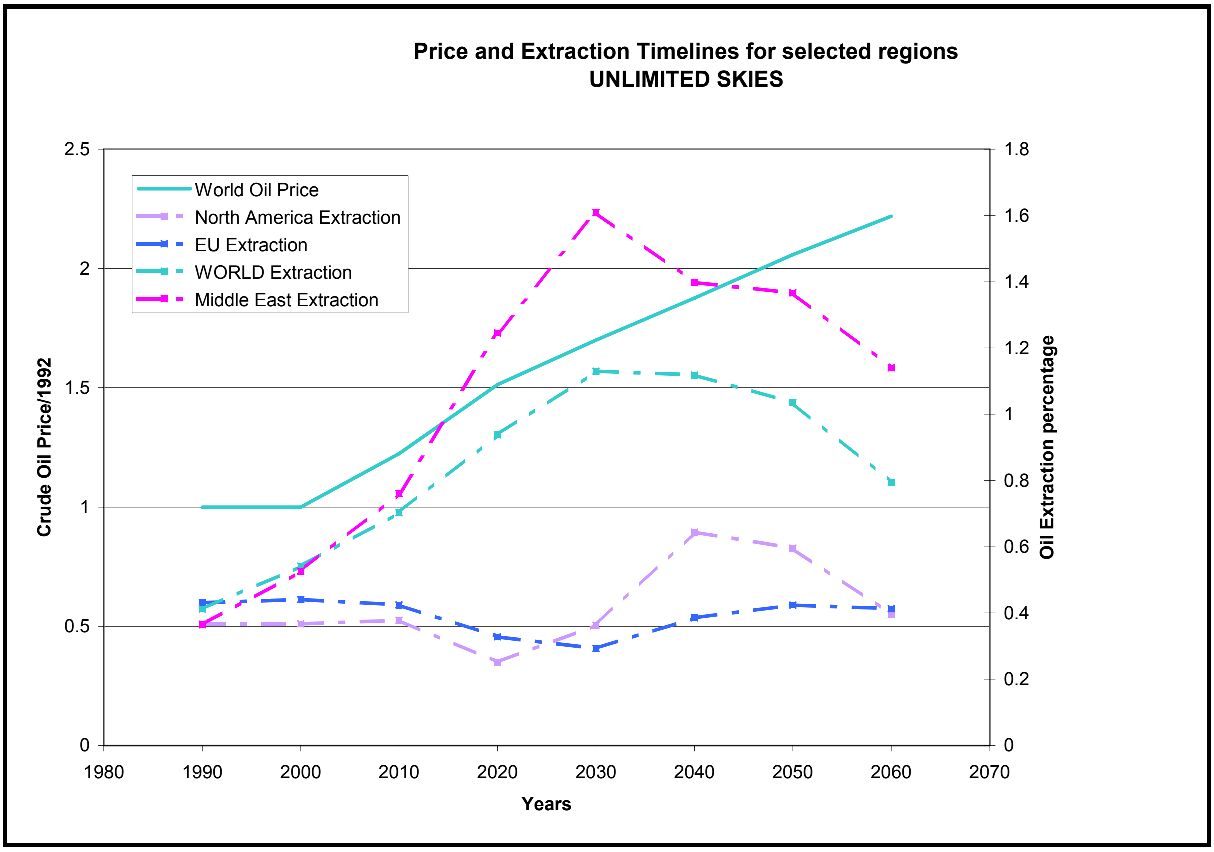


Figure 8: Oil price development for the Unlimited Skies scenario

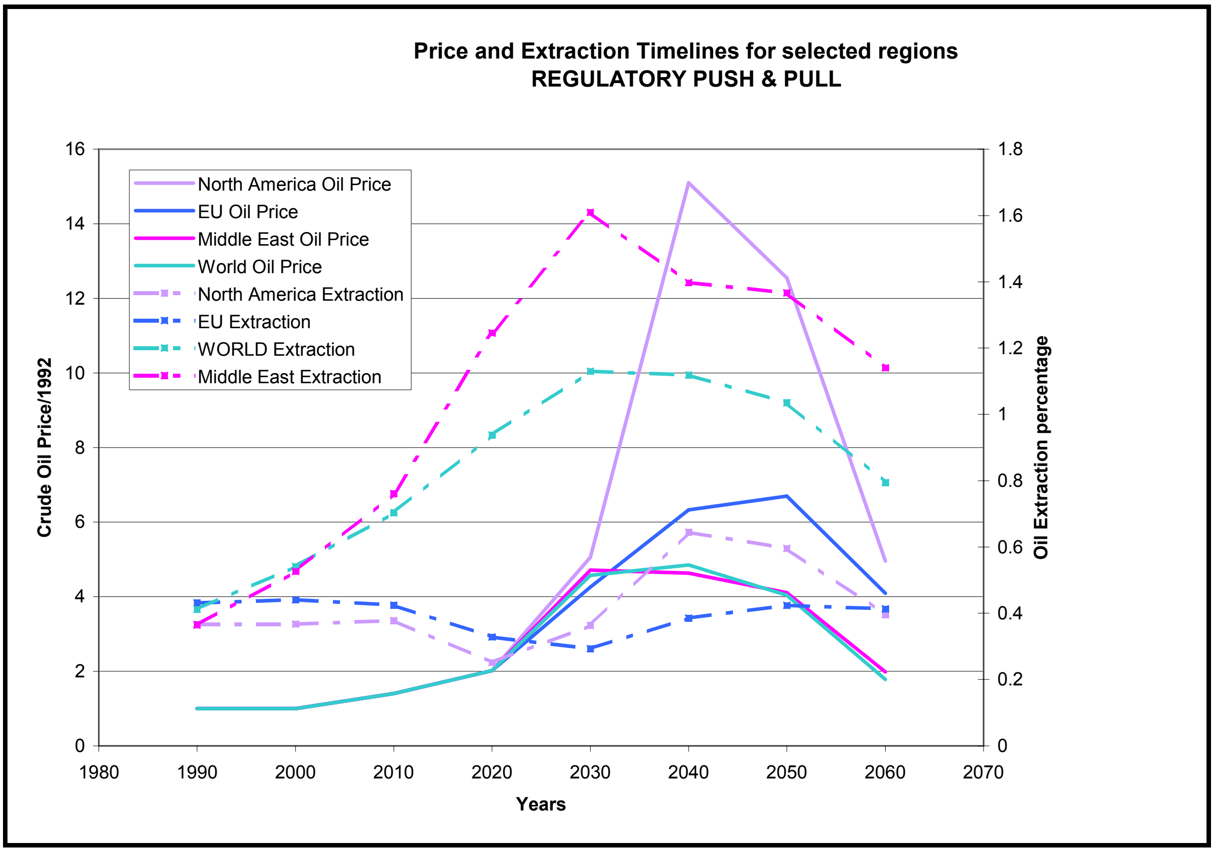


Figure 9: Oil price development for the Regulatory Push & Pull scenario

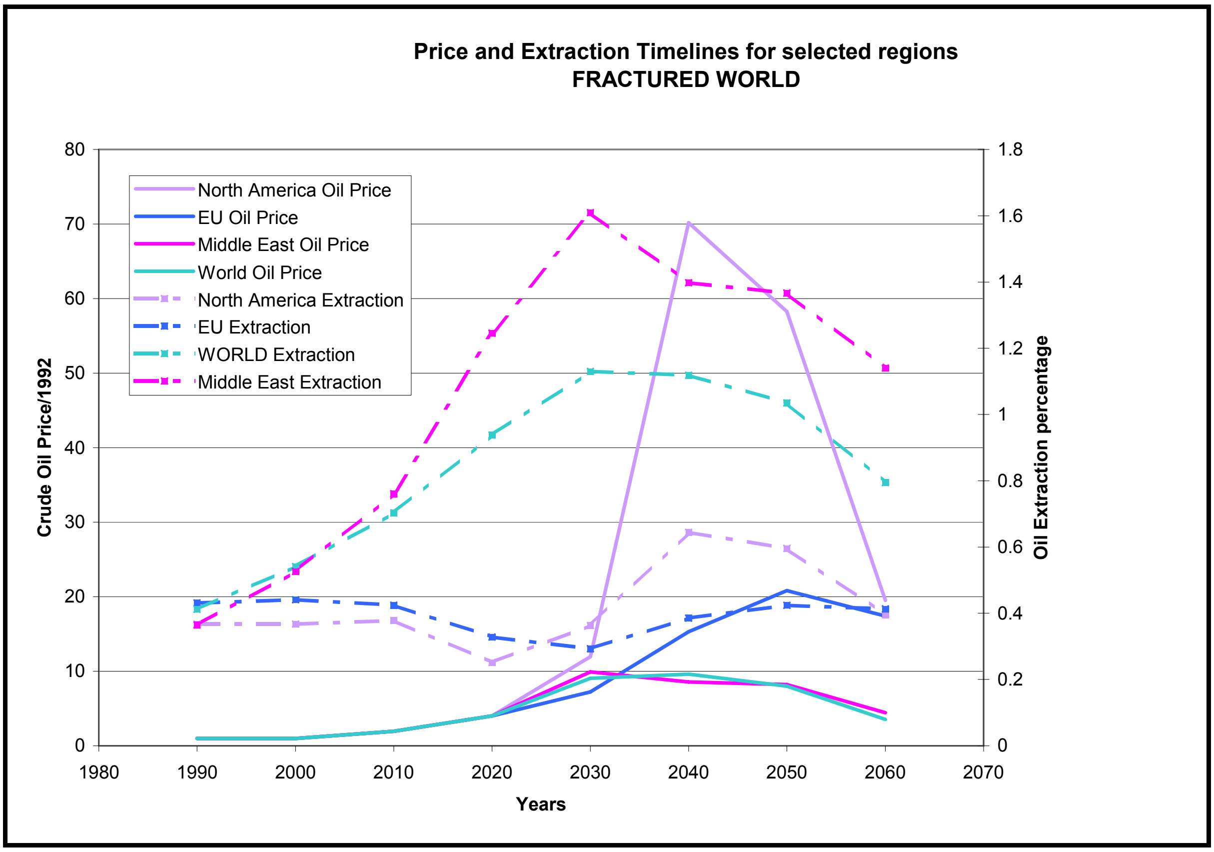


Figure 10: Oil price development in typical regions for the Fractured World scenario

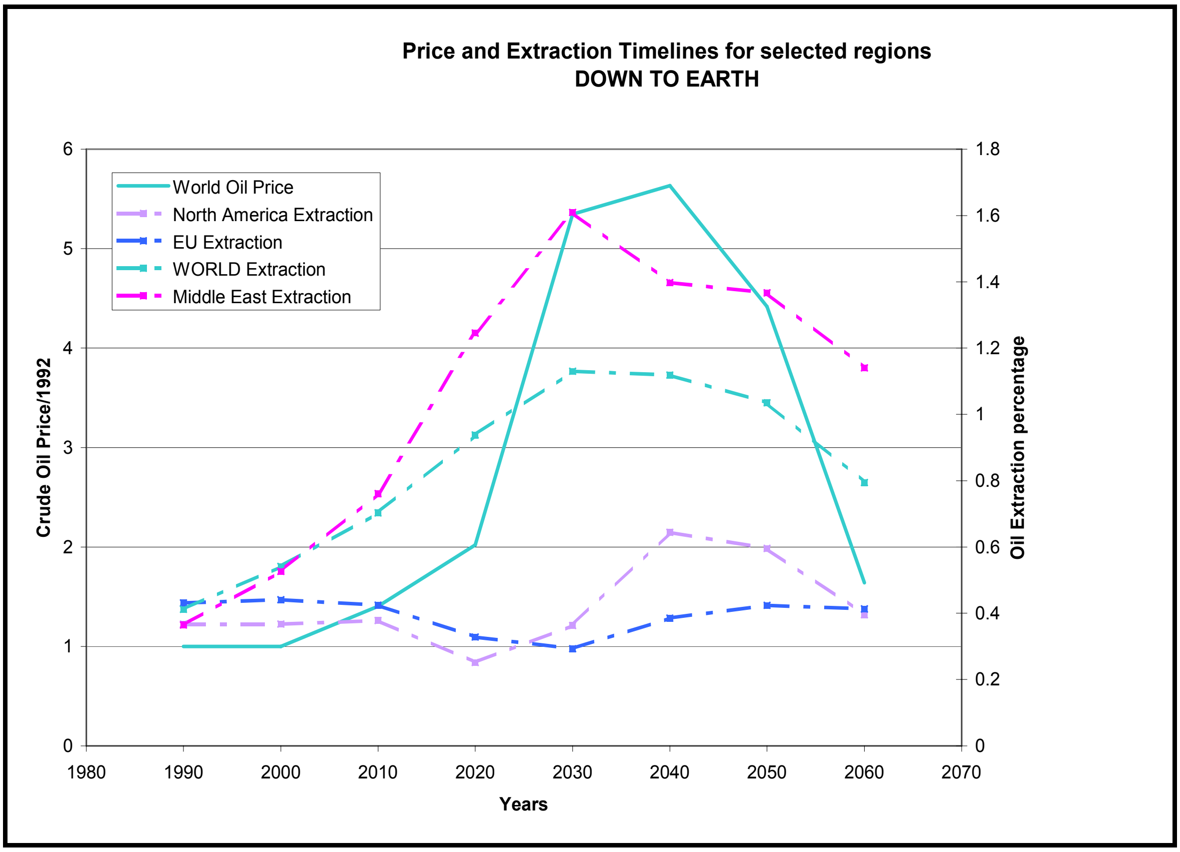


Figure 11: Oil price development for the Down to Earth scenario

- **Cost components**

Costs are an important driving factor in the development of aviation. They are key indicators for the winners and losers of airlines and manufacturers. Costs drive the fare levels and hence the transport volumes.

The cost of aviation can be divided in several components. For a typical long-range aircraft their contribution to the airline operating costs is as follows:

♦ Capital costs	28%
♦ Fuel costs	23%
♦ Maintenance costs	17%
♦ Route, landing and slot costs	11%
♦ Crew costs	21%

In developing the costs components, it can be assumed that some of the costs are following GDP/capita developments, e.g. labour costs, and others have an autonomous, GDP/capita-independent change in time. Effectiveness, efficiency and technology developments have a stake in this. In those cases where constraints become effective, meaning supply is smaller than demand with respect to some relevant aviation scenario feature, e.g. runway infrastructure, a suitably relevant cost component will be increased to a higher level up to where supply meets demand.

Those costs components that feature a significant labour (wages) component, probably show a tight relation between GDP/capita developments. The relation between GDP/capita and the costs components usually have a world-level and a (IATA) regional component.

Table 7 gives an overview of the quantitative assumptions for the scenario dependent long-term development of the various cost components including:

- fuel costs development
- cabin and cockpit crew costs
- safety and security related costs
- volume costs(annual costs not directly related to aircraft operations as ground expenses, passenger services etc.)
- aircraft new prices
- maintenance costs
- finance costs and capital depreciation

Full details are described in Deliverable D9. Some examples of the scenario differentiated assumptions are visualized in the figures 12 -14 which show for the Unlimited Skies scenario the assumed – regional differentiated - developments of flight crew and maintenance costs, and new aircraft prices.

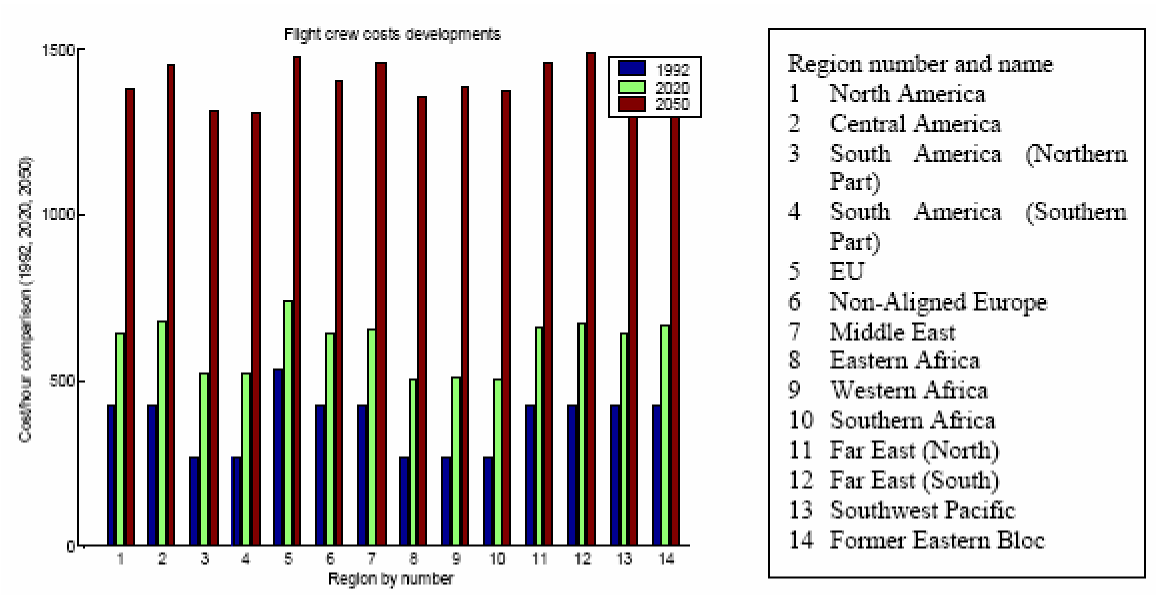


Figure 12: Flight crew costs per flying hour for Unlimited Skies 1992, 2020, and 2050

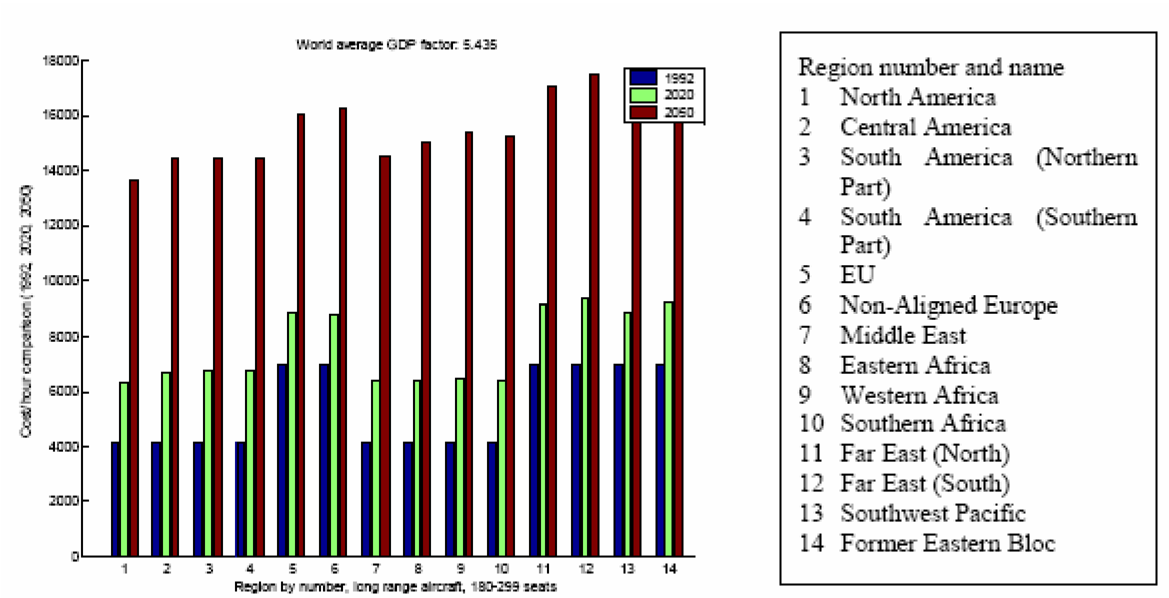


Figure 13: Maintenance costs 1992, 2020, 2050 for long haul aircraft with 180-299 seats for Unlimited Skies

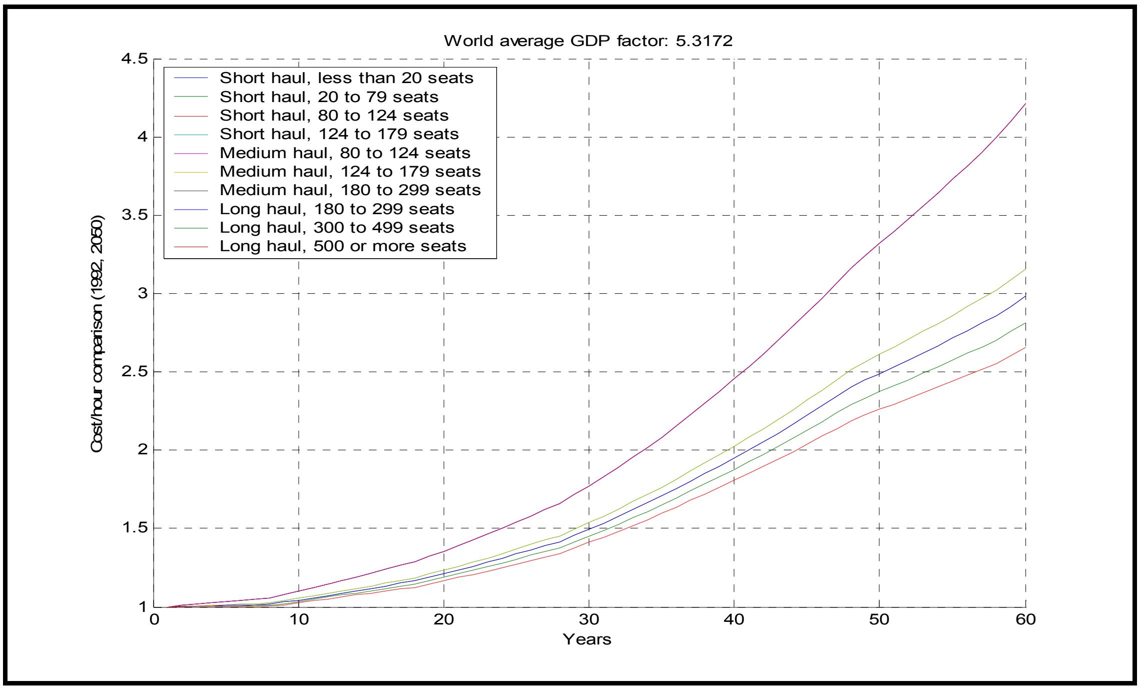


Figure 14: Aircraft new price increase as a function of years beyond 1992 for the Unlimited Skies scenario. Impact of technology (beyond a reference rate) is not included.

Scenario Drivers	Maximum	Source	CONSAVE Scenarios: High Growth – Unlimited Skies	CONSAVE Scenarios: High Growth – Regulatory Push&Pull	CONSAVE Scenarios: Fractured World	CONSAVE Scenarios: Down to Earth	Minimum	Source
Population [billion]	8.0	UN 2002	7.5		8.2	7.5	7.1	UN 2002
Economic growth rates (p.a.)	3.9%	IPCC SRES A1	3.9%	3.8%	2.3%	3.3%	2.0%	International Energy Outlook - Scenario C (EIA 2001)
World GDP-mer (trillion $)	58	International Energy Outlook 2003	57	56.4	40	53	40	Global Energy Perspectives - B
Energy use [EJ]	730	International Energy Outlook - Scenario B (EIA 2001)	700	610	600	580	430	Faktor 4-Szenario
Ratio of global oil production (1990=1)	1.7	US DoE 1999	1.3		2.2	1.5	0.9	Global Energy Perspectives - C
Crude oil price (1990=1)	no value found		1.5	2	4	2	1	U.S. Department of Energy 2001
Zero-carbon energy rate	27%	Global Energy Perspectives - C	15%	20%	regional differences	20%	20%	Global Energy Perspectives - A
Air Transport Demand Index (1990=1)	3.3	CAEP/4 - FESG Report 4, 1998 - Fe	3.2	2.6	2.0	1.9	2.2	CAEP/4 - FESG Report 4, 1998 - Fc
Fuel Efficiency Change	-20%	Scientific Advisory Board of the German Ministry of Transport	-10 to -20% below 2000 level (0.75% reduction p.a.)		2020: -10 to -20% below 2000 level (-0.75% p.a.); N.America: -2% p.a. after 2020; Eurasia & Far East: -1% p.a.	+10% c.f. 2000 levels (+0.5% increase p.a.)	12% below 1999 levels	IPCC 1999
LTO NOx Levels	50% below CAEP/2 levels	IPCC 1999	45% of 2000		N.America - gradual increase to 2x 2000 levels (+11.5% p.a.); Eurasia & Far East - maintain 2020 tech levels; Middle East - 2010 to 2020 aircraft mean levels; Subcontinent, Unaligned Regions - post-2000 aircraft mean levels	30% of 2000	4% below CAEP/2 levels	IPCC 1999
Noise Reduction	- 10 dB	Scientific Advisory Board of the German Ministry of Transport	10 dB reduction by 2020				-4dB'	Based on 2.2x traffic increase to keep current noise levels
Fleet Lifespan (in years)	35	IPCC 1999	<30	<25	NAmerica, Eurasia, Far East <20; All other regions >30	<20	25	IPCC 1999
Aircraft Size Growth	1% per year	Airbus 2003	large		large	large	0,2% per year (until 2015)	ICAO 2004
CO2 Emissions [billion kg pa]	300	IPCC 1999 - Scenario Ecb	906.5	748.9	622.6	624.9	850	IPCC 1999 - Scenario Eeh

Table 8: Ranges of assumptions for the scenario year 2020 made in different studies plus two results (demand growth factor (1990), CO_2 emissions)

Scenario Drivers	Maximum	Source	CONSAVE Scenarios				Minimum	Source
			High Growth		Fractured World	Down to Earth		
			Unlimited Skies	Regulatory Push&Pull				
Population [billion]	12.8	UN 2002	8.7		11.3	8.7	7.4	UN 2002
Economic growth rates (p.a.)	3.9%	IPCC SRES A1	3.9%	3.8%	2.4%	3.2%	1.2%	IPCC IS92c
World GDP-mer (trillion $)	196	Shell 2001	180	174.6	82	136	72.8	Global Energy Perspectives - B
Energy use [EJ]	1121	Shell - Spirit of the Coming Age	1350	1100	970	810	434	Faktor 4-Szenario
Ratio of global oil production (1990=1)	2.6	Global Energy Perspectives - A 1	2.2		1.7	1.5 - 1.8	0.8	Global Energy Perspectives - C 2
Crude oil price (1990=1)	no value found		2	4	8	4	no value found	
Zero-carbon energy rate	43%	Global Energy Perspectives - C1	33%	40%	regional differences	30%	27%	Global Energy Perspectives - A 2
Air Transport Demand Index (1990=1)	21.0	EDF Scenario IS92e High (Eeh)	10.4	7.2	3.4	2.0	3.9	CAEP/4 - FESG Report 4, 1998 - Fc
Fuel Efficiency Change	50% below 1999 levels	IPCC 1999	2020: -10 to -20% below 2000 level (-0.75% p.a.), -1.5% p.a. after 2020		2020: -10 to -20% below 2000 level (-0.75% p.a.); N.America: -2% p.a. after 2020; Eurasia & Far East: -1% p.a.	2020: +10% c.f. 2000 levels (+0.5% p.a.), -1% p.a. after 2020	30% below 1999 levels	IPCC 1999
LTO NOx Levels	70% below CAEP/2 levels	IPCC 1999	35% of 2000		N.America - gradual increase to 2x 2000 levels (+11.5% p.a.); Eurasia & Far East - maintain 2020 tech levels; Middle East - 2010 to 2020 aircraft mean levels; Subcontinent, Unaligned Regions - post-2000 aircraft mean levels	80% below CAEP/2 levels	10% below CAEP/2 levels	IPCC 1999
Noise Reduction	Possibly close to background levels outside airport	Silent Aircraft Project	10 dB reduction by 2020, further 8dB by 2050		10 dB reduction by 2020, further 3 to 8 dB by 2050 according to region	10 dB reduction by 2020, further 10dB by 2050	6dB	Based on 3.9x traffic increase to keep current noise levels
Fleet Lifespan (in years)	35	IPCC 1999	<30	<25	NAmerica, Eurasia, Far East <20; All other regions 30+	<20	25	IPCC 1999
Aircraft Size Growth	no value found		large		regional: NAmerica, Eurasia - large growth; Middle East, Subcontinent, Far east, Unaligned Regions - no change	large	no value found	
CO2 Emissions [billion kg pa]	230.6	ICAO CAEP/4 FESG 1998 Scenario Fc1	2441.6	1653.8	955	719.4	1975	IPCC 1999 - Scenario Eeh

Table 9: Ranges of assumptions for the scenario year 2050 made in different studies plus two results (demand growth factor (1990), CO2 emissions)

5.6 Impacts of the new IPCC/SRES GDP assumptions on the comparability of the IPCC/ICAO/FESG scenarios 2050 with CONSAVE results

One part of the concept for CONSAVE 2050 was to use the aviation scenarios for the year 2050 developed by the ICAO/CAEP working group FESG[4] for IPCC Special Report from 1999 on "Aviation and the Global Atmosphere [3] for comparisons.

However, whereas CONSAVE is based on new GDP assumptions of IPCC, published in 2000 within the IPCC/SRES exercise [8], the FESG scenarios use "old" GDP growth rates alternatives of the IPCC IS92 Emission Scenarios [9]. Therefore it has to be checked to which extend the FESG scenarios have to be modified, to allow for useful comparisons of the respective results. One sub-tasks of WP 3 was related to a discussion of this question. The results are presented in the following.

Within the FESG aviation scenarios [4] - developed by the ICAO/CAEP working group FESG for the IPCC Special Report - the global demand for air transport has been determined using the logistic function

RPK/GDP = 26.24 / (1 + 9.04 exp (-0.073t)), where
RPK = Revenue Passenger Kilometer and t = time (in years).

That means that within the FESG scenarios GDP is the (only) explicit determining factor for the quantification of the volume of global demand. The three FESG scenario families Fa, Fc, and Fe are based on the GDP assumptions of three of the six IPCC Emission Scenarios from 1992, named IS92a, IS92c, and IS92f respectively. (Each FESG scenario family has two sub-scenarios, related to the two technology scenario alternatives developed as well for the IPCC/1999 work) With respect to assumptions on the further development of GDP the selected sample represents the full range of alternatives considered in IPCC/1992, as IS92e is the scenario with the highest growth in GDP and IS92c the scenario with the lowest assumed GDP growth. (The IS92a scenario has a medium GDP growth.)

For a comparison of the FESG scenario results to CONSAVE outcomes it has to be checked to which extend the FESG findings have to be modified taking into account the new IPCC GDP assumptions.

As the new IPCC 2000 scenarios are not an updating of the IP92 scenarios, a direct adjustment of the FESG scenarios to the new GDP assumptions is not possible.

Instead, for the check of the comparability of the FESG scenarios two aspects were considered:

a) Is their a change of the full range of different GDP growth rate assumptions from the "old" IS92 scenarios to the new IPCC 2000 scenarios?

b) What are the results for global air traffic demand of new defined "extreme" FESG scenarios - using the extremes for the GDP growth rate assumptions of the new IPCC 2000 scenarios - compared to the respective findings for the "old" extreme scenarios?
(This test is very similar but not fully equal to (a))

Change of the range of GDP growth rate assumptions

The following overview shows the GDP growth rates assumptions of the respective two extreme IPCC scenarios of the scenario sets from 1992 and 2000. For the IPCC/SRES GDP growth the range of assumptions for the various sub-scenarios belonging to one scenario family is given in brackets behind the selected family value.

IPCC 1999 scenarios

IS92e (highest) used for Fe:	1990 – 2025	3.5%
(Interpolated by FESG)	1995 – 2050	3.9%
	1990 – 2100	3.0%
IS92c (lowest) used for Fc:	1990 – 2025	2.0%
(Interpolated by FESG)	1995 – 2050	2.0%
	1990 – 2100	1.2%

Scenarios of the IPCC/SRES 2000 exercise

A1 (highest)	1990 – 2020	3.3%	(2.8% - 3.6%)
	1990 – 2050	3.6%	(2.9% - 3.7%)
	1990 – 2100	2.9%	(2.5% - 3.0%)
A2 (lowest)	1990 – 2020	2.2%	(2.0% - 2.6%)
	1990 – 2050	2.3%	(1.7% - 2.8%)
	1990 – 2100	2.9%	(2.0% - 2.3%)

For the different time periods the following change in for the range of GDP growth rate assumptions can be observed:

<u>1990 – 2020/2025</u>
GDP growth rate assumptions
for the IS92 scenarios for 1990 – 2025: between 2.0% and 3.5%
for IPCC 2000 scenarios for 1990 – 2020: between 2.0% (2.2%) and 3.6% (3.6%)
(CONSAVE assumptions in brackets)

=> There is no change worth mentioning in the range for the GDP growth rate assumptions for the time until 2020/2025.

<u>1990/1995 – 2050</u>
GDP growth rate assumptions
for the IS92 scenarios for 1995 – 2050: between 2.0% and 3.9%
for the IPCC 2000 scenarios for 1990 – 2050: between 1.7% (2.3%) and 3.7% (3.6%)
(CONSAVE assumptions in brackets)

=> The range of GDP growth rate assumptions for this time period is somewhat, but not significantly different for the two IPCC scenario sets.

<u>1990 – 2100</u>
GDP growth rate assumptions
for the IS92 scenarios: between 1.2% and 3.0%
for the IPCC 2000 scenarios: between 2.0% (2.25%) and 3.0% (3.0%)
(CONSAVE assumptions in brackets)

=> There is a significant change in the range for the GDP growth rate assumptions between the IPCC 1992 scenarios and the IPCC 2000 scenarios. From the IPCC 2000 view the overall growth rates for world in the 21 th century will probable not fall below 2% (A value which equals the so called long-term “secondary” growth rate, regarded in the past.)

However, as the largest time horizon considered within the FESG scenarios is the year 2050, the significant change in the range of the GDP growth rate assumptions between the two IPCC scenario sets for 1992 and 2000 is irrelevant for the intended comparison of FESG results with CONSAVE findings.

➔ For the time period for which comparisons are possible (until 2050), there is no significant change in the range of the respective GDP growth rate assumptions. Therefore there is – based on this aspect - no objection against the comparison of unmodified FESG scenario results for global demand in air traffic with respective outcomes of CONSAVE.

Modifications of the "extreme" FESG scenarios Fc, Fe

The IPCC 1992 scenarios IS92c and IS92e were selected as base for the FESG scenarios Fc and Fe because they represent the two extremes with respect to the IS92 GDP growth rate assumptions. A useful modification of the FESG scenarios could be to use the two IPCC 2000 scenarios with the most extreme assumptions for the long-term development of GDP growth rate to define two new extreme FESG scenarios.

With respect to the *"high" FESG scenario Fe*, applying the GDP growth rate assumptions from the "highest" IPCC 2000 scenario instead of those from "highest" IP92 scenario would not result in a major change of the derived global demand:

IPCC 2000 scenario A1: 1990/2020 = 3.4%, 1990/2050 = 3.7% (1990/2100 = 3.0%) IS92e:
1990/2025 = 3.5%, 1995/2050 = 3.9% (1990/2100 = 3.0%)

(It should be noted, that FESG has modified the GDP assumptions from IS92e to fit the Boeing forecast for 2015, resulting in a modest increase of the original IS92e values.)

With respect to the *"low" FESG scenario Fc*, applying the GDP growth rate assumptions from the "lowest" IPCC 2000 scenario instead of those from the "lowest" IS92 scenario would result in comparably small changes for the development until 2050 as well:

IPCC 2000 scenario A2: 1990/2020 = 2.0%, 1990/2050 = 1.7% (1990/2100 = 2.3%) IS92c:
1990/2025 = 2.0%, 1995/2050 = 2.0% (1990/2100 = 1.2%)

=> The difference for the GDP growth rate assumptions between the "old" and new IPCC scenario sets is low to zero for the time period until 2020.

Estimating that the GDP growth rate for IS92c for 1990 – 2050 to be 2.0% (same as 1990/2025 and 1995/2050), it follows

for Fc (old): GDP (2050,old) = GDP (1990) x 3.281 (2.0% from 1990 – 2050)
for A2 (new): GDP (2050,new) = GDP (1990) x 2.750 (1.7% from 1990 – 2050)

using the FESG formula for RPK it follows:

RPK (2050, new) / RPK (2050, old) = GDP (2050, new) / GDP (2050, old)
= GDP (1990) x 2.750 / (GDP (1990) x 3.281) = 0.84

=> The change to a new extreme low FESG scenario based on the new IPCC 2000 scenario assumptions for GDP would result in a – in the view of the general underlying uncertainties comparably small - decrease (16%) for the global air traffic demand compared to the "old" low FESG scenario Fc.

➔ The consequence of this test is: As the difference for the results for the global air traffic demand is low if the two "old" extreme FESG scenarios would be substituted by the new extremes based on the GDP growth assumptions of the new IPCC 2000 scenarios, unmodified findings from the FESG scenario work can be applied for useful comparisons with respective outcomes from CONSAVE 2050.

(Only for the development beyond the year 2050 the new "low" FESG would have significantly higher GDP growth rate assumptions resulting in an increase of air transport demand and in remarkable enhancement of derived results with a percentage depending on the respective functional relation to air transport demand.)

➔ Both tests have the same outcome: FESG scenario results can be used unmodified for comparisons with the respective CONSAVE findings.

5.7 Quantification of the Background Scenarios

5.7.1 Overview

Following the concept of CONSAVE, the quantification of the CONSAVE background scenario was based on the long-term databases developed for the IPCC/SRES exercise. For each of the four CONSAVE scenarios (of three scenario families) the one of the 40 IPCC-SRES scenarios, with the closest storyline to the CONSAVE scenario was selected as a reference scenario. As far as possible, the related existing IPCC-SRES quantifications were directly adopted for the respective CONSAVE scenarios. If necessary, the original SRES values have been modified to take into account differing characteristic features in the underlying storylines for the CONSAVE and the IPCC/SRES reference scenario. For reasons of scenario economy, the number of different background scenario assumptions has been minimized. For instance, two scenario families (High Growth, and Down to Earth) share the same low population projection.

The quantification of the background scenarios, elaborated by the sub-contractor IIASA, were finally used nearly unchanged as input for the AERO-model, because – with some minor exceptions– no objections to the background scenarios were raised from the European Review on the total preliminary results of CONSAVE 2050 (see deliverable D10, Annex 10 in PART II). The only modification worth mentioning is a reduction of the GDP for RPP by 3%, (see 5.3.2).

The quantified results of the Background Scenarios are presented as

- global snapshot values for the years 2020, 2050, and 2100 (used also for the discussion of the taxonomy of the CONSAVE Background Scenarios)
- detailed global and regionalized data for the decades 1990 to 2100.

5.7.2 Global snapshot values for 2020, 2050, and 2100

At first, for the four key drivers population, GDP, (primary) energy use, air transport demand, and in addition for the general level of air transportation constraints, global quantitative snapshot overviews of the scenarios are given for the years 2020, 2050, and 2100 and compared to the range of results from scenarios available in the literature obtained from the IPCC SRES and aviation reports respectively. It is indicated which (combination of) original background scenario variable quantification from the IPCC/SRES report fit best to the corresponding CONSAVE background scenarios.

The evolution of the scenarios is illustrated in Tables 10 - 13. Each (sub-) scenario is represented by a different color code, with grey shades indicating differences between the CONSAVE scenarios to the entire range as available in the published scenario literature.

Population and Economic Growth

There is good congruence between the CONSAVE aviation background scenario storylines and those of IPCC-SRES in terms of demographic and economic development. Hence the scenario quantification was drawn to a large extent from the original IPCC scenario data.

	Population Billion			World GDP (mer) trillion $		
	2020	2050	2100	2020	2050	2100
Min-Literature	7	7.8	6	30	50	65
Max-Literature	9	13	20	80	180	700
High Growth						
Unlimited Skies	7.5	8.7	7.1	57	180	528
Regulatory Push&Pull	7.5	8.7	7.1	57	180	528
Fractured World	8.2	11.3	15.1	40	82	243
Down to Earth	7.5	8.7	7.1	53	136	328

Table 10: Population and Economic Growth

Population:
The CONSAVE scenarios include two (low/high) demographic projections. Two scenario families with either high income or high ecological consciousness share the same (low) projection. The corresponding matching between the CONSAVE and the IPCC-SRES population scenarios is as follows:

"High Growth" (2 scenarios): IPCC-SRES A1
"Fractured World" (1 scenario): IPCC-SRES A2
"Down to Earth" (1 scenario): IPCC-SRES B1 (identical population projection as in IPCC-SRES-A1).

Economic Growth:
For GDP, the two CONSAVE sub-scenarios of the "High Growth" scenario, "Unlimited Skies" and "Regulatory Push & Pull" are sharing the same GDP projection. As planed by the CONSAVE team and later on as well required by the European Review, the GDP for the "Regulatory Push & Pull" scenario was eventually modified for internal consistency reasons to be somewhat lower than the GDP for the scenario "Unlimited Skies", as it turned out (as to be expected) from the quantification process for the CONSAVE aviation scenarios that the demand for air transport is lower in constrained "Regulatory Push & Pull" scenario than in the unconstrained "Unlimited Skies" scenario, leading to a decrease in GDP, depending on the contribution of the GDP from aviation to the total GDP. Finally, the relative reduction in GDP was assumed to be in the order of 3% (see 5.3.2).

The quantitative matching between the respective CONSAVE and IPCC-SRES GDP growth scenarios is:

"High Growth" (2 scenarios): SRES A1
"Fractured World" (1 scenario): SRES A2
"Down to Earth" (1 scenario): SRES B1

Note especially that even if global scenario values seem to be quite close in the "Down to Earth" and "Fractured World" scenarios, their respective regional distributions are radically different (converging per capita income levels in "Down to Earth" versus continued disparities in "Fractured World"), cf. the numerical appendix.[5]

As a rule (and reflecting the model calibration of the AERO model), GDP growth scenarios are expressed in constant US $ (1990) calculated at prevailing market exchange rates (MER). For further information, also GDP scenarios expressed in purchasing power parities (PPP, derived from the published 4-region IPCC-SRES GDP-PPP scenarios) are given in the appendix of the deliverable D7 (see Part II, Annex 7) for 14 world regions. These scenarios differ from the GDP-MER scenarios in terms that initial per capita income levels in developing countries are higher, with their long-term growth rates being lower. In other words, both economic metrics converge to similar values in the long-term (2050-2100). Notwithstanding this difference in economic metric, the corresponding scenario descriptions within a given scenario family (IPCC-SRES-A1, -A2, and -B1 corresponding to their equivalent CONSAVE scenarios High Growth, Fractured World, and Down to Earth respectively) are fully self-consistent. Differences between GDP-MER and GDP-PPP scenarios are only important when considering possible alternative model calibrations between activity (e.g. air transport volume) and economic growth variables in case such recalibration should be considered in future for the AERO model.

Energy Demand, Resource Availability, and Energy Prices (Oil)

With exception of one scenario (Fractured World), there is also good agreement between the SRES scenarios and the proposed CONSAVE scenarios with respect to growth in energy demand, resource availability and (to a lesser extent on) resulting energy prices. With exception of energy demand (that does not seem to be a variable directly entering the AERO model), resource availability and energy prices are essentially global boundary conditions. Hence in the beginning there were no regional values developed. However, during the quantification process eventually regional values were elaborated as input for the AERO-model as well, using information from IIASA on the energy resources and annual energy extraction for the 14 IATA regions. (For more details see 5.5.)

Energy demand:
In terms of energy demand the following correspondence between the IPCC-SRES scenarios and those developed for IPCC-SRES exists:

"Unlimited Skies": SRES-A1B or SRES-A1G
"Regulatory Push & Pull": SRES-A1T (lower demand due to regulatory enhanced conservation effort)
"Fractured World": SRES-A1
"Down to Earth": SRES-B1 (lowest energy demand of all scenarios due to post-material lifestyles).

[5] Caution needs also to be exercised when comparing the IPCC-SRES GDP scenarios to the previous IPCC IS92 scenarios, because regional growth rates differ, even if global GDP levels might be similar between the scenarios (such as for instance between IS92a and IPCC-SRES-B2). Generally, the SRES scenarios assume higher GDP growth in the developing countries than globally similar IS92 scenarios. However, the final CONSAVE scenario set excludes the "Middle of the Road" scenarios such as IPCC-SRES-B2, so this issue should not of direct concern to the CONSAVE scenario quantifications. It is important however, to emphasize these differences when comparing the CONSAVE scenarios to previous scenario studies that have drawn on the IPCC IS92 scenarios set (most notably the IPCC special report on aviation). Note also that there is also no comparable IPCC-SRES or CONSAVE scenario to the low population, low income, scenario IS92c.

	Energy use ZJ		
	2020	2050	2100
Min-Literature	400	400	293
Max-Literature	1400	2360	3350
High Growth			
Unlimited Skies	700	1350	2250
Regulatory Push&Pull	610	1100	1630
Fractured World	600	970	1720
Down to Earth	580	810	510

Table 11: Energy use

Resource scarcity:
Instead of total "call on resources", annual extraction (primary energy supply) is used as indicator of relative resource scarcity in the scenarios as background information. Given the nature of the air-transport industry relying exclusively on oil products, corresponding oil production profiles derived from the IPCC-SRES scenarios are the most pertinent indicators. Two indicators of relative resource scarcity are listed below: Peak of world oil production (as indicator of possible peak in resource scarcity/price volatility) and levels of world oil production relative to the base year of 1990 for the three CONSAVE benchmark years 2020, 2050, and 2100. *Ceteris paribus*, the larger the difference between future scenario values compared to the year 1990, the higher the *potential* stress on resource availability and hence the potential "demand pull" for introduction of alternative aviation fuels (natural gas and hydrogen). After a peak, this indicator as a rule declines as relative resource scarcity is gradually overcome by introduction of alternatives as illustrated in the IPCC-SRES scenarios. For reasons of scenario consistency therefore, it is essential to reflect this in the AERO model scenario quantifications. For instance, it would be entirely inconsistent to assume in a "Down to Earth" scenario for 2050 a continued reliance of aircrafts on conventional oil derived fuels, given that oil supply has peaked and is increasingly falling short of 1990 provision levels (thus assuming that the few remaining oil could be used exclusively by the air transport sector). Instead, assumptions concerning alternative aviation fuels should reflect the pathways of indicators of relative oil resource availability/scarcity as illustrated by the corresponding IPCC-SRES scenarios and as listed below.

Indicator of Relative (Oil) Resource Availability 1
(Peak of world oil production):

"Unlimited Skies": IPCC-SRES A1G (2080)
"Regulatory Push & Pull": SRES A1T (2050)
"Fractured World": IPCC-SRES A2 with modifications (see below) 2020
"Down to Earth": IPCC-SRES B1 (2020)

Indicator of Relative (Oil) Resource Availability 2
(Ratio of global oil production relative to base year 1990 for 2020/2050/2100)

"Unlimited Skies": IPCC-SRES A1G: 1.3/2.2/2.7
"Regulatory Push & Pull": SRES A1T: 1.5/2/0.6
"Fractured World": IPCC-SRES A2 (modified, cf. below): 2.2/1.7/0[6]
"Down to Earth": IPCC-SRES B1: 1.5/1.5-1.8/0.4-0.8[7]

[6] Oil production and use converges to zero by 2100 in this scenario.

For the Fractured World scenario, different assumptions compared to the SRES A2 scenario are required. First, contrary to SRES-A2, the scenario storyline postulates very strong policies towards regional energy self-sufficiency and as substantial decline in international oil trade. Global oil trade could decline in absolute amounts by 2020, and approach zero beyond 2050 in this scenario. As a result, oil dependence varies considerably across the regions beyond 2020, and especially beyond 2050 between low (Europe) to high (Middle East). The corresponding SRES-A2 scenario values do not reflect such a scenario. In order to bring the two different scenarios more in line, the import price for oil in the Fractured World scenario to reflect increasing trade restrictions was substantially increased (see 5.5).

Energy prices, especially oil:

Unless specified otherwise, the unconstrained CONSAVE scenarios largely rely on the scenarios of energy prices as reported in the SRES report. For the aviation constrained scenarios (not treated in IPCC SRES), additional price mark-ups were tested during the quantification process with the AERO-model. Tentative quantifications are given below. (For the final decisions see 5.5.) All values are an index, compared to the average oil price in 1990 (25 $/bbl) and are given for the periods 1990/2020/2050/2100. (Reflecting the global nature of oil trade only international (global) prices were given by IIASA, regionalized values were elaborated during the quantification process for the aviation scenarios.)

"Unlimited Skies": SRES-A1: 1/1.5/2/2.5"
"Regulatory Push&Pull": modified SRES-A1: 1/2/4/6
"Fractured World": suggested values: 1/4/8/16
"Down to Earth": modified SRES-B1: 1/2/4/6 (same prices as in Regulatory Pull, but lower demands due to lifestyle changes)

The qualitative background scenario storylines for "Down to Earth" describe this scenario as one of globally converging lifestyles focusing on resource efficiency and environmental conservation as well as effective governance to address all major environmental problems both domestically as well as internationally. An important difference to the IPCC-SRES-B1 from which a number of quantitative background scenario assumptions have been derived is the fact that "Down to Earth" addresses climate change vigorously and effectively in an internationally concerted effort. Global Climate change is contained and atmospheric CO_2 concentrations are stabilized at 450 ppmv by 2100.

Therefore it was tested in the scenario quantification with the AERO-model how the results are influenced by the introduction of a global carbon tax, that could amount to some 50-100 $/tC by 2020, 250-500 $/tC by 2050, finally rising to 2000 $/tC by 2100[8], and would lead to further energy price increases and act as additional restraint on energy-intensive air transportation.

Quantification of Air Transport Demand

As opposed to the previous IPCC aviation scenarios, the CONSAVE scenarios will employ a variety of functional models linking air transport to overall economic growth, energy prices, etc. in order to appropriately reflect possible new constraints and discontinuities in geopolitics or lifestyles. In the following some first refection how air transport demand might develop in correspondence to the quantification of the background scenarios.

These numbers related to air transport were considered as preliminary as elaborated prior to detailed modeling exercises and served only as a yardstick guide for the subsequent detailed

[7] This range corresponds to the B1-IMAGE (marker) and B1-MESSAGE scenarios respectively. The lower MESSAGE oil use and dependency ratios are suggested are more appropriate for the CONSAVE Down to Earth scenario as the higher B1 marker scenario quantifications of the IMAGE model.
[8] These numbers are derived from model simulations performed within IPCC TAR for a stabilisation at 450 ppmv and using the IPCC-SRES-B1 scenario as reference case.

quantifications with the AERO model, aiming at assisting the adoption of corresponding model input parameter values. Within the WP 3 storylines, numbers and AERO-models results were made consistent by an iterative process.

	Air transport demand Index 1=1990		
	2020	**2050**	**2100**
Min-Literature	2.7	4.2	6.6
Max-Literature	**9.3**	**24.8**	**100**
High Growth			
Unlimited Skies	**5.4**	**25.8**	**95**
Regulatory Push&Pull	**4.4**	**16**	**47.6**
Fractured World	**2.5**	**4**	**8**
Down to Earth	**2.3**	**2**	**0.5**

Table 12: Air transport demand

"Unlimited Skies": Applying IPCC model[9] findings to the (high) GDP growth rates of the "Unlimited Skies" scenario, results in a very high air transport demand scenario highlighting the challenges ahead for the global aviation industry. Equivalent quantifications include for instance the EDF Eeh Scenario discussed in the IPCC Aviation report [3] (even if based on a lower GDP scenario (IS92a).

"Regulatory Push & Pull": The (hypothetical) "unconstrained" demand of this scenario should be the same as in Unlimited Skies above. However, a number of constraints as well as regulatory actions addressing those are likely to dampen the effect on global transport volume. An illustrative scenario quantification would be along the IPCC Fe scenario, implying a lower aggregate GDP-air transport elasticity, or alternatively simply significant impacts from regulation-induced price increases.

"Fractured World": This fragmented scenario assumes an absolute decline in international flights and the second lowest GDP-air transport elasticity of all scenarios considered. The available scenario literature provides no equivalent example, making this scenario quantification highly interesting but also challenging (some tentative regional specific assumptions are suggested below).

The qualitative background scenario storyline for the "Fractured World" postulates the emergence of large, in-wards looking regional blocks that coexist not without conflicts and have comparatively little exchange with each other in terms of people, ideas, and goods. Hence inter-regional trade and travel would be significantly hampered in this "Fractured World". The scenario storyline postulates various barrier divides that characterize these regional blocks, including a North Atlantic, Pacific, Mediterranean, as well as a Himalayan divide within Asia.

The following regional "blocks" were used for the modeling work with the AERO model (including their corresponding IATA regions as used in the model):[10]
NAFT (North America, Central America)
Eurasia (EU, Former Eastern Block)

[9] *IPCC model* refers to the functional model of a globally uniform GDP-air transport elasticity that remains consistently above 1 over the entire scenario time period used in the IPCC Special Report on Aviation.
[10] *NAFT* (derived from the twin definitional characteristics of this region: the NAFTA free trade agreement and the extremely high priority accorded to securing and maintaining crude ***oil*** supply (Naft in Esperanto).
Eurasia (Europe stretching to Sakhalin)
TŌ Goku or 東国 (Land of the East in Japanese and Chinese respectively)
Sub-Himalayas (geographical denomination).

東国 *Tō Goku* (Far East North)
"Sub-Himalayas" (Far East South)

All other regions are to be considered as "periphery" to these 4 major regional blocks, including:
Latin America (South America northern and southern parts)
Africa (Non-aligned Europe, Eastern Africa, Western Africa, Southern Africa)
Middle East
Oceania (Southwest pacific)

For the long-term growth or air transport volumes in Fractured World it was proposed by IIASA to assume that domestic air travel continues to grow roughly along current elasticities to 2020, in order to decline thereafter to about half of that value by 2050 and again by another half by 2100. Illustrative current short term (1992-1998) elasticities for domestic air travel are:

North America: 1; Europe: 2; Asia: 5.

International air travel in this scenario is projected to reach a maximum by 2010 in order to decline precipitously thereafter as a result of regional conflicts and isolationist policies. First, interregional traffic between the "big 4" will be over-proportionally affected, whereas "South-South" travel (e.g. between Africa and Latin America) would remain unaffected. By 2050 and beyond even these international air transport links would weaken, leading to an absolute decline in international air travel globally, compared to present day levels)

"Down to Earth": This scenario of significant lifestyle changes postulates an entire decoupling of air transport from GDP growth (and as such can be considered a novelty in the air transport scenario literature). Up to 2020, a rapidly falling GDP-air transport elasticity could be assumed. Thereafter, it is simply suggested to postulate saturating (and subsequently declining) absolute air transport demands on a per capita basis, leading by 2100 to about half of global air transport, compared to today.
An overview of the implied global air transport demand elasticities of the initial scenario quantifications is outlined below for three periods: 1990-2020, 2020-2050, 2050-2100.[11]

		Period Elasticities	
	1990-2020	**2020-2050**	**2050-2100**
High Growth			
Unlimited Skies	**2.6**	**1.8**	**1.4**
Regulatory Push & Pull	**2.0**	**1.2**	**1.0**
Fractured World	**1.7**	**0.6**	**0.5**
Down to Earth	**0.9**	**-0.1**	**-0.5**

(These starting values proposed by IIASA were eventually modified during the quantification process with he AERO-model, see 5.3.)

[11] Note that in the final model runs, these period average elasticities should be represented/calculated by continuous time trend function. For instance, in the "Unlimited Skies" scenario global air transport/GDP elasticities should approach 1 by 2100 (compared to the 2050-2100 period average of 1.4).

Table 8d gives an overview to which level the different air transport scenarios are influenced by constraints:

	Air transport constraints Index 0=none, Index 5=high		
Min-Literature	**2020** 0	**2050** 0	**2100** 0
Max-Literature	**5**	**5**	**5**
High Growth			
Unlimited Skies	**0**	**0**	**1**
Regulatory Push&Pull	**2**	**3**	**3**
Fractured World	**3**	**4**	**4**
Down to Earth	**3**	**5**	**5**

Table 13: Air transport constraints

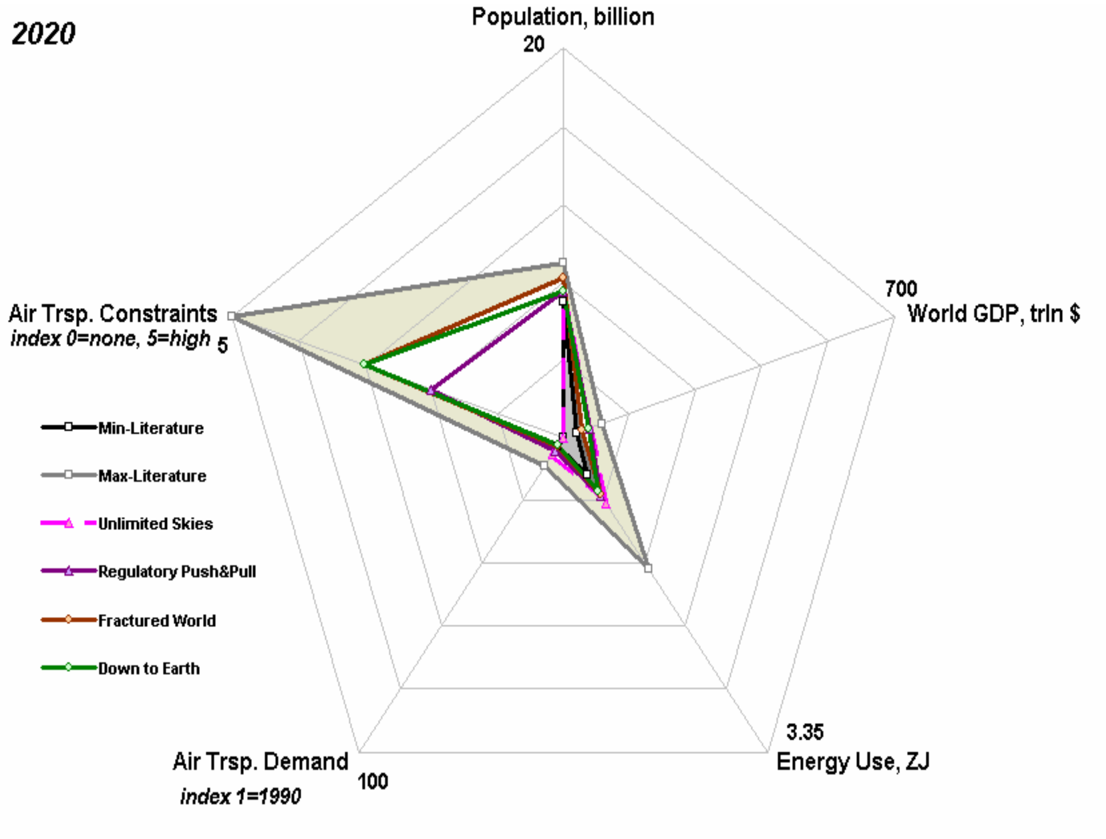
Quantitative Scenario Taxonomy

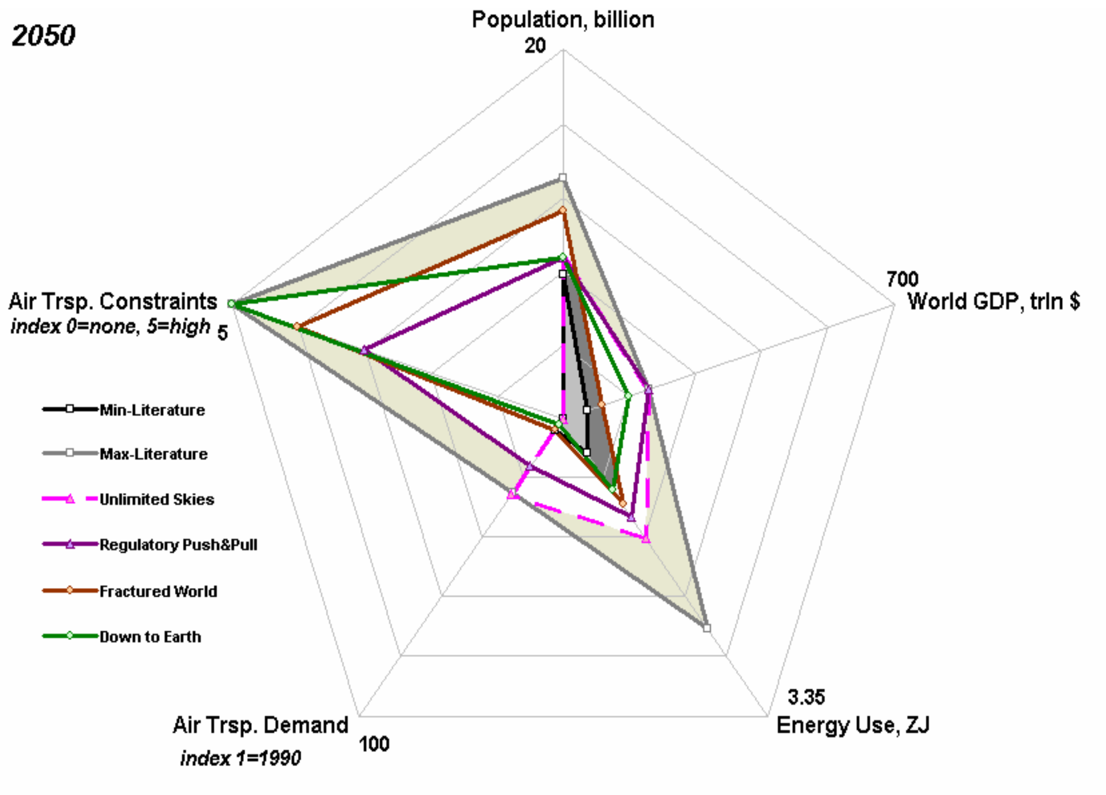
Figure 15 summarizes the quantitative scenario taxonomy. Note that the graphics always represent the entire scenario "space" over the time period 1990 to 2100, which explains the smaller scenario coverage by 2020 and 2050. Areas shaded gray denote global scenario quantifications below or above the respective scenario range available in the literature.

More emphasis has been given in the CONSAVE scenario exercise to explore extremes of boundary conditions for air transport, which explains why no scenarios describing more moderated, "middle of the ground" developments are included. Because of reasons of interdependence of scenario variables and for reasons of scenario economy, the scenario space is therefore not filled at equal intervals or with homogeneous distributions. Equally, given a limited number of scenarios (4) and the focus on aviation, it was not possible to explore the entire uncertainty space in terms of background scenarios available in the literature.[12] Hence, the present scenarios do not span the extremes of high population, high energy demand growth, or of low economic development as indicated in the shaded areas of the scenario snowflake diagrams below (representing the scenario space described by the entirety of the long-term scenario literature that is not covered by the present CONSAVE background scenarios). Nonetheless given the limited number of scenarios and their specific aviation focus, the coverage of uncertainty in terms of scenario background variables is quite satisfactory.

The corresponding CONSAVE background scenarios should therefore turn out to be quite robust *vis-à-vis* major long-term scenario uncertainties of characteristic background scenario variables. The relative higher frequency of low demand and constrained scenarios should not be interpreted as implying higher scenario likelihood, but simply reflects the specific research questions explored within the CONSAVE project as well as the scenario choices made by the CONSAVE team for reasons of scenario economy that put more emphasis on "downside" risks scenarios for the aviation sector in terms of (lower than expected) demand growth or (higher than expected) regulatory constraints.

[12] For instance, the IPCC-SRES report explored 40 scenarios altogether, explaining its wider coverage of the scenario space in terms of background variables.


2020
Population, billion
20
700
World GDP, trln $
3.35
Energy Use, ZJ
Air Trsp. Demand
index 1=1990
100
Air Trsp. Constraints
index 0=none, 5=high
5
Min-Literature
Max-Literature
Unlimited Skies
Regulatory Push&Pull
Fractured World
Down to Earth


2050
Population, billion
20
700
World GDP, trln $
3.35
Energy Use, ZJ
Air Trsp. Demand
index 1=1990
100
Air Trsp. Constraints
index 0=none, 5=high
5
Min-Literature
Max-Literature
Unlimited Skies
Regulatory Push&Pull
Fractured World
Down to Earth

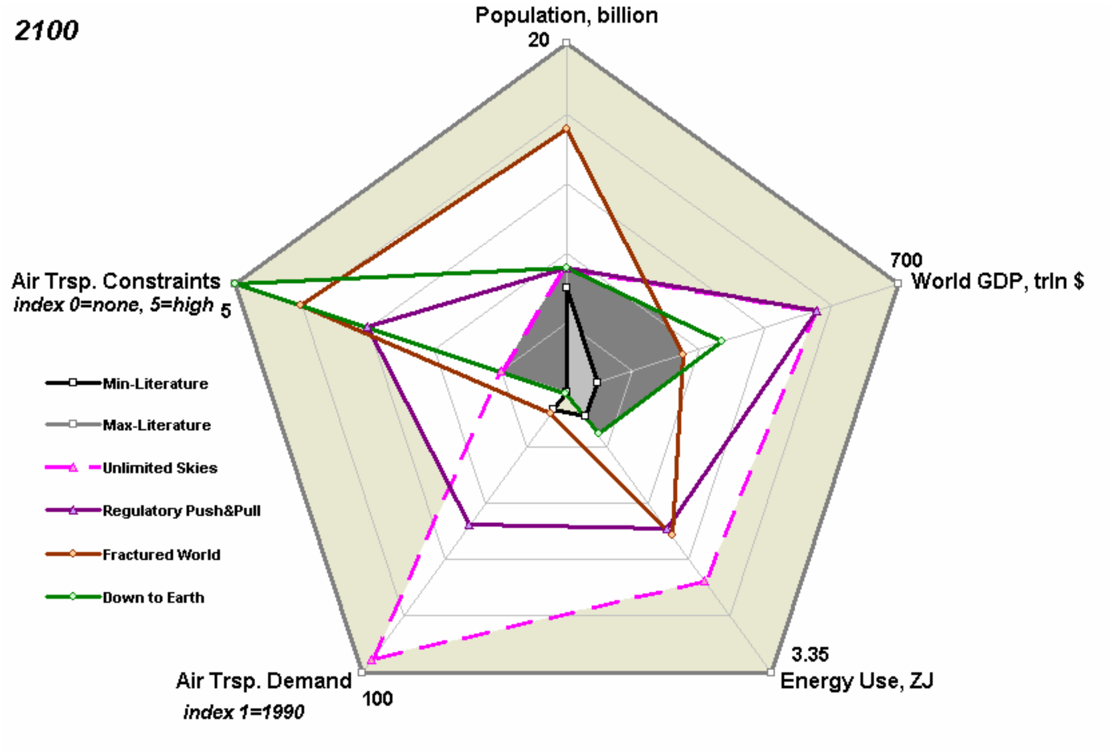


Figure 15: CONSAVE scenario taxonomy

5.7.3 Detailed global and regional data for the decades 1990 – 2100 for population and GDP

The global scenario background values for population and economic growth (GDP expressed both at market exchange rates and at purchasing power parities) were disaggregated into the 14 IATA world regions, used by the AERO model. Values for the decades from 1990 and 2100 are given. The complete tables are given in Annex 3.

These numbers intend to assist in the development of regionally disaggregated scenario input assumptions for the AERO model. These regional disaggregations have been prepared by the sub-contractor IIASA especially for this CONSAVE project based on unpublished data underlying the IPCC-SRES report as well as consulting with various IPCC modelling teams.

The complete description of the work on the quantification of the CONSAVE Background Scenarios (CONSAVE deliverable D7) is documented in Annex 7 of Part II of the report.

5.8 Quantification of CONSAVE Scenarios on aviation and its emissions - Discussion of results and comparisons with other relevant work

5.8.1 Introduction

On the basis of the input assumptions which interpret the characteristics of the four CONSAVE scenarios, quantifications of aviation scenarios were developed with the AERO-model.

The CONSAVE relevant features of the AERO model have been described in chapters (4.2) and (5.5) and documented in detail in Deliverable D9, Appendices A and B.

Combining AERO-model system information and results from other sources, especially from ICAO/CAEP, a harmonized development in aviation and its emissions was developed for the period to 2005, following which the CONSAVE scenarios start to diverge from each other.

For each CONSAVE scenario, complete scorecards of the global values of the most interesting features of the quantification by the AERO-model are given in Annex IV. Discussing not only absolute figures of single scenarios but also the typical differences between the scenarios, the presentation of results starts with a comparison of the different outcomes for the basic versions of the four CONSAVE scenarios for the time horizon years 2020 and 2050. Effects of alternative sub-scenarios and scenario specific tests for the scenarios are described in chapter 5.8.3. Finally an outlook to the time horizon year 2100 is undertaken, combining the available information to develop for all scenarios a rough estimate for the further development of global air transport demand in the second half of the century. Further details of the quantified results from the AERO-model are reported in Deliverable D9 (see Part II, ANNEX 9).

5.8.2 Comparison of the results for the four CONSAVE Scenarios

Quantification results for the four scenarios (basic versions) are presented and discussed for the following categories:

- Air traffic demand
- Movements and fleet
- Fuel consumption, global emissions
- Local air quality around airports and noise
- Cost effects on airlines
- Effects on airports

<u>Air traffic demand</u>

The results for the demand for air transport are especially important, because demand is the main influencing parameter for many other quantified outcomes.

Global passenger demand

The scenario-dependant developments of passenger kilometers and number of passengers have been calculated.

Table 14 and Figure 16 show the quantified results for each scenario from 2005 until 2050 plus the historical passenger demand growth (in terms of pax-km) from 1970 until 2000 and predictions for 2005 (which are in line with the respective forecast from ICAO/FESG [25]). Annual growth rates and total growth (as a multiple of 2000) are also shown for each scenario.

The significant differences in air transport demand between the four scenarios are in line with what could be expected on the base of the storylines. While in scenario DtE demand is nearly stagnating over the whole period until 2050 because of the assumed customer behaviour, FW shows a slow increase after 2020, mainly driven by intra-continental flights. Demand in ULS develops with similar rates as in history while in RPP, dampening effects of regulations take place. The values for ULS might be regarded as high when considering actual European capacity problems, but the increase in trips per capita (shown in figure 17) is quite moderate, also reflecting the assumed effect of saturation of the air transport market until 2050.

Billion pax-km pa	1970	1975	1980	1985	1990	1995	2000	2005	2020	2050
History	551	836	1250	1573	2182	2567	3308	4091		
ULS								4091	6505	21185
RPP								4091	5284	14636
FW								4091	4157	6990
DtE								4091	3920	4164

Table 14: World passenger demand 1970-2050 in billion pax-km p.a.

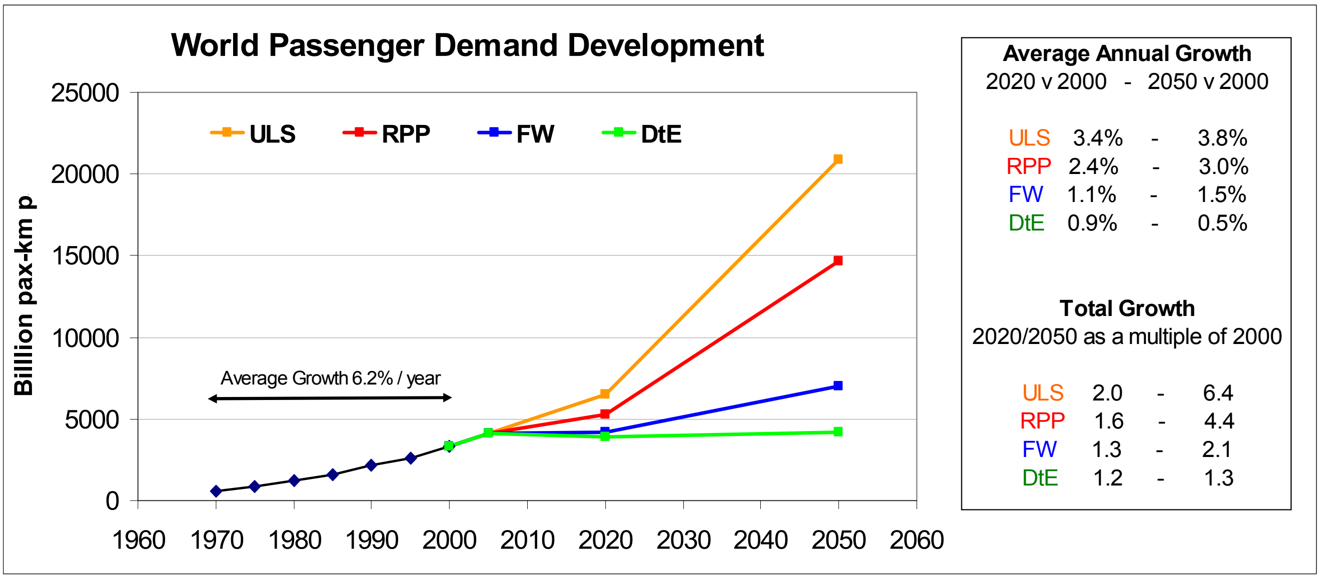


Figure 16: World passenger demand 1970-2050 in billion pax-km p.a.

Saturation of demand for air transport (see chapter 5.5) is the observation that the number of trips per capita increases less for a given GDP/capita increase as markets start to become mature at high levels of demand. The level of this effect is part of the travelling behaviour included in the storylines and estimated from the scenario features. Because of the constrained nature of the CONSAVE scenarios, the saturation is considered to be generally low. But to some extent the effect will affect all scenarios, being most relevant for the Unlimited Skies scenario with the highest level of demand.

For the purpose of this study, saturation dampening of air transport is estimated to be ca. 15% in (the AERO-model base) year 1992 for business and leisure travel for the North American market. For cargo, no saturation is assumed. For the purpose of a sensitivity analysis, the saturation level of the trips per capita for the North American region were set at 0% and 30% and the Unlimited Skies scenario processed for 2050. The results of the respective test calculations are shown in figure 17.

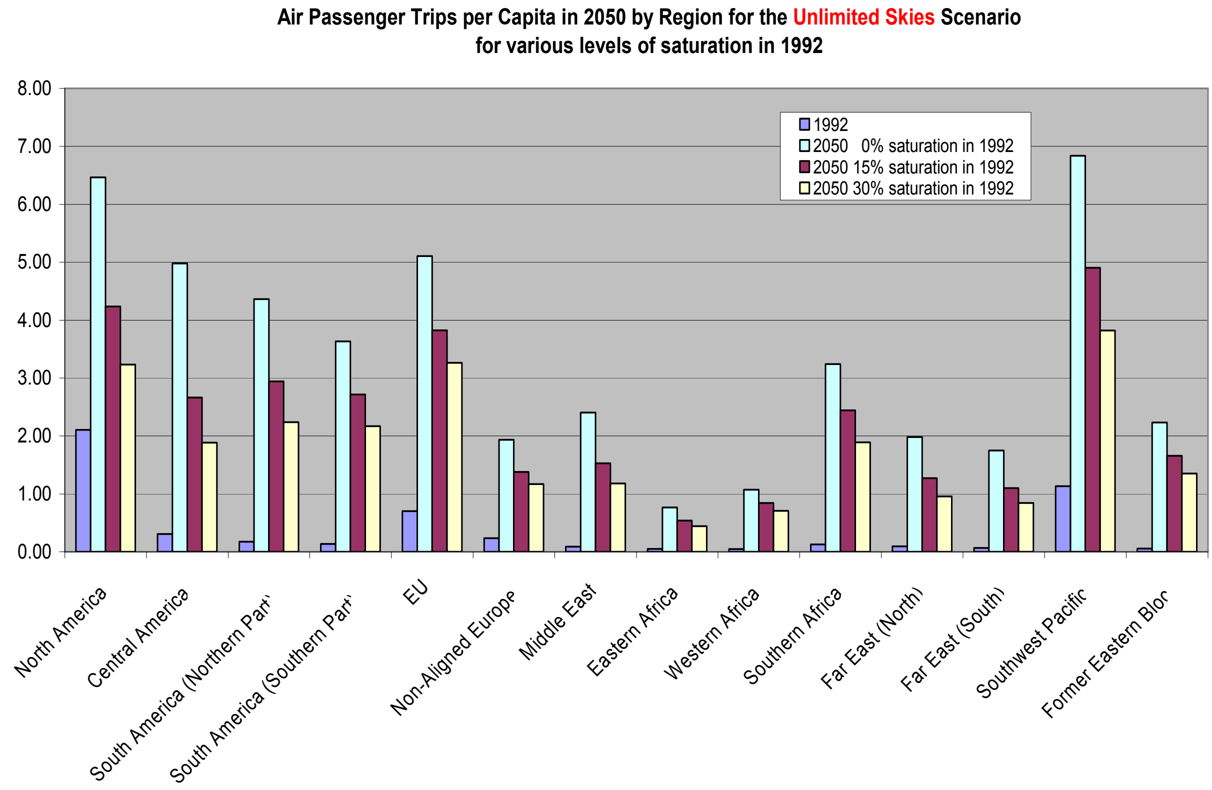


Figure 17: Trips per capita in 2050 for IATA regions for scenario ULS and for various levels of saturation

Table 15 and figure 18 show a comparison of CONSAVE quantification results with outcomes from FESG scenarios [31] and forecasts from ICAO [26], Airbus [29] and Boeing [30]. The differences between the high growth scenario results are significant for 2020, but relatively low for 2050, indicating, that the assumed constraints can be overcome in the long run.

billion pax-km pa	2000	2005	2015	2020	2050
ULS	3308	4091	5573	6505	21185
RPP	3308	4091	4852	5284	14636
FW	3308	4091	4135	4157	6990
DtE	3308	4091	3976	3920	4164
FESG 1999 Fa				6553	13934
FESG 1999 Fc				5071	7817
FESG 1999 Fe				8302	21978
FESG 2003				7050	
ICAO 2004			5120		
Airbus 2003				7619	
Boeing 2004				7739	

Table 15: Comparison of passenger demand with forecasts from ICAO, Airbus, Boeing and FESG

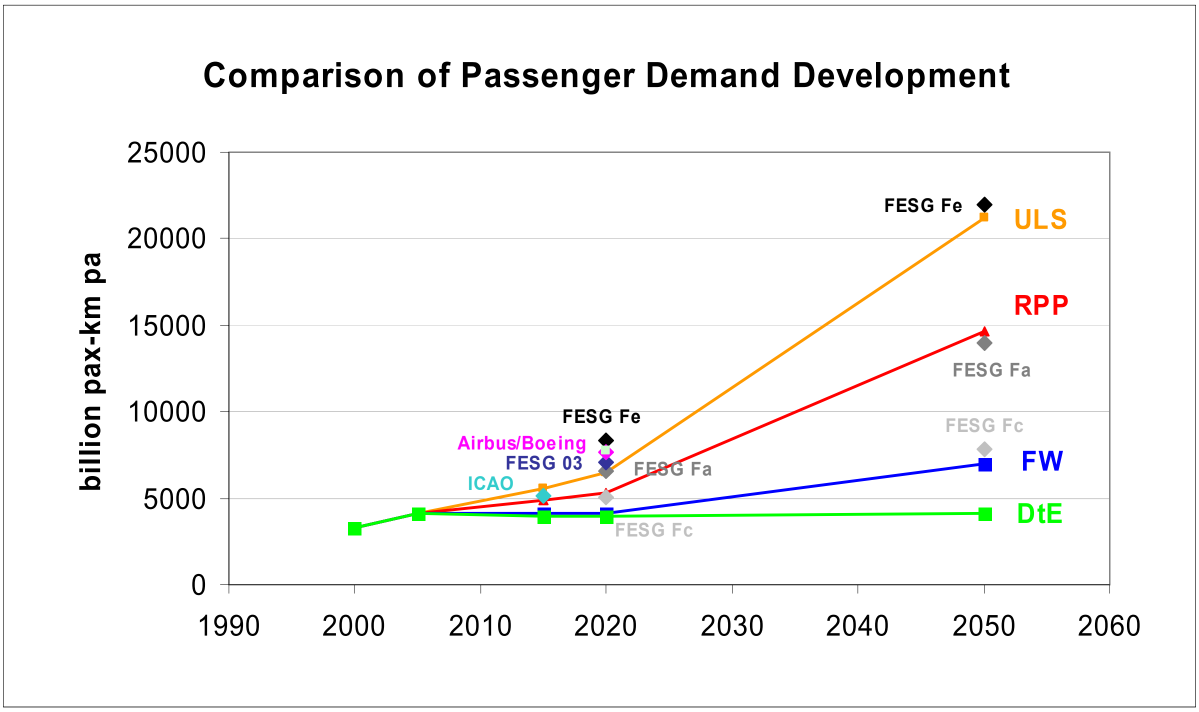


Figure 18: Comparison of passenger demand with results from ICAO, Airbus, Boeing and FESG

Although AERO2k [28] does not report pax-kilometres, a comparison with forecast results of this study is possible on the basis of aircraft kilometres. Table 16 and figure 19 show the results, with AERO2k values for 2025 being in the middle of the range for the four CONSAVE scenarios.

Billion ac-km p.a.	2000	2002	2005	2020	2025*	2050
ULS	31	34	38	61	84	202
RPP	31	34	38	51	65	139
FW	31	34	38	44	50	77
DtE	31	34	38	38	38	41

* The values for the CONSAVE scenarios for the year 2025 are approximated from (linear) interpolation (see figure 19)

Table 16: Annual global aircraft kilometres

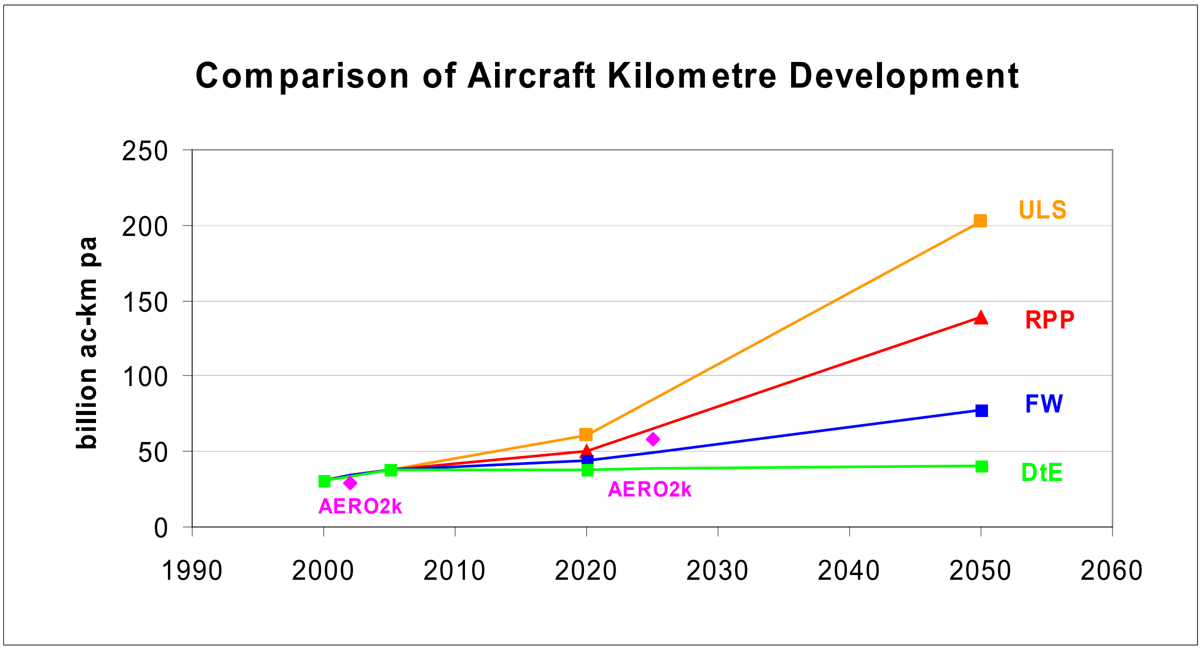


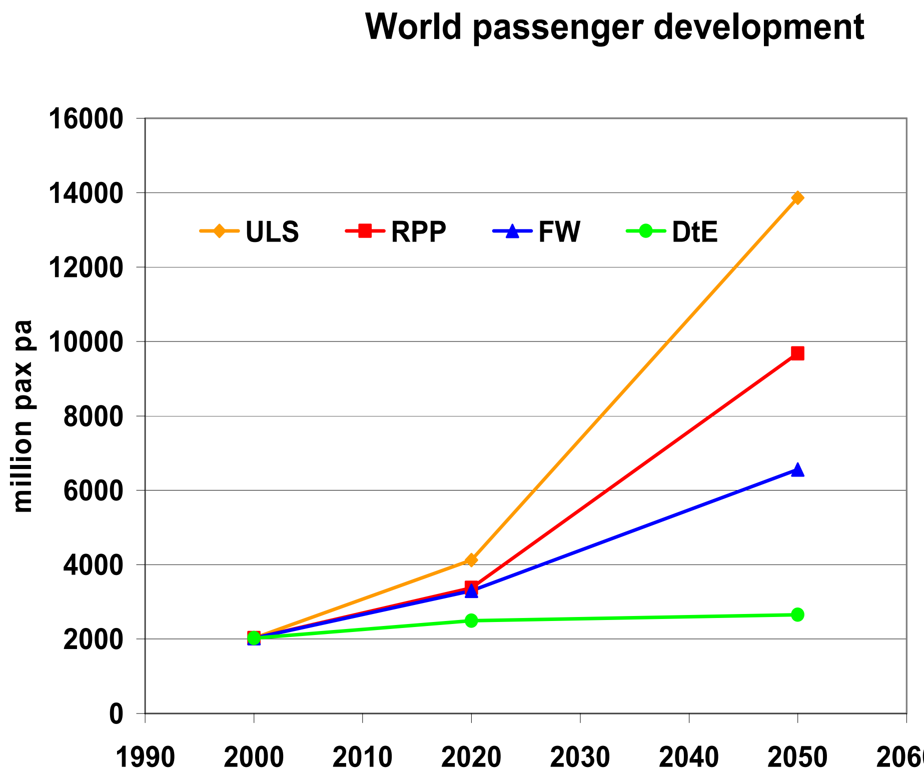
Figure 19: Comparison of aircraft kilometre with results from AERO2k

Table 17 und figure 20 show for each scenario the quantified results for the total passenger volume plus related annual growth rates and total growth factors (as a multiple of 2000).

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

Table 17: Annual global numbers of passengers



Average annual growth		
	2000-2020	2000-2050
ULS	3.6%	3.9%
RPP	2.6%	3.2%
FW	2.5%	2.4%
DtE	1.0%	0.5%
Growth factor		
2020/2050 as a multiple of 2000		
	2020/2000	2050/2000
ULS	2.0	6.9
RPP	1.7	4.8
FW	1.6	3.2
DtE	1.2	1.3

Figure 20: World passenger demand in the four scenarios

Regional air transport demand– traffic flow for major route groups

The traffic flow for the major route groups (in billion pax-km), absolute values and the respective annual growth rates and growth factors are given in the tables 18-20 and figure 21 and 22. Both, scheduled passenger traffic and Charter are included in the figures given.

In considering the regional results and for plausibility checks one has to keep in mind (among others), that:

- the passenger growth in each region is mainly a function of the respective GDP/per capita, population and elasticities (where the scenario-specific values for regional GDP and population are directly taken from IPCC/SRES, to be consistent – following the concept of CONSAVE - with this globally accepted work),
- even if growth rates might be high/low compared to average, resulting absolute values can be still significantly lower/higher than average,
- regions can be very inhomogeneous with respect to the future growth in air transport for the various countries belonging to the region. E.g. Far East North comprises both Japan with an already comparably mature market and presumably moderate growth and China with an expected high further development of demand (but starting from presently low pax-km volumes).
- Large distances between mayor cities of a region or to external cities, caused foe example by large or extended territories and as a consequence of a comparably peripheral location on the globe (both the case for example for South America) are combined with a high potential for air transport demand.

PASSENGER-KM BY MAJOR ROUTE GROUPS		ULS		RPP	RPP-noH2	RPP-H2	FW		DtE	
[billion pax-km pa]	**2000**	**2020**	**2050**	**2020**	**2050**	**2050**	**2020**	**2050**	**2020**	**2050**
Intra North America	782	1.144	1958	950	1.317	1.214	778	1.110	829	750
Intra Europe	424	637	1296	547	915	850	454	576	493	438
North America – Europe	407	559	1008	463	657	632	349	319	412	353
Intra Asia	355	1.032	4614	825	3.288	3.116	1.077	1.444	470	566
North America – Asia	161	250	471	198	323	311	104	115	165	150
Europe – Asia	208	438	1526	343	1.024	992	135	224	223	239
North America to Central & South America	154	413	949	326	621	596	235	200	224	238
Europe - Middle East	101	154	495	121	330	310	86	94	100	112
Europe – Africa	55	91	678	76	446	434	80	115	62	87
Europe – Other	124	289	855	233	603	584	119	191	156	177
Intra Central & South America	94	426	1438	347	1.058	1.004	217	1.097	196	257
North America – Other	72	116	275	92	177	169	65	63	80	75
Intra Middle East	31	84	551	67	376	339	71	227	50	87
Middle East - Far East	78	225	1288	174	864	825	64	123	105	158
Intra Africa	17	48	1036	41	696	664	52	384	30	67
Far East - Southwest Pacific	103	212	602	167	431	410	66	106	121	129
Intra Southwest Pacific	56	87	167	71	119	104	61	100	66	58
Intra Former Eastern Block	21	86	526	71	369	352	48	239	34	45
Far East - Former Eastern Block	34	120	649	97	452	437	48	156	51	62
All Other	32	94	802	77	564	544	48	107	52	86
Total	**3308**	**6505**	**21185**	**5284**	**14630**	**13886**	**4157**	**6990**	**3920**	**4136**

Table 18: Traffic flow for major route groups in billion pax-km p.a.

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; in the high growth scenarios due the fact that both markets have a high level of saturation level in 2050. In the Fractured World the Intra Middle East market will comparably strong due the fact that there will be enough oil available to keep the ticket prices low. In the DtE scenario the increases in air transport are for all route groups low; the traffic flow within North America, for North America – Asia and for North America - Europe will even be reduced, caused by the change in mobility patterns which will influence especially markets with presently high levels of air transport. With respect to major corridors, within ULS and RPP air traffic Europe - Asia, and Middle East - Asia will grow with the highest absolute numbers (+ 1.3 trillion pax-km and + 1.2 trillion pax-km respectively in ULS, + 0.8 trillion pax-km and + 0.8 trillion pax-km, respectively for RPP (kerosene fleet). Air transport between Europe and Africa increases as with high absolute values, whereas the increase of the already quite mature markets North America – Europe and North America to Asia will be comparably low, which is valid also for the demand for air transport from North America to the other regions.

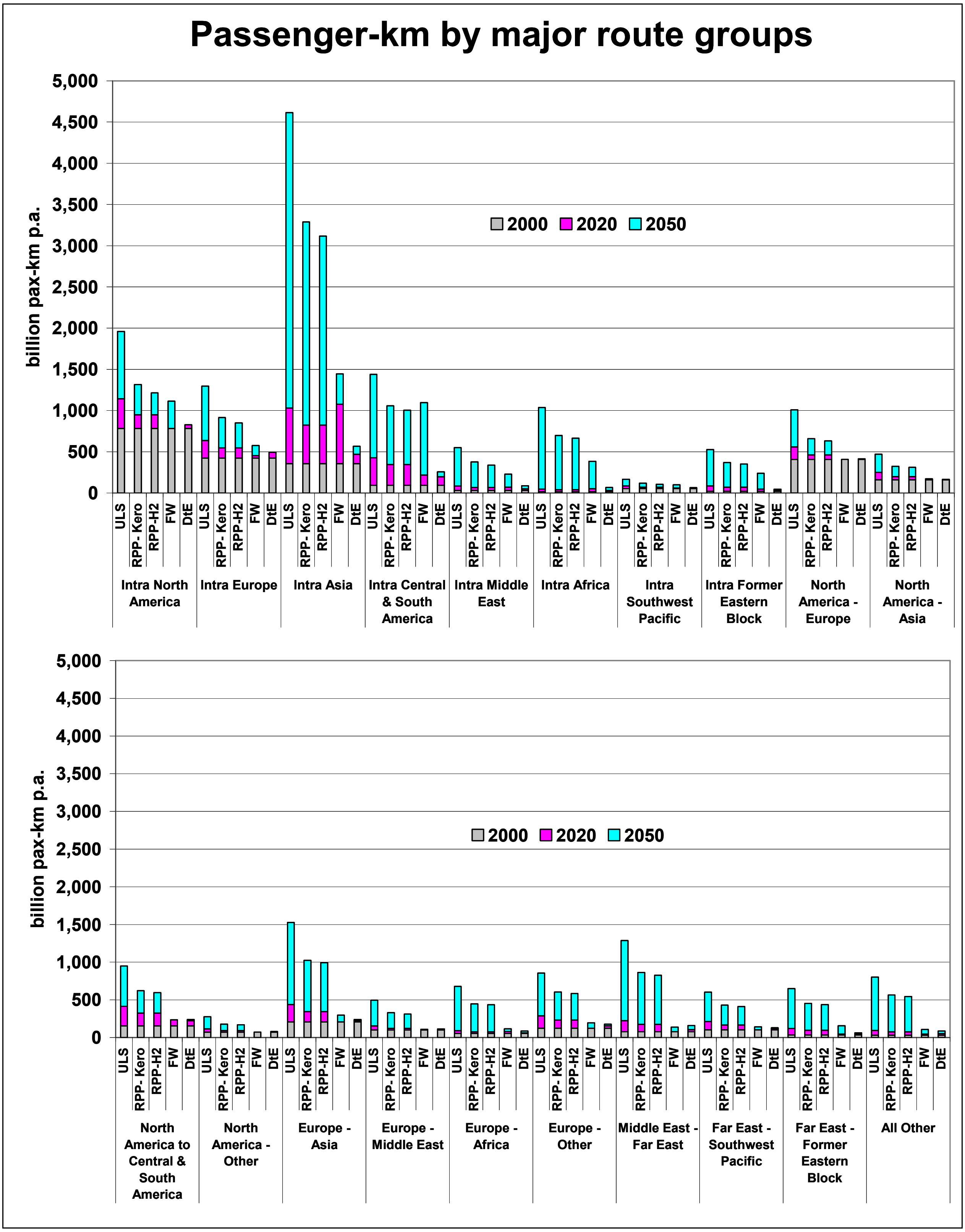


Figure 21: Traffic flow for major route groups in billion pax-km p.a.

PASSENGER-KM BY MAJOR ROUTE GROUPS Annual Growth Rates 2000-2050	ULS	RPP-noH2	RPP-H2	FW	DtE
Intra North America	1.9%	1.0%	0.9%	0.7%	-0.1%
Intra Europe	2.3%	1.5%	1.4%	0.6%	0.1%
North America – Europe	1.8%	1.0%	0.9%	-0.5%	-0.3%
Intra Asia	5.3%	4.6%	4.4%	2.8%	0.9%
North America – Asia	2.2%	1.4%	1.3%	-0.7%	-0.1%
Europe – Asia	4.1%	3.2%	3.2%	0.2%	0.3%
North America to Central & South America	3.7%	2.8%	2.7%	0.5%	0.9%
Europe - Middle East	3.2%	2.4%	2.3%	-0.1%	0.2%
Europe – Africa	5.2%	4.3%	4.2%	1.5%	0.9%
Europe – Other	3.9%	3.2%	3.2%	0.9%	0.7%
Intra Central & South America	5.6%	5.0%	4.8%	5.0%	2.0%
North America – Other	2.7%	1.8%	1.7%	-0.3%	0.1%
Intra Middle East	5.9%	5.1%	4.9%	4.1%	2.1%
Middle East - Far East	5.8%	4.9%	4.8%	0.9%	1.4%
Intra Africa	8.6%	7.7%	7.6%	6.5%	2.8%
Far East - Southwest Pacific	3.6%	2.9%	2.8%	0.0%	0.4%
Intra Southwest Pacific	2.2%	1.5%	1.2%	1.2%	0.1%
Intra Former Eastern Block	6.7%	5.9%	5.8%	5.0%	1.6%
Far East - Former Eastern Block	6.1%	5.3%	5.2%	3.1%	1.2%
All Other	6.7%	5.9%	5.9%	2.5%	2.0%

Table 19: Traffic flow for major route groups - Annual Growth Rates 2000-2050

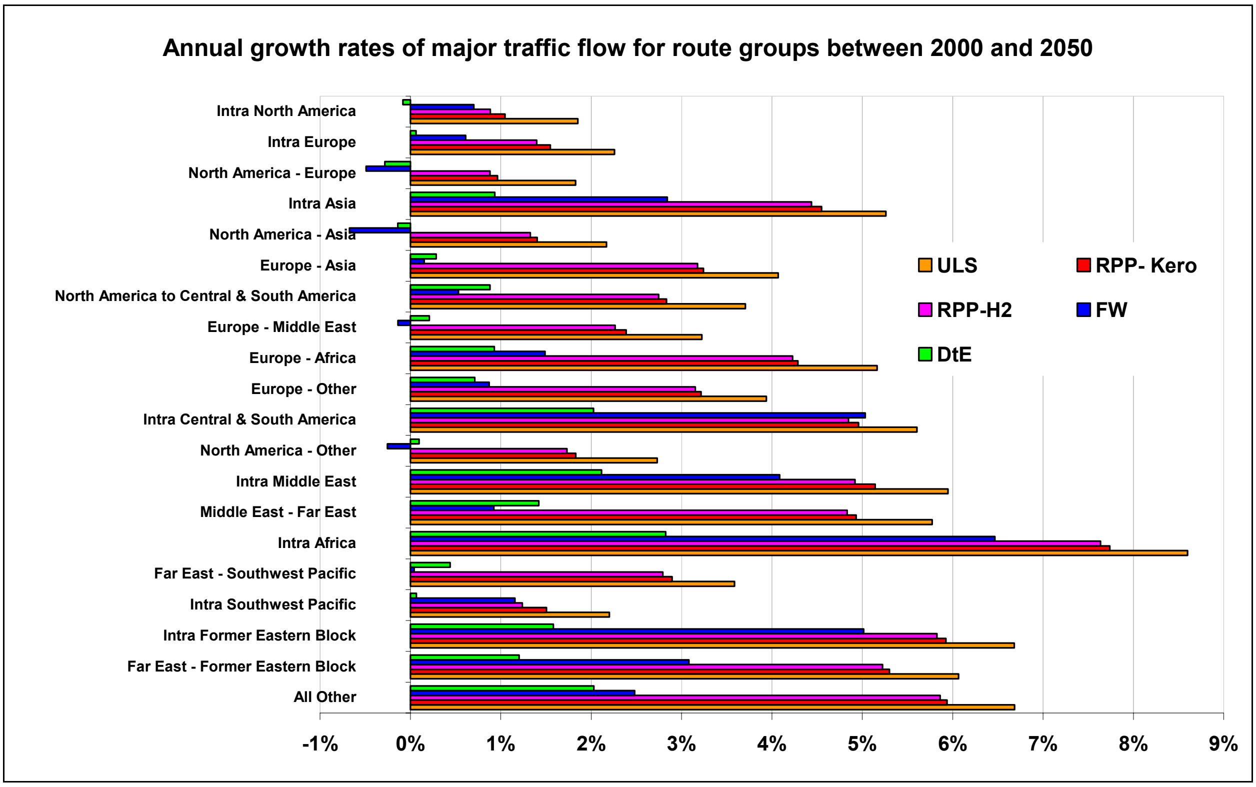


Figure 22: Annual growth rates of traffic flow for route groups between 2000 and 2050

PASSENGER-KM BY MAJOR ROUTE GROUPS	ULS		RPP	RPP-noH2	RPP-H2	FW		DtE	
Growth Factors relating to 2000	**2020**	**2050**	**2020**	**2050**	**2050**	**2020**	**2050**	**2020**	**2050**
Intra North America	1.5	2.5	1.2	1.7	1.6	1.0	1.4	1.1	0.96
Intra Europe	1.5	3.1	1.3	2.2	2.0	1.1	1.4	1.2	1.0
North America – Europe	1.4	2.5	1.1	1.6	1.6	0.9	0.8	1.0	0.87
Intra Asia	2.9	13.0	2.3	9.3	8.8	3.0	4.1	1.3	1.6
North America – Asia	1.6	2.9	1.2	2.0	1.9	0.6	0.7	1.0	0.93
Europe – Asia	2.1	7.3	1.7	4.9	4.8	0.6	1.1	1.1	1.2
North America to Central & South America	2.7	6.2	2.1	4.0	3.9	1.5	1.3	1.5	1.6
Europe - Middle East	1.5	4.9	1.2	3.3	3.1	0.8	0.9	1.0	1.1
Europe – Africa	1.7	12.4	1.4	8.2	7.9	1.5	2.1	1.1	1.6
Europe – Other	2.3	6.9	1.9	4.9	4.7	1.0	1.5	1.3	1.4
Intra Central & South America	4.5	15.3	3.7	11.2	10.7	2.3	11.6	2.1	2.7
North America – Other	1.6	3.8	1.3	2.5	2.4	0.9	0.9	1.1	1.0
Intra Middle East	2.7	18.0	2.2	12.3	11.0	2.3	7.4	1.6	2.8
Middle East - Far East	2.9	16.5	2.2	11.1	10.6	0.8	1.6	1.4	2.0
Intra Africa	2.8	61.8	2.4	41.6	39.6	3.1	22.9	1.8	4.0
Far East - Southwest Pacific	2.0	5.8	1.6	4.2	4.0	0.6	1.0	1.2	1.2
Intra Southwest Pacific	1.5	3.0	1.3	2.1	1.9	1.1	1.8	1.2	1.0
Intra Former Eastern Block	4.2	25.4	3.4	17.8	17.0	2.3	11.5	1.7	2.2
Far East - Former Eastern Block	3.5	19.0	2.8	13.2	12.8	1.4	4.6	1.5	1.8
All Other	3.0	25.4	2.4	17.9	17.3	1.5	3.4	1.6	2.7

Table 20: Traffic flow for major route groups – Growth Factors

The growth factors differ significantly within the scenarios and the regions, dependant from the combinations of reasons mentioned above. Intra Africa, as a so far underdeveloped market, shows the highest growth factor (F) in all scenarios (F= 62, 42, 23, and 4, respectively for ULS; RPP; FW; and DtE). In contrast, Intra North America, the Intra Europe, and the Intra South Pacific market will have the lowest growth factors: They all will reach a high level of saturation.

Regional air transport demand – passenger volume in the IATA regions

In the following tables 21-23 and figures 23-25 the development of the demand for passenger air transport within the 14 IATA regions, used in the AERO-model, is presented, covering the complementary aspects: absolute values, average annual growth rates, growth factors, and per capita figures.

The absolute numbers for regional demand for air transport are given in table 21 and figure 23.

Within the high growth scenarios ULS and RPP, in the time period to 2050, the by far highest increase in absolute numbers can be regarded for the region Far East-South (+ 2.95 billion pax and + 2.01 billion pax, respectively) and Far East-North (+ 1.67 billion pax and + 1.17 billion pax, respectively). The already mature markets North America (+ 1.07 billion pax and 0.46 billion pax, respectively) and EU (+ 1.02 billion pax and + 0.53 billion pax, respectively) have lost their dominant positions. Comparably low are the increases until 2050 in Southwest Pacific and Africa.

Within the Fractured World, Far East would still grow remarkably but with much lower absolute values. However, in this scenario Central and South America (both parts) have about the same absolute increase as Far East – North (ca. + 0.5 billon pax each), mainly caused by a high increase in population and comparably long average flight distances within these regions. In DtE, the change in air travel behaviour results in most regions in either an only small increase in absolute numbers or even in a decrease compared to 2000 (as for North America and EU).

		ULS		RPP		FW		DtE	
Million pax pa	**2000**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
North America	735	1069	1806	888	1194	763	1128	777	709
Central America	91	286	664	227	487	148	648	146	165
South America (Northern Part)	31	150	539	124	403	79	531	69	96
South America (Southern Part)	51	239	876	195	642	126	554	110	144
EU	438	662	1440	556	971	463	583	488	424
Non-Aligned Europe	78	124	333	106	241	96	177	97	112
Middle East	68	167	982	132	663	122	338	97	152
Eastern Africa	8	21	277	18	191	21	126	14	29
Western Africa	10	27	679	23	443	29	290	17	40
Southern Africa	7	16	318	14	219	21	97	11	19
Far East (North)	214	535	1881	431	1386	497	752	288	302
Far East (South)	184	586	3134	467	2190	793	931	240	316
Southwest Pacific	73	115	230	94	163	78	127	85	76
Former Eastern Bloc	35	121	702	99	487	66	272	53	68
Total	**2023**	**4121**	**13861**	**3375**	**9680**	**3301**	**6555**	**2492**	**2651**

Table 21: Passenger demand for IATA regions

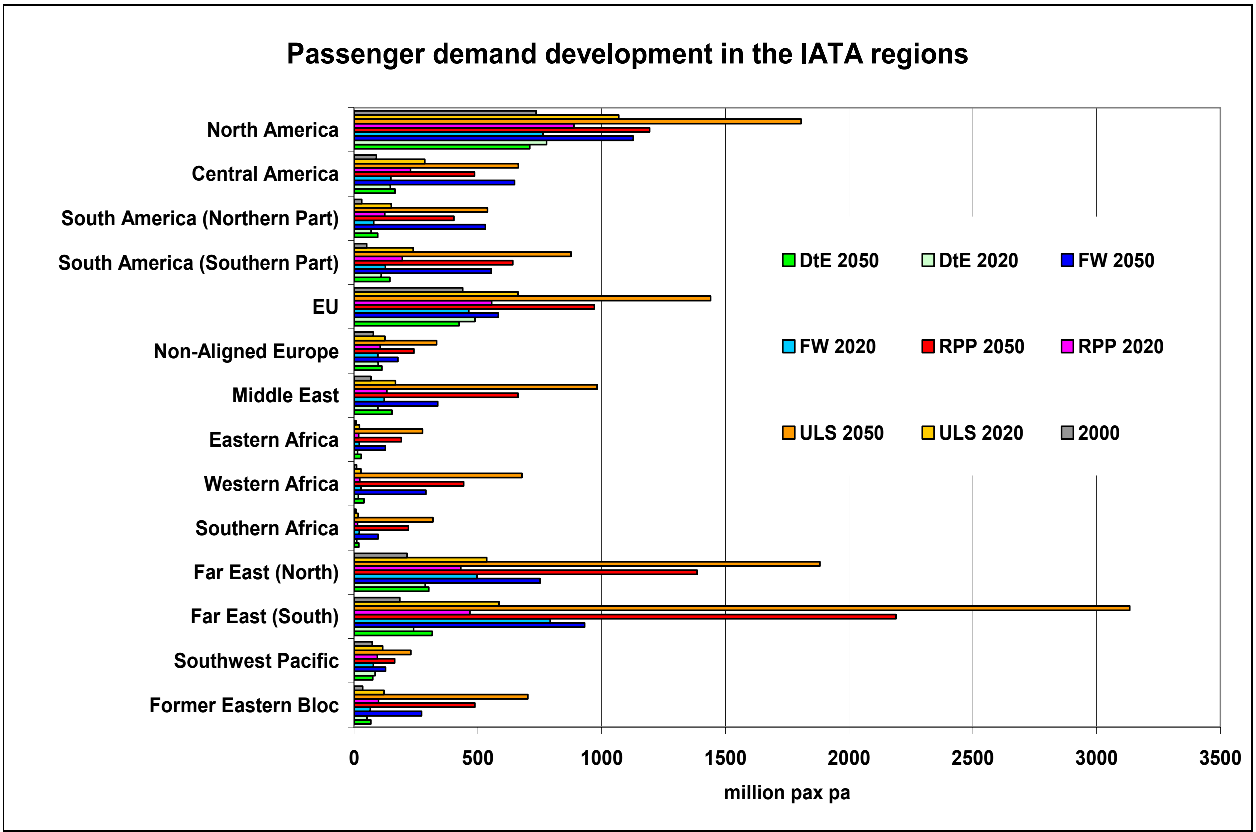


Figure 23: Development of the demand for air transport between 2000 and 2050 within the 14 IATA-regions

Table 22 shows the annual average growth of passenger demand for the different IATA regions, ranked by the maximum growth per region and time in ULS.

IATA regions:	Annual growth of passenger demand			
2000-2020	ULS	RPP	FW	DtE
North America	1.9%	0.9%	0.2%	0.3%
Central America	5.9%	4.7%	2.5%	2.4%
South America (Northern Part)	8.3%	7.2%	4.8%	4.1%
South America (Southern Part)	8.0%	6.9%	4.6%	3.9%
EU	2.1%	1.2%	0.3%	0.5%
Non-Aligned Europe	2.4%	1.5%	1.0%	1.1%
Middle East	4.6%	3.4%	3.0%	1.8%
Eastern Africa	5.4%	4.5%	5.2%	3.1%
Western Africa	5.3%	4.5%	5.6%	2.9%
Southern Africa	4.1%	3.2%	5.3%	1.8%
Far East (North)	4.7%	3.6%	4.3%	1.5%
Far East (South)	6.0%	4.8%	7.6%	1.3%
Southwest Pacific	2.3%	1.3%	0.4%	0.8%
Former Eastern Bloc	6.4%	5.3%	3.2%	2.0%
2020-2050				
North America	1.8%	1.0%	1.3%	-0.3%
Central America	2.8%	2.6%	5.0%	0.4%
South America (Northern Part)	4.3%	4.0%	6.6%	1.1%
South America (Southern Part)	4.4%	4.0%	5.1%	0.9%
EU	2.6%	1.9%	0.8%	-0.5%
Non-Aligned Europe	3.3%	2.8%	2.1%	0.5%
Middle East	6.1%	5.5%	3.5%	1.5%
Eastern Africa	8.9%	8.1%	6.2%	2.5%
Western Africa	11.3%	10.3%	8.0%	2.8%
Southern Africa	10.4%	9.6%	5.3%	1.9%
Far East (North)	4.3%	4.0%	1.4%	0.2%
Far East (South)	5.7%	5.3%	0.5%	0.9%
Southwest Pacific	2.3%	1.9%	1.6%	-0.4%
Former Eastern Bloc	6.0%	5.5%	4.9%	0.8%
2000-2050				
North America	1.8%	1.0%	0.9%	-0.1%
Central America	4.1%	3.4%	4.0%	1.2%
South America (Northern Part)	5.9%	5.3%	5.9%	2.3%
South America (Southern Part)	5.9%	5.2%	4.9%	2.1%
EU	2.4%	1.6%	0.6%	-0.1%
Non-Aligned Europe	2.9%	2.3%	1.6%	0.7%
Middle East	5.5%	4.7%	3.3%	1.6%
Eastern Africa	7.5%	6.7%	5.8%	2.7%
Western Africa	8.9%	8.0%	7.0%	2.9%
Southern Africa	7.8%	7.0%	5.3%	1.9%
Far East (North)	4.4%	3.8%	2.5%	0.7%
Far East (South)	5.8%	5.1%	3.3%	1.1%
Southwest Pacific	2.3%	1.6%	1.1%	0.1%
Former Eastern Bloc	6.2%	5.4%	4.2%	1.3%

Table 22: Annual average growth of passenger demand for IATA regions (for 2000-2020-2050)

Regional growth rates for passenger demand between 2000 and 2050 are quite different, depending on the scenarios and the various regions, with a range from -0.1% up to about 9%.

Table 23 and Figure 24 are showing the total growth factors of passenger demand for the different IATA regions for the period from 2000 to 2050 for each scenario, ranked by the maximum growth per region in ULS. Figure 25 shows the same information on a world map.

Highest growth factors for air transport demand are to be expected in those regions in which the strongest GDP growth has been assumed (and where population will grow with high rates).

Total growth in passenger demand (2050 as a multiple of 2000)	**ULS**	**RPP**	**FW**	**DtE**
North America	2.5	1.6	1.5	1.0
Central America	7.3	5.4	7.1	1.8
South America (Northern Part)	17.5	13.1	17.3	3.1
South America (Southern Part)	17.2	12.6	10.9	2.8
EU	3.3	2.2	1.3	1.0
Non-Aligned Europe	4.3	3.1	2.3	1.4
Middle East	14.5	9.7	5.0	2.2
Eastern Africa	36.9	25.4	16.8	3.8
Western Africa	70.3	45.9	30.0	4.1
Southern Africa	42.8	29.5	13.1	2.5
Far East (North)	8.8	6.5	3.5	1.4
Far East (South)	17.0	11.9	5.1	1.7
Southwest Pacific	3.2	2.2	1.7	1.0
Former Eastern Bloc	20.0	13.9	7.7	1.9

Table 23: Growth factors of regional passenger demand for 2050 relative to 2000

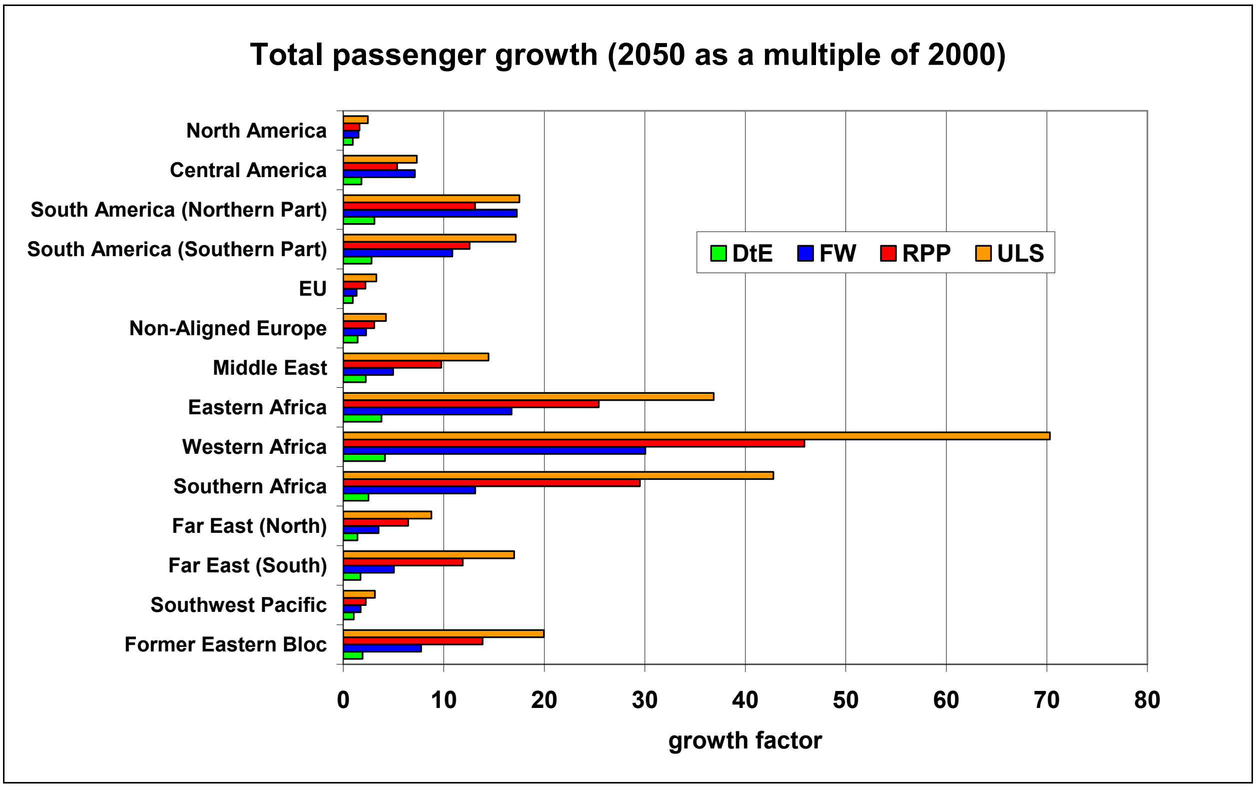


Figure 24: Growth factors of regional passenger demand for 2050 relative to 2000

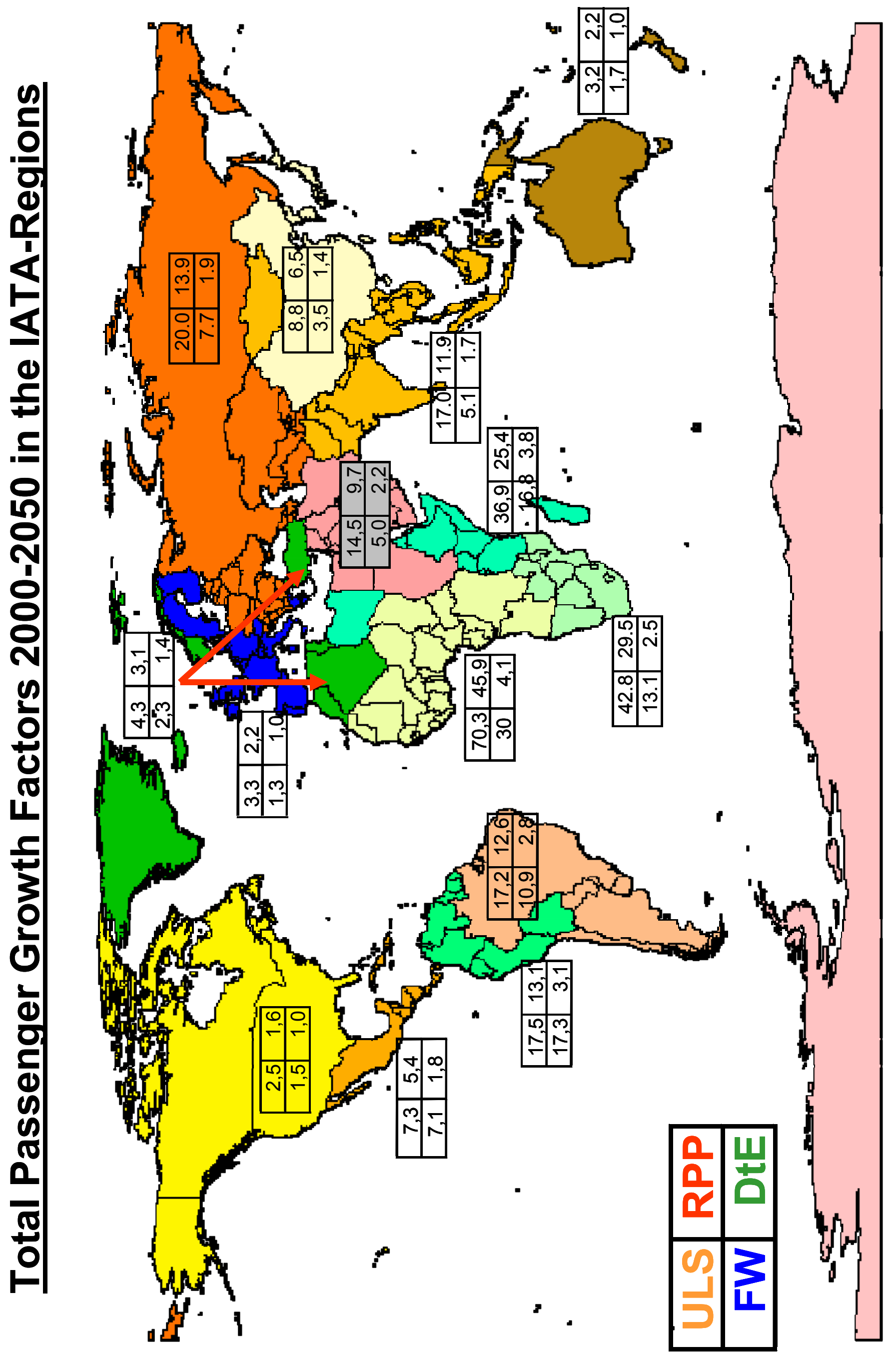


Figure 25: Growth factors of passenger demand 2000-2050 in the IATA-regions

Tables 24/25 and figures 26/27 are showing another aspect of the demand for air transport: the passenger trips per capita for the different IATA regions in 2020/2050, ranked by maximum growth per region in ULS.

The count for the trips per capita is actually based on the number of flights made per passenger. It does not compensate for passengers travelling through a hub: Travelling from A to B through hub C counts for two flights. As a consequence, for the regions with a relatively high passenger transfer rates (dense hub and spoke systems) the trips per capita grow at a higher rate with GDP per capita.

Air Passenger Trips per capita 2020 by region	ULS	RPP	FW	DtE
Southwest Pacific	3.04	2.46	1.96	2.24
North America	2.94	2.45	2.05	2.14
EU	1.71	1.44	1.19	1.26
Central America	1.32	1.05	0.61	0.67
South America (Northern Part)	0.99	0.81	0.46	0.45
South America (Southern Part)	0.83	0.68	0.39	0.38
Non-Aligned Europe	0.63	0.54	0.45	0.49
Middle East	0.38	0.30	0.25	0.22
Far East (North)	0.33	0.27	0.27	0.18
Former Eastern Bloc	0.28	0.23	0.14	0.12
Far East (South)	0.24	0.19	0.30	0.10
Southern Africa	0.14	0.12	0.17	0.09
Eastern Africa	0.06	0.05	0.06	0.04
Western Africa	0.05	0.04	0.05	0.03

Table 24: Passenger trips per capita in 2020 for IATA regions

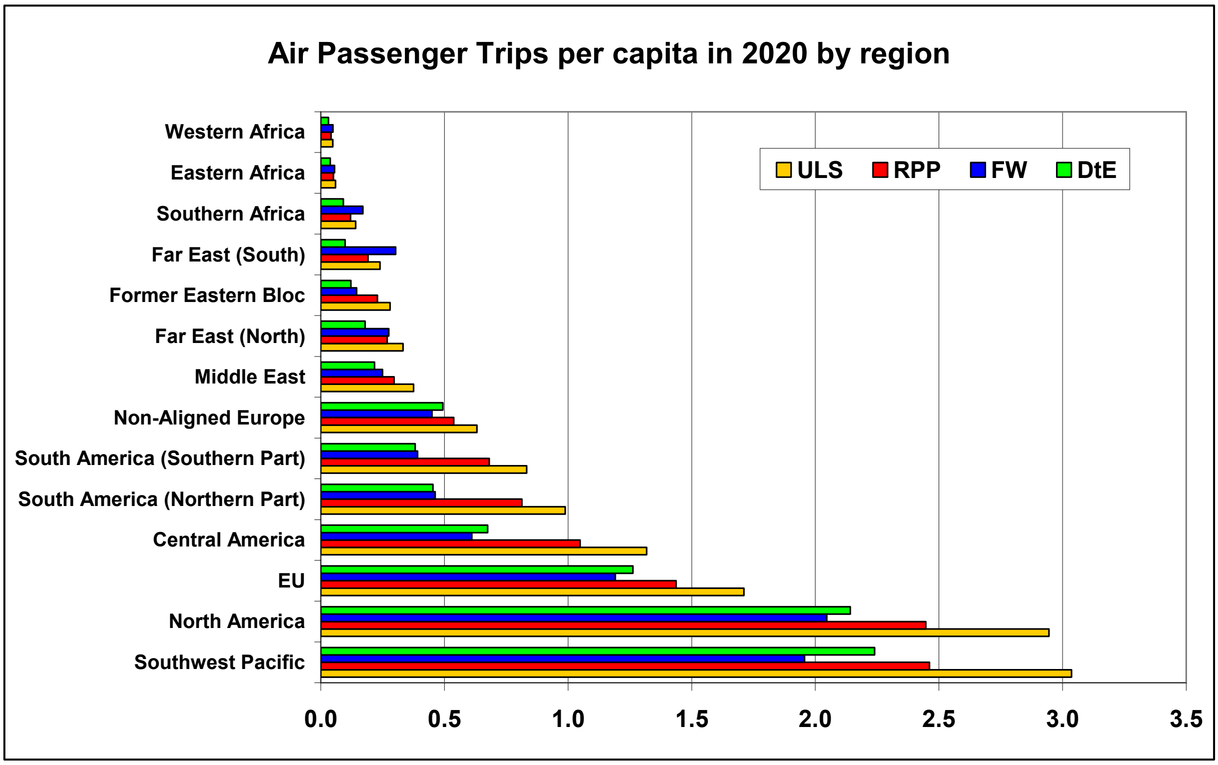


Figure 26: Passenger trips per capita in 2020 for IATA regions

Air Passenger Trips per capita 2050 by region	ULS	RPP	FW	DtE
Southwest Pacific	4.88	3.48	2.26	1.35
North America	4.23	2.80	2.44	1.53
EU	3.79	2.56	1.53	1.11
South America (Northern Part)	2.94	2.20	2.05	0.37
South America (Southern Part)	2.71	1.99	1.19	0.31
Central America	2.66	1.95	1.83	0.46
Southern Africa	2.45	1.69	0.65	0.12
Former Eastern Bloc	1.66	1.15	0.52	0.13
Middle East	1.51	1.02	0.36	0.16
Non-Aligned Europe	1.37	0.99	0.55	0.35
Far East (North)	1.27	0.93	0.33	0.13
Far East (South)	1.10	0.77	0.26	0.09
Western Africa	0.84	0.55	0.31	0.04
Eastern Africa	0.54	0.37	0.21	0.05

Table 25: Passenger trips per capita in 2050 for IATA regions

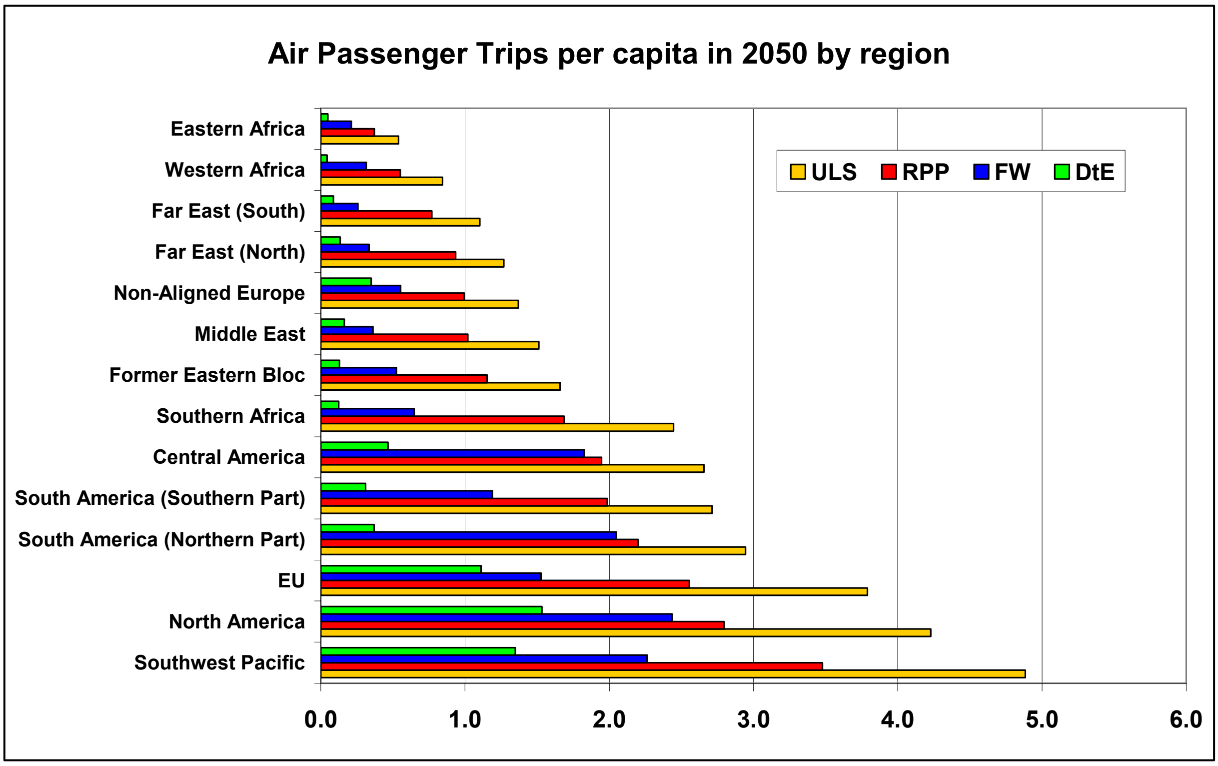


Figure 27: Passenger trips per capita in 2050 for IATA regions

The regional differences in the number (n) of annual air passenger trips per capita reduce significantly over time until 2050. However, the difference in the per capita air passenger trips for the region with the highest numbers (Southwest Pacific with 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 numbers (Eastern Africa with n=0.54 for ULS, n=0.37 for RPP, n=0.21 for FW, n=0.05 for DtE) still remains very high, with a ratio {r} for the respective numbers (n) in the order of r=10 for all scenarios (even somewhat higher for DtE).

The most intensive mobility will be within Southwest Pacific, followed by North America and Europe. As well as mirroring GDP growth rates and GDP level (buying power per capita), geographical circumstances and the availability of other modes of transport, e.g. railways, are also reflected. The trips per capita up to 2020 in DtE in saturated markets are higher than in FW, indicating that the reorientation of customer behaviour takes place mainly in these regions. After 2020 the increasing GDP and welfare assumed for all regions provides FW globally with a higher growth than DtE. The significantly deviating values by region in FW are caused by two underlying mechanisms:

- In larger regions or co-operating regions, air traffic between and within these regions is still a preferred means of long-distance travel;
- In smaller regions, trips are short in distance and at the same time cheaper compared to long distance travel. Hence the number of trips is higher but trips are shorter.

Market sectors of passenger air transport demand

An overview of the different demand market sectors is given for each scenario in table 26 and figure 28. While "Economy" describes full-fare tickets, "Discount" implies significant discount on the full fares. (With low cost carriers are coming on the scene, discount in air transport has reached a new level. In the base calibration year for the AERO-model (1992), low cost carriers as such were not yet on the scene, although point-to-point flights are implicitly included in the base).

Demand-group billion pax-km pa	**ULS**			**RPP**		**FW**		**DtE**	
	2000	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
First/business	110	185	607	150	413	119	205	113	121
Economy	385	670	2493	546	1696	451	782	393	420
Discount	2860	4934	15954	3991	11044	3147	5422	2922	3142
non-scheduled	477	716	2046	597	1483	440	580	492	480
In percentage									
First/business	2.9%	2.8%	2.9%	2.8%	2.8%	2.9%	2.9%	2.9%	2.9%
Economy	10.0%	10.3%	11.8%	10.3%	11.6%	10.8%	11.2%	10.0%	10.1%
Discount	74.6%	75.8%	75.6%	75.5%	75.5%	75.7%	77.6%	74.5%	75.5%
non-scheduled	12.4%	11.0%	9.7%	11.3%	10.1%	10.6%	8.3%	12.6%	11.5%

Table 26: Passenger demand groups in billion pax-km p.a.

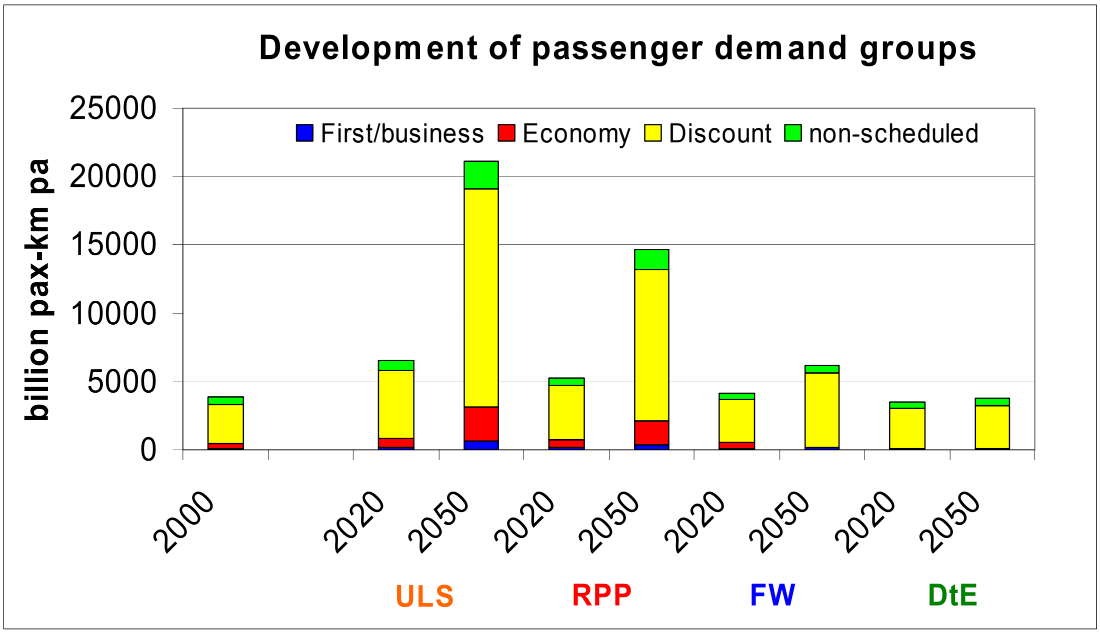


Figure 28: Passenger demand groups in billion pax-km p.a.

The respective shares of first, business, and economy classes are relatively stable over scenario and time. However, with the exception of the Down to Earth scenario, the percentage of non-scheduled flights is decreasing over time.

Table 27 and Figure 29 are showing the quantification results for cargo demand for each scenario from 2005 until 2050. The growth rates for cargo demand, especially those for the DtE scenario, are significantly higher than those for passenger demand. Nonetheless, the slope of the increase in cargo demand for the different scenarios is very similar to the respective slope of the increase of passenger demand developments, with one exception: international transfer of goods and materials in FW is only slightly enhanced in the period to 2050 because of the assumed world fragmentation, leading to a regional focus of production and resource usage. While fragmentation causes a strong decrease of international passenger flights and a balancing increase of domestic passenger flights, the global autarky hinders international exchange of goods and resources.

Cargo demand	2000	2005	2020	2050	Average annual growth 2000-2020	total growth 2020 as a multiple of 2000	average annual growth 2000-2050	total growth 2050 as a multiple of 2000
ULS	127.5	179.1	422.5	1954.5	6.2%	3.3	5.6%	15.3
RPP	127.5	179.1	351	1214.9	5.2%	2.8	4.6%	9.5
FW	127.5	179.1	229.6	325.1	3.0%	1.8	1.9%	2.5
DtE	127.5	179.1	235.9	279.8	3.1%	1.9	1.6%	2.2

Table 27: Cargo demand in billion tonne-km p.a.

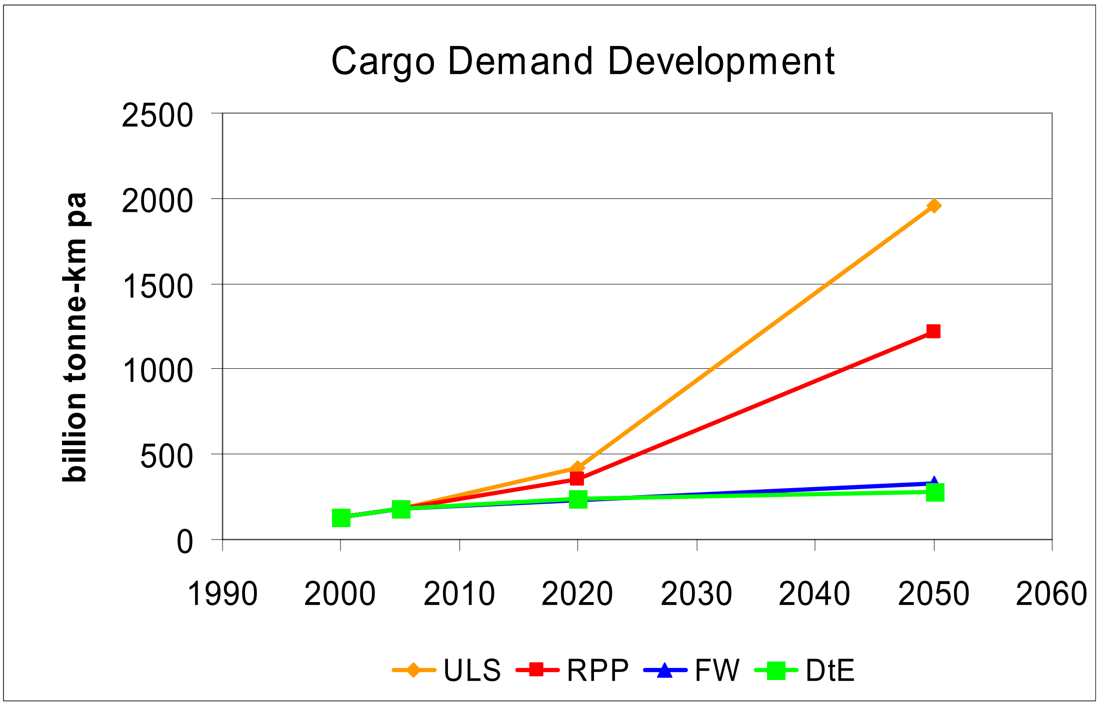


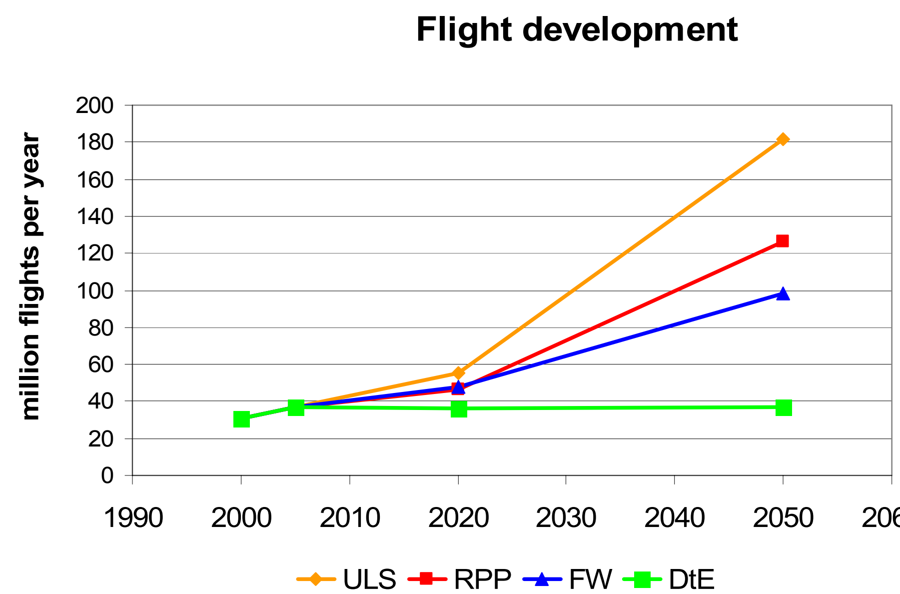
Figure 29: Cargo demand in billion tonne-km p.a.

Aircraft movements

Table 28 and figure 30 show the quantification results for the number of flights for each scenario from 2005 until 2050 plus the annual growth rates and total growth (as a multiple of 2000), combining effects from passenger and cargo demand. Note that FW has a similar total increase of demand as the DtE, but the regional structure of the traffic differs significantly. The long haul traffic volume between (IATA) regions is low in FW compared to intra-regional traffic, implying that the number of flights in FW is higher than in the DtE scenario.

Flights	2000	2005	2020	2050	average annual growth 2020	total growth 2020 as a multiple of 2000	average annual growth 2050	total growth 2050 as a multiple of 2000
ULS	30.7	37	55.5	181.9	3.0%	1.8	3.6%	5.9
RPP	30.7	37	46.3	126.5	2.1%	1.5	2.9%	4.1
FW	30.7	37	48.1	98.2	2.3%	1.6	2.4%	3.2
DtE	30.7	37	36	36.9	0.8%	1.2	0.4%	1.2

Table 28: Flight development (in million p.a.), annual growth rates, and growth factors



	average annual growth 2050	total growth 2050 as a multiple of 2000
ULS	3.6%	5.9
RPP	2.9%	4.1
FW	2.4%	3.2
DtE	0.4%	1.2

Figure 30: Flight development (in million p.a.), annual growth rates, and growth factors

Fleet

Table 29 and figure 31 show the flights per year performed with younger (<=12 years) and older (>12 years) aircraft.

Million flights pa		ULS		RPP		FW		DtE	
	2000	2020	2050	2020	2050	2020	2050	2020	2050
Technology age > 12 years	15.8	31.4	108.6	26	75.5	26.4	61.7	19.6	20.7
Technology age <= 12 years	15	24.1	73.3	20.3	50.9	21.7	36.4	16.5	16.2

Table 29: Flights by aircraft technology age

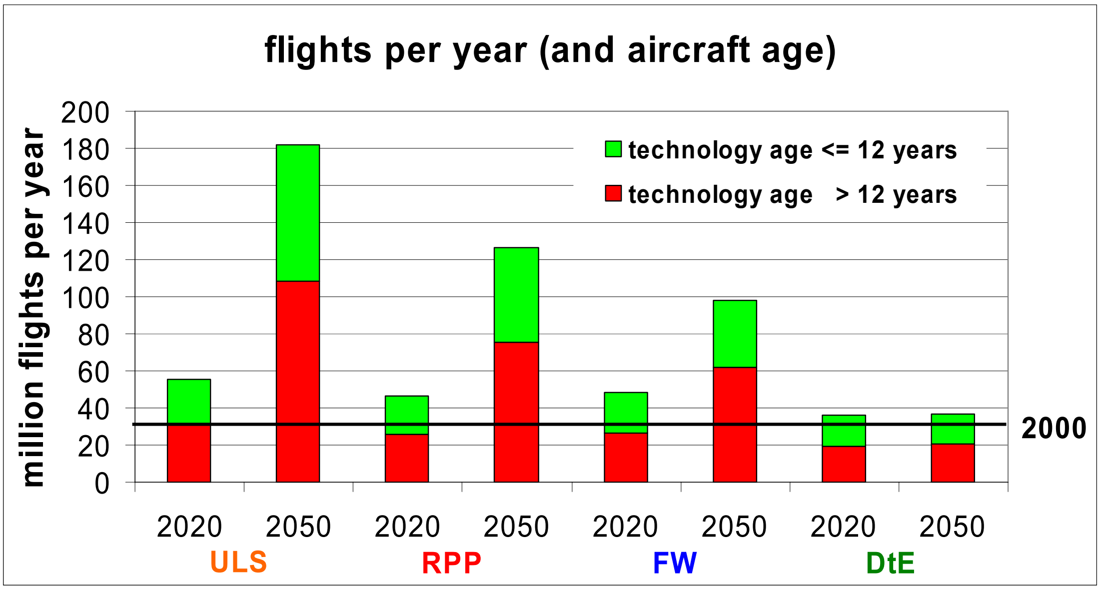


Figure 31: Flights by aircraft technology age

In table 30, the share of the old/new aircraft on total flights is given. The results mirror the increase of aircraft lifetimes in all scenarios.

Share of old/new aircraft in percentage	2000	ULS		RPP		FW		DtE	
		2020	2050	2020	2050	2020	2050	2020	2050
Technology age > 12 years	51%	57%	60%	56%	60%	55%	63%	54%	56%
Technology age <= 12 years	49%	43%	40%	44%	40%	45%	37%	46%	44%

Table 30: Share of old/new aircraft on total flights

In table 31 and figure 32 the expected number of aircraft (for passenger and freight transport) is given. This number is mainly influenced by demand, fleet mix and seat capacity. ULS, RPP and DtE are operating with a higher share of bigger aircraft because of the assumed infrastructure (ULS) constraints as well as regulations (RPP and DtE), while in FW regionally technologies are causing a higher number of different (related to engines/fuel) aircraft.

Number of aircraft	2000	2020	2050
ULS	25317	36341	107345
RPP Kerosene	25317	31091	74318
RPP H2	25317	31091	90484
FW	25317	32607	60144
DtE	25317	24597	24779

Table 31: Number of aircraft

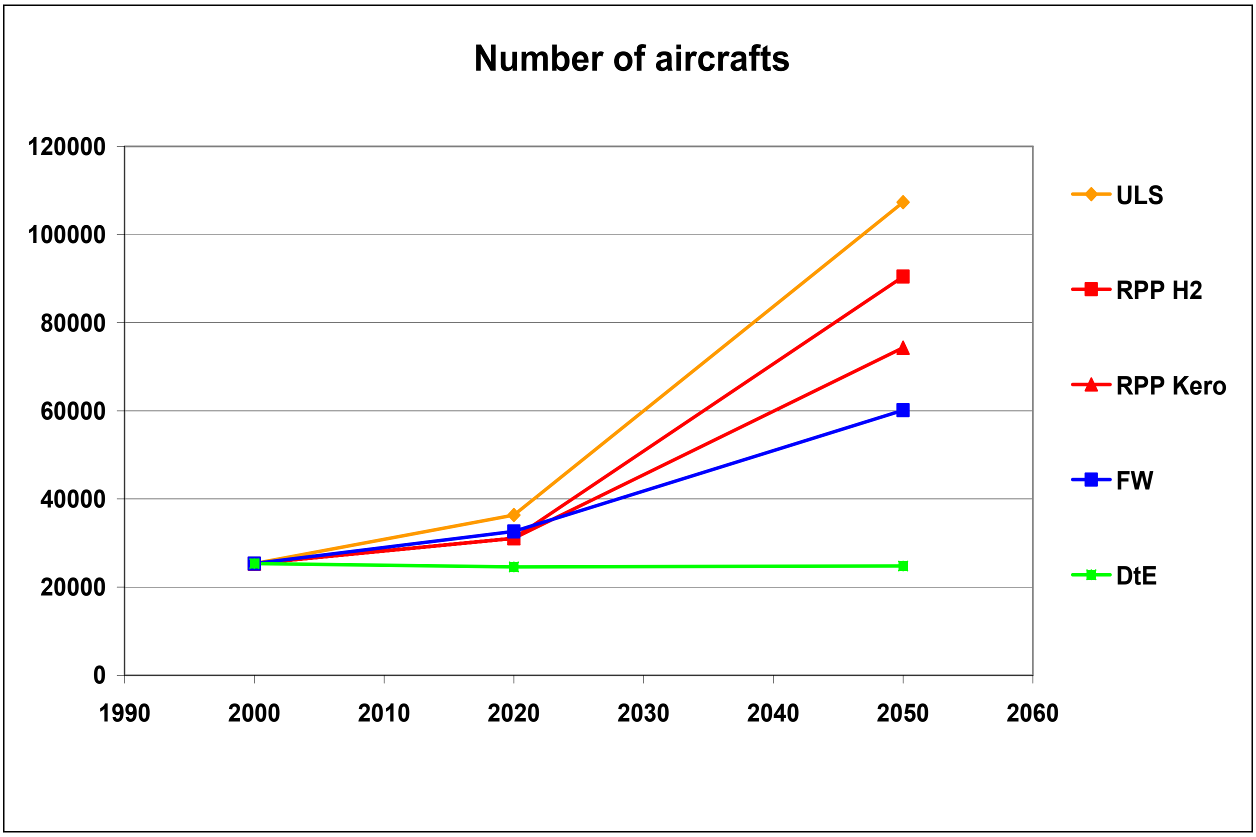


Figure 32: Number of aircraft

The development of the mix of the aircraft fleet (for passenger + freight transport) calculated for the four basic scenarios and the RPP cryoplane sub-scenario within the considered time period until 2050 is shown in table 32 and figure 33. The AERO-model uses 10 different generic seat classes, divided in 4 classes for short haul and three classes for medium and long haul aircraft each.

The results are of special interest, as they mirror the calculation process of the AERO-model to reach economic balanced situations for the scenario. Two examples of the high diversity of detailed information included in these results:

Aircraft by Size		ULS		RPP	RPP-noH2	RPP-H2	FW		DtE	
	2000	2020	2050	2020	2050	2050	2020	2050	2020	2050
Short haul, less than 20 seats	2624	3661	5782	3190	4234	6951	3521	5176	2943	2376
Short haul, 20 to 79 seats	7783	6460	13609	5733	10377	18422	6631	11571	4871	4778
Short haul, 80 to 124 seats	2473	5888	19896	4978	14117	14103	5857	12801	3665	3946
Short haul, 124 to 179 seats	1562	3066	9237	2569	6282	7146	2294	4880	1928	2064
Medium haul, 80 to 124 seats	759	3402	9434	2850	6680	7208	2833	7009	2276	2340
Medium haul, 124 to 179 seats	3702	3978	12730	3392	8598	10741	3861	7064	2674	2682
Medium haul, 180 to 299 seats	3968	4079	15442	3358	10264	11300	3301	5181	2485	2676
Long haul, 180 to 299 seats	1498	981	3337	972	2106	2439	1025	1515	756	720
Long haul, 300 to 499 seats	941	4245	15321	3634	10194	10532	3172	4835	2738	2956
Long haul, 500 or more seats	8	581	2557	415	1466	1642	112	112	261	241
Total	**25317**	**36341**	**107345**	**31091**	**74318**	**90484**	**32607**	**60144**	**24597**	**24779**

Table 32: Fleet mix until 2050

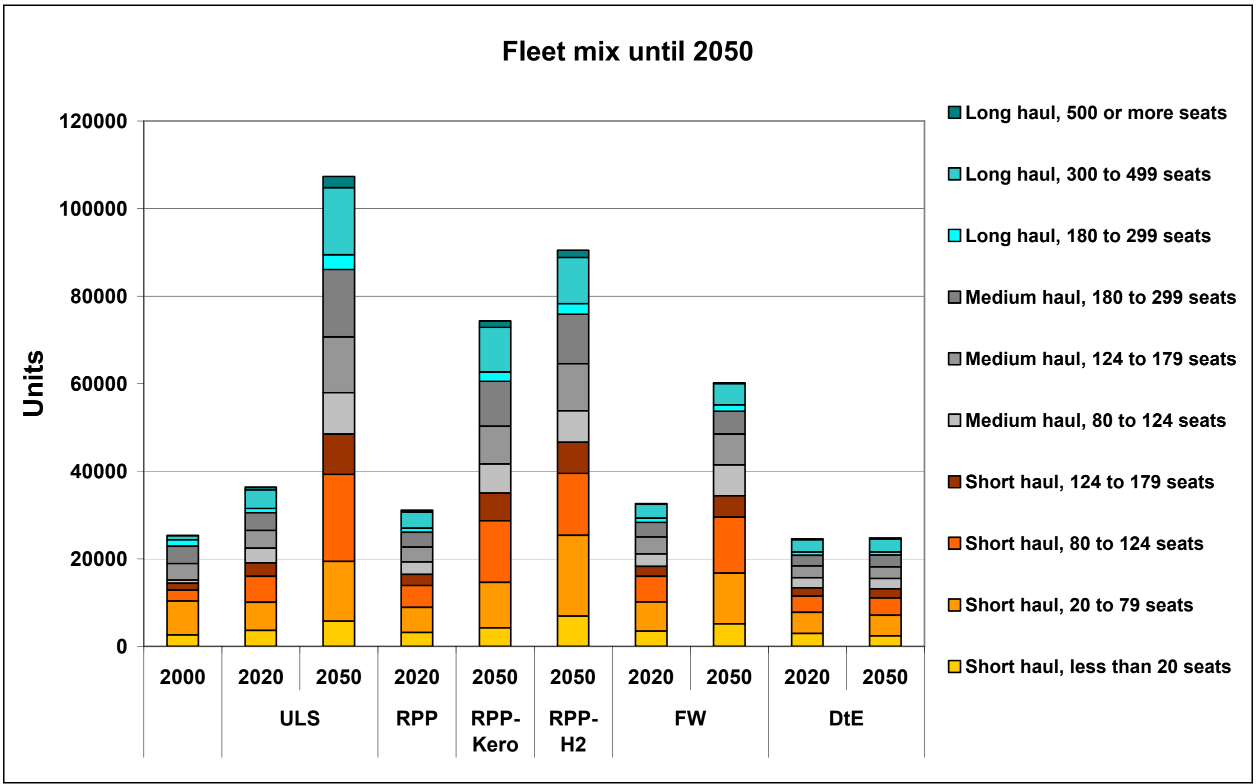


Figure 33: Fleet mix development until 2050

There is a significant increase of the number of aircraft with more than 300 seats for all scenarios. The share of these large aircraft is increasing from 3.7% in 2000 to 16.7%, 17.7%, 13.5%, 8.2% and 12.8% in the year for ULS, RPP kerosene, RPP hydrogen, FW, DtE respectively, all logical results of the respective storylines.

Nonetheless, is the rollover from a kerosene based to a hydrogen based fleet of the RPP H2 sub-scenario especially characterised by a remarkable high increase of small short haul aircraft with 20 to 79 seats in the time period to 2050, which might be explainable as an typical effect of the introduction phase (resulting also in a - compared to the RPP kerosene basic scenario - much higher total number of aircraft in the RPP H2 sub-scenario).

Fuel consumption and emissions from aviation

Fuel use

The fuel consumption modelled in AERO is mainly a function of demand plus aircraft fleet technology. Consequently, table 33 and figure 34 show the same pattern as the demand results with relatively higher values for DtE and FW for 2050, mirroring the comparatively older fleet with less efficient aircraft in these scenarios, resulting from the assumption that a bigger market generates a higher innovation speed.

Billion kg pa	2000	2005	2020	2050
ULS	168	196	287	773
RPP	168	196	237	524
FW	168	196	197	303
DtE	168	196	198	228

Table 33: Fuel use in billion kg p.a.

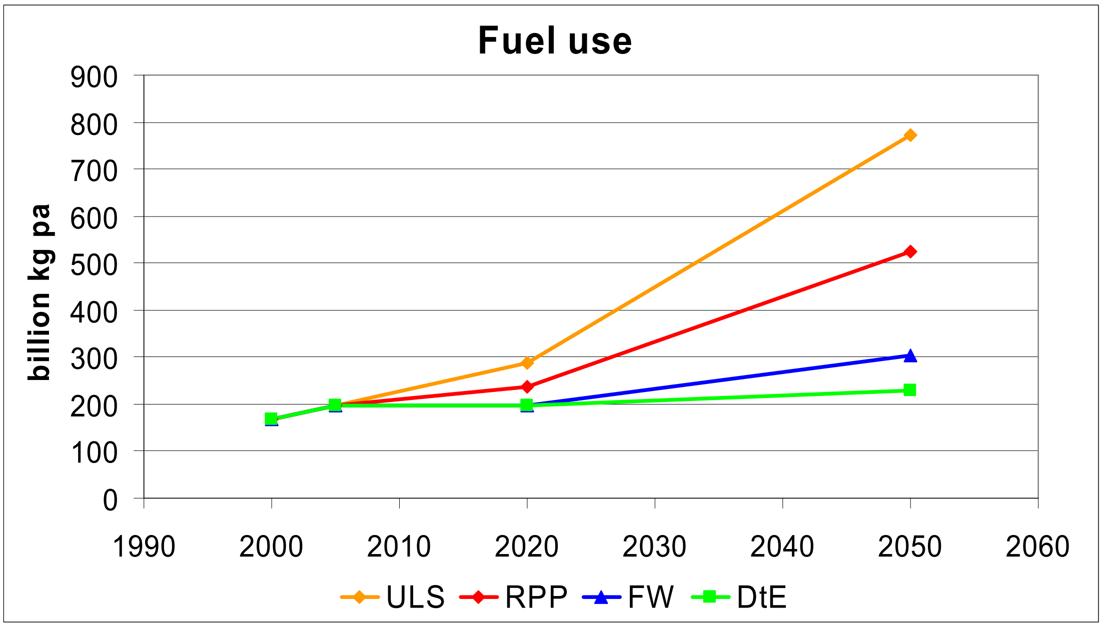


Figure 34: Fuel use in billion kg p.a.

Table 34 and figure 35 show the development of the specific fuel consumption in aviation (kg fuel per ac-km) for the four basic scenarios and the RPP sub-scenario kerosene to hydrogen roll-over. Due to further improvements in fuel efficiency in ULS and RPP the specific fuel consumption in these scenarios will be reduced 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%), as the energy density for hydrogen is higher than for kerosene.

Kg / ac-km	2000	2005	2020	2050
ULS	5.03	4.80	4.40	3.55
RPP kerosene	5.03	4.80	4.32	3.42
RPP hydrogen	5.03	4.80	-	2.71
FW	5.03	4.80	4.04	3.21
DtE	5.03	4.80	4.69	4.18

Table 34: Specific fuel consumption (Fuel/ac-km)

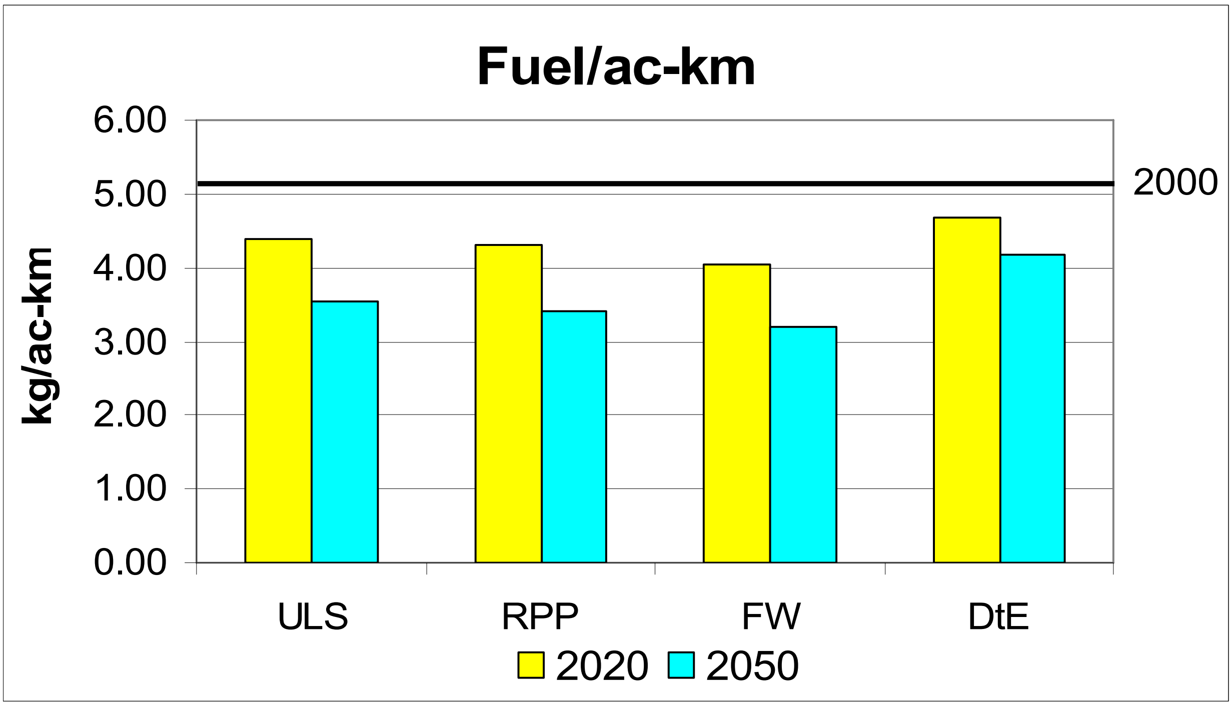


Figure 35: Specific fuel consumption (Fuel/ac-km)

Table 35 and Figure 36 show the fuel consumption per revenue tonne kilometres (RTK), as a further basic indicator for fuel efficiency. The RTK figures include tonne kilometres for passenger and freight transport. More effective engines and bigger aircraft assumed for ULS and RPP lead to higher efficiency compared to FW and DtE caused by a more innovation friendly market.

Kg/tonne-km	2000	2020	2050
ULS	0.367	0.268	0.190
RPP	0.367	0.270	0.196
FW	0.367	0.306	0.295
DtE	0.367	0.315	0.327

Table 35: Fuel/RTK in kg/tonne-km

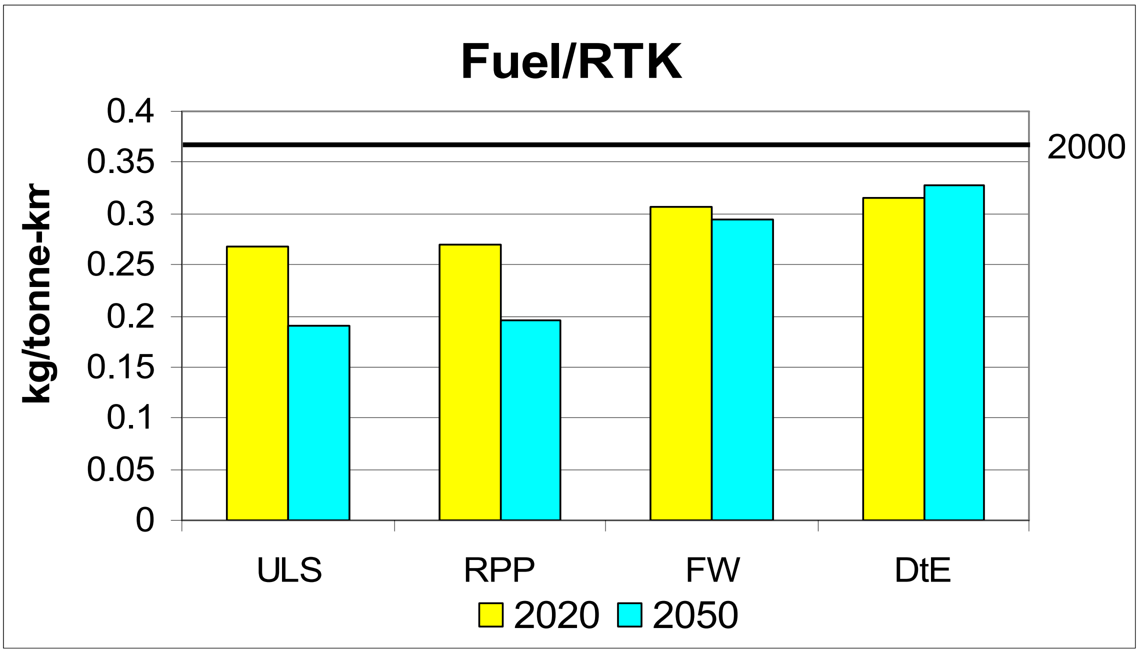


Figure 36: Fuel/RTK in kg/tonne-km

Table 36 and figure 37 show the fuel consumption per aircraft tonne kilometres (ATK) as a measure of aviation specific fuel consumption. Again, more effective engines and bigger aircraft assumed for ULS and RPP lead to higher efficiency compared to FW and DtE, resulting from a more innovation friendly market.

Kg/tonne-km	2000	2020	2050
ULS	0.23	0.17	0.11
RPP	0.23	0.17	0.12
FW	0.23	0.18	0.15
DtE	0.23	0.20	0.17

Table 36: Fuel/ATK in kg/tonne-km

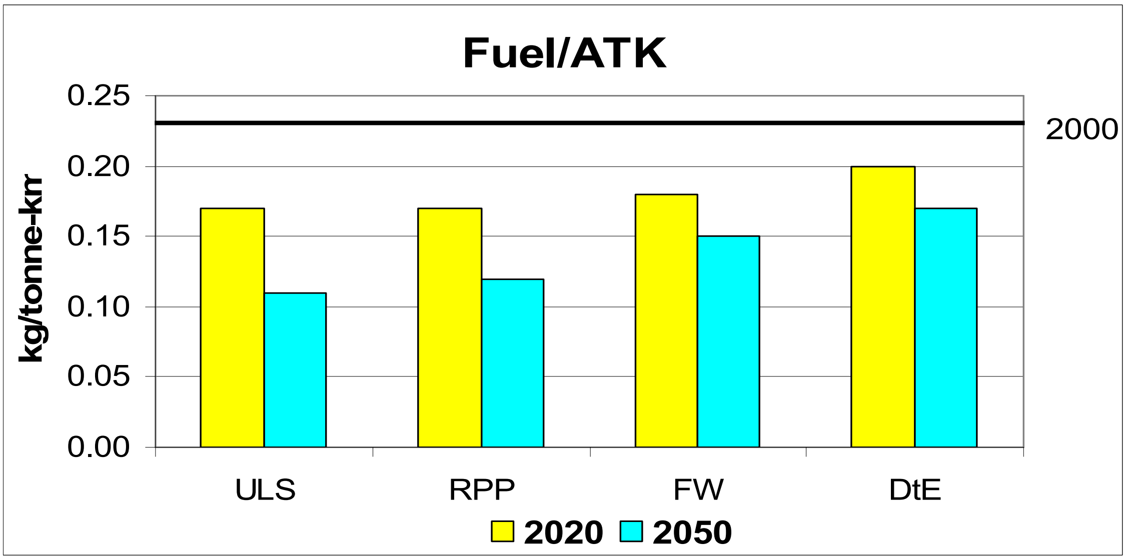


Figure 37: Fuel/ATK in kg/tonne-km

CO2 emissions

The CO2 emission per kg fuel can be regarded as a constant - there are only minor dependencies from the fuel quality and from CO emissions. For CONSAVE 2050 a conversion factor of 3.157 [25] has been used. Table 37 and figure 38 show the annual CO2 growth rate. Even with the more effective engines and bigger aircraft assumed for ULS and RPP (all kerosene fleet), the CO2 emissions in these scenarios are higher than in FW and DtE on account of the significantly higher number of flight movements. Related to CO2 emissions scenario DtE is the only basic version with lower CO2 emissions in 2050 than in 2020. (A sharp fleet reduction in CO2 emissions between 2020 and 2050 has also been calculated for the RPP *sub-scenario with transition to hydrogen* - see chapter 5.8.3 for details)

Growth/year	2000-2020	2020-2050
ULS	2.7%	3.4%
RPP	1.7%	2.7%
FW	0.8%	1.4%
DtE	0.8%	0.5%

Table 37: Average annual CO2 growth

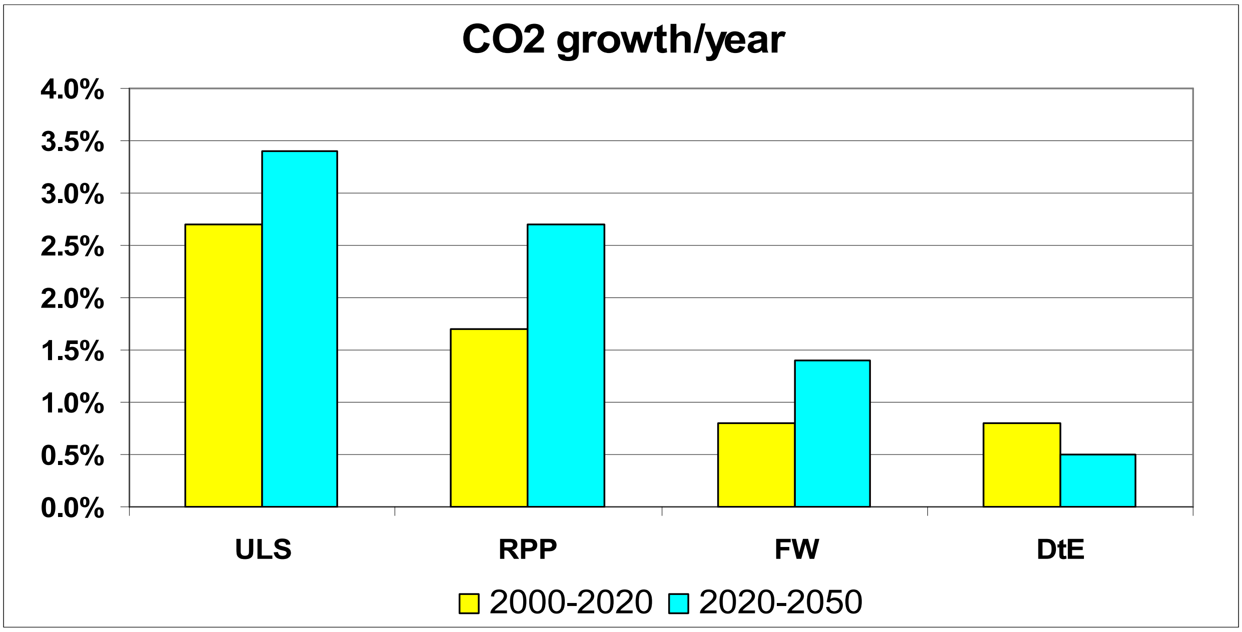


Figure 38: Average annual CO2 growth

Table 38 and figure 39 show a comparison of CONSAVE quantification results for CO2 emissions with the FESG/IPCC scenarios for 2050 [3], [4] and with the forecast from the AERO2k project for the year 2025 [28]. Both the results from AERO2k and FESG fall into the range of the outcomes for CONSAVE scenarios.

Billion kg pa	2000	2005	2020	2025	2050
ULS	531	619	907	1163	2442
RPP	531	619	749	900	1654
FW	531	619	623	678	955
DtE	531	619	625	641	719
FESG 1999 Fc					847
FESG 1999 Fa					1485
FESG 1999 Fe					2350
AERO2k				1029	

Table 38: Comparison of CO2 emissions with AERO2k and FESG

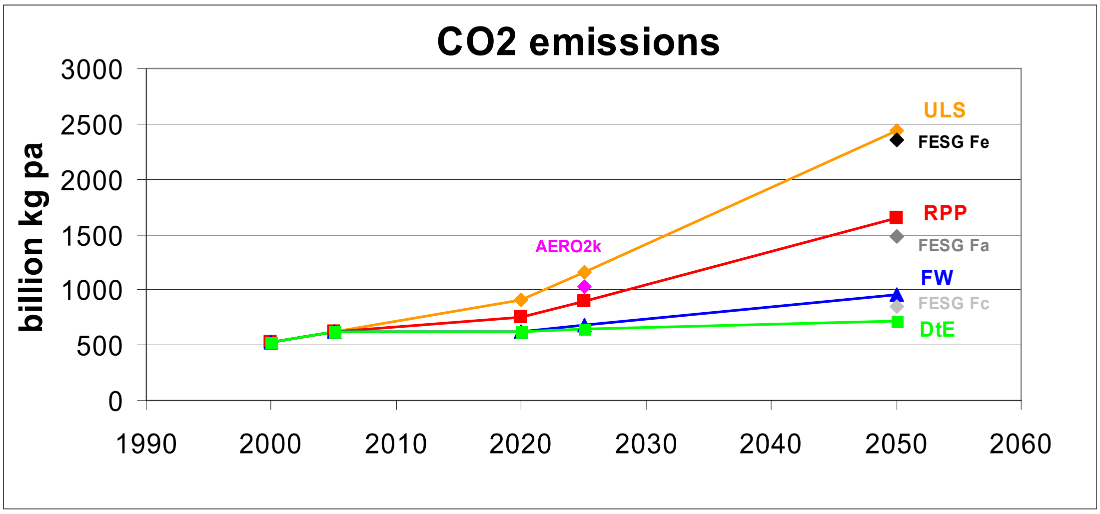


Figure 39: Comparison of CO2 emissions with AERO2K and FESG

Table 39 and figure 40 show the CO2/RTK-reduction in percentage relative to 2000. Again, more effective engines and bigger aircraft assumed for ULS and RPP lead to more CO2 reduction compared to FW and DtE resulting from a more innovation friendly market.

CO2/RTK-Reduction in Percentage	2000	2020	2050
ULS	100%	73%	52%
RPP	100%	74%	53%
FW	100%	83%	81%
DtE	100%	86%	89%

Table 39: CO2/RTK relative to 2000

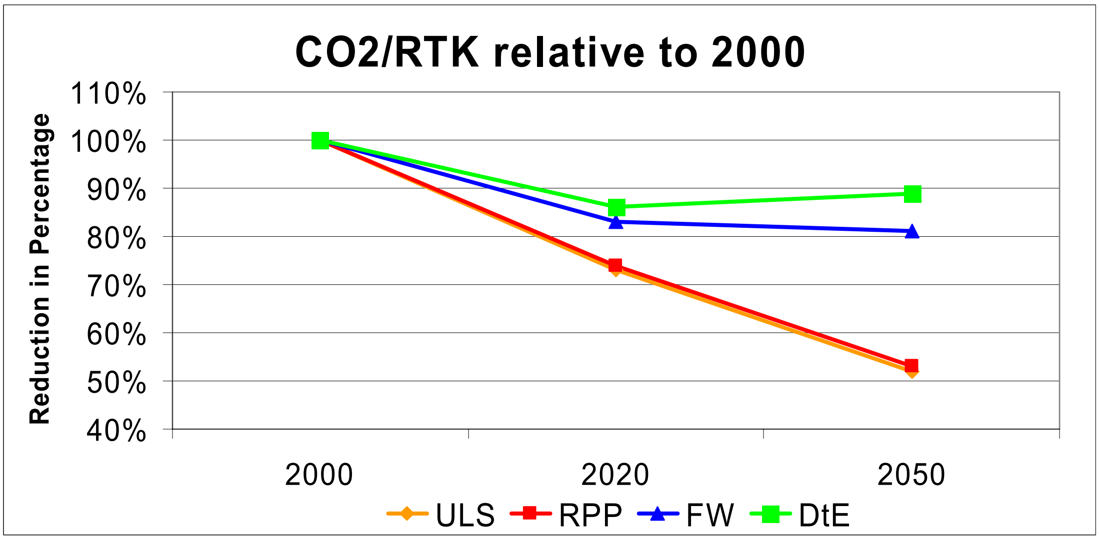


Figure 40: CO2/RTK relative to 2000

NOx emissions

Whereas the CO2 emission per kg fuel is (nearly) a constant, the NOx emission is highly dependent on the technology driven NOx emission index. Table 40 and figure 41 show that the NOx emission index is reduced significantly in the environmentally orientated scenarios RPP (medium reduction) and DtE (strong reduction).

Gram/kg fuel	2000	2020	2050
ULS	13	12	10
RPP	13	12	9
FW	13	12	11
DtE	13	10	5

Table 40: NOx emission index in gram/kg fuel

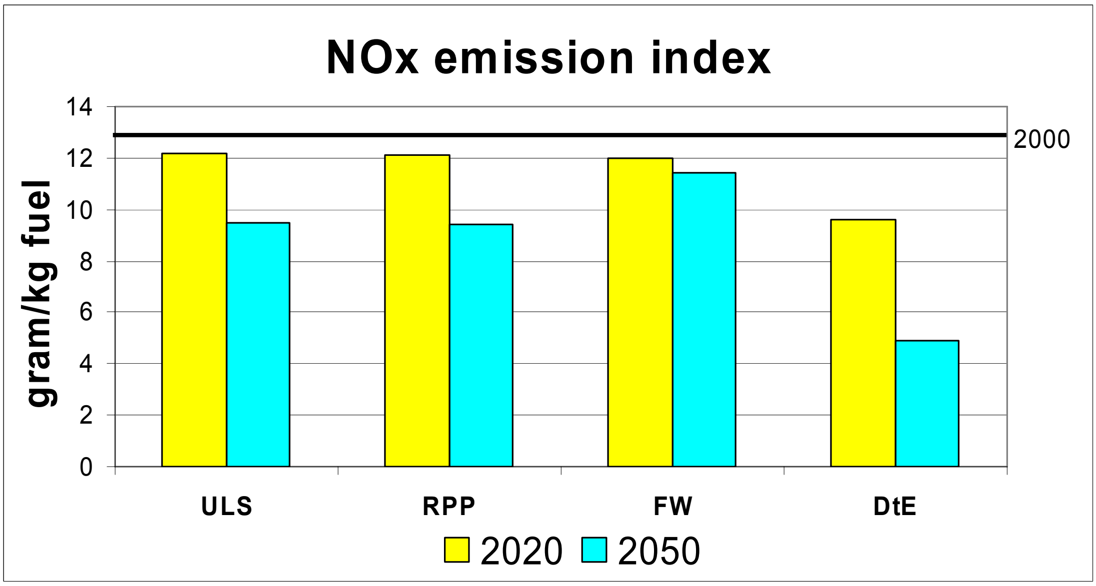


Figure 41: NOx emission index in gram/kg fuel

Based on these scenario-specific NOx emission indices, in the following tables 41-43 and figures 42-44, the development of global NOx emissions is shown for all scenarios until 2020 and 2050. While in DtE strong emphasis is given to NOx reduction even before 2020 (and more by 2050), the success in NOx reduction in other scenarios is low until 2020. Up to 2050 ULS and even more RPP show larger improvements, but far less than DtE. In FW emission reduction is not high on the agenda, with the result that only some blocks improve the NOx-reduction technology.

The average annual growth for NOx emissions from aviation are given in table 41 and figure 42.

Growth/year	2000-2020	2020-2050
ULS	2.3%	2.5%
RPP	1.3%	1.8%
FW	0.3%	1.3%
DtE	-0.8%	-1.8%

Table 41: Average annual NOx growth

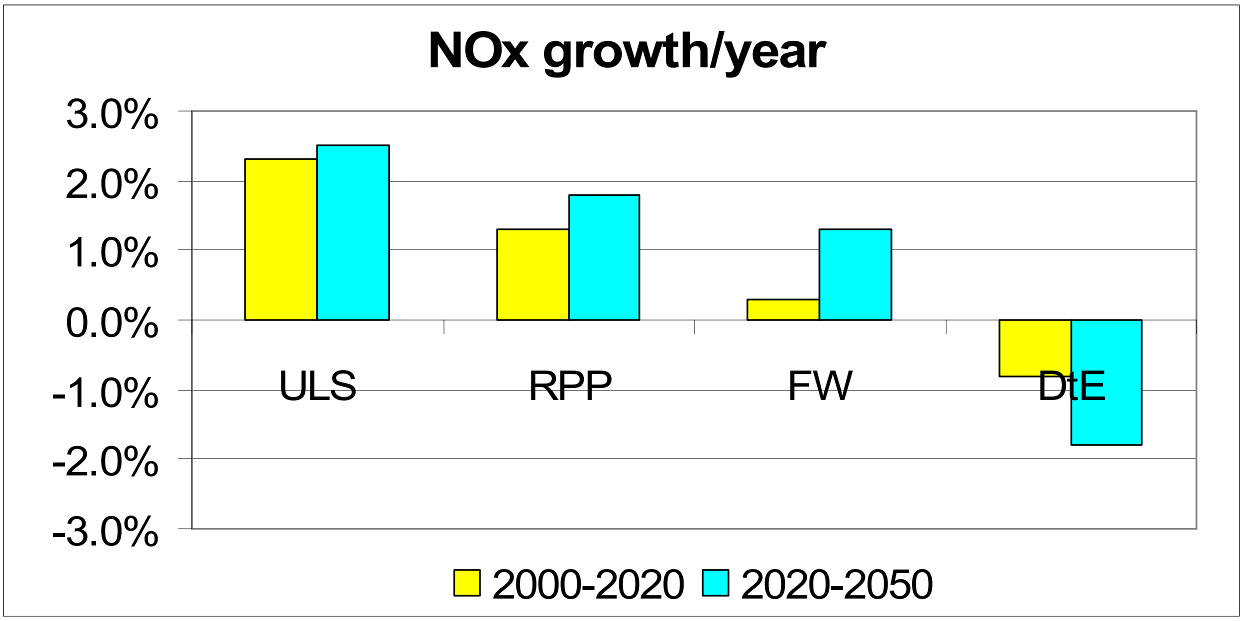


Figure 42: Average annual NOx growth

Table 42 and figure 43 show a comparison of CONSAVE quantification results for NOx emissions with FESG/IPCC scenarios for 2050 [3], [4] as well as with the forecast from the AERO2k project [28]. Whereas the AERO2k result for 2025 fits well into the range of NOx emissions for the four basic scenarios, the spectrum of values for CONSAVE results for 2050 shows a lower level of NOx emissions than for the FESG scenarios. This reflects the fact that for the CONSAVE project a more aggressive NOx reduction technology up to 2050 is assumed than for the FESG/IPCC work.

Million kg pa	2000	2005	2020	2025*	2050
ULS	2228	2637	3495	4131	7313
RPP	2228	2637	2871	3212	4914
FW	2228	2637	2361	2544	3459
DtE	2228	2637	1898	1767	1113
FESG 1999 Fc					4000
FESG 1999 Fa					7200
FESG 1999 Fe					11400
AERO2k				3308	

* The values for the CONSAVE scenarios for the year 2025 are derived from (linear) interpolation (see figure 43)

Table 42: NOx emissions in million kg p.a. and comparison with results from AERO2k and FESG

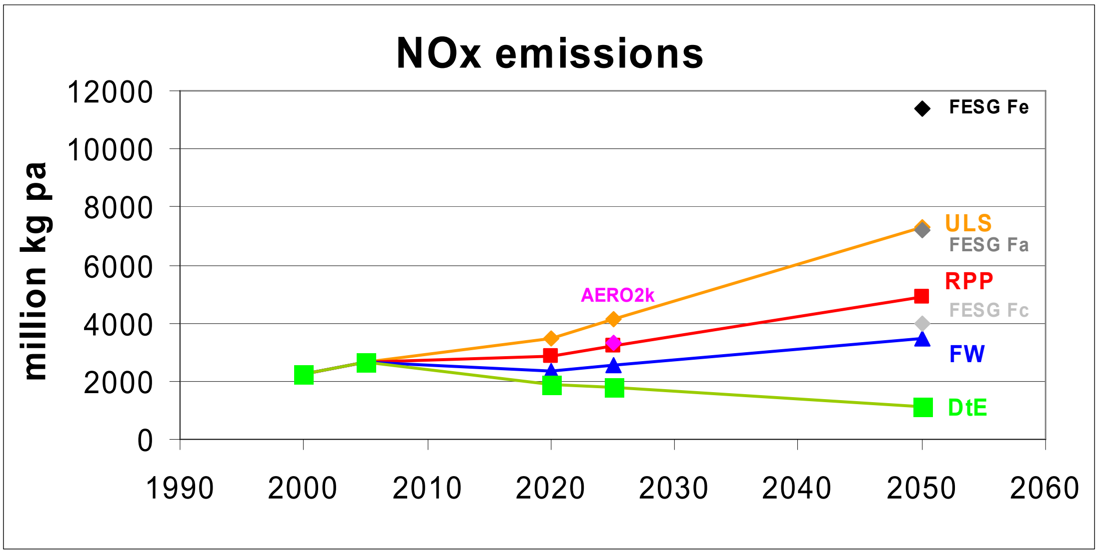


Figure 43: NOx emissions in million kg p.a. and comparison with results from AERO2k and FESG

Table 43 and figure 44 show the NOx/RTK-reduction in percentage relative to 2000. NOx per RTK is remarkably reduced for all basic scenarios beside the Fractured World, for which only in some regions high efforts go to a reduction of NOx emissions from aviation.

NOx/RTK Reduction in Percentage	2000	2020	2050
ULS	100%	67%	37%
RPP	100%	67%	38%
FW	100%	75%	69%
DtE	100%	62%	33%

Table 43: NOx/RTK relative to 2000

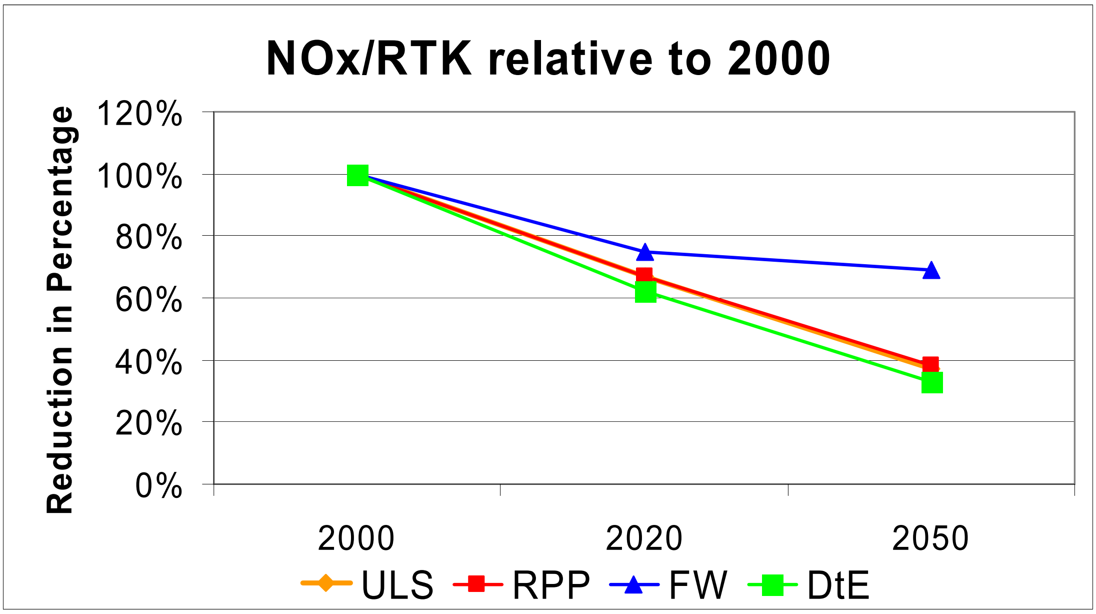


Figure 44: NOx/RTK relative to 2000

In table 44, an overview is given of the growth factors for flown distance, fuel consumption and emissions for all scenarios and time horizons.

DtE has a higher increase in fuel and CO2 emissions than in aircraft kilometres, as in this scenario the focus is more on NOx reduction engine technology than on fuel reduction. AS a result the fleet consists of smaller, more luxurious and relatively older aircraft, and there are more short-range flights, resulting in comparably low fuel per km efficiency.

Growth factors relative to 2000	ULS 2020	ULS 2050	RPP 2020	RPP 2050	FW 2020	FW 2050	DtE 2020	DtE 2050
Aircraft km	2.0	6.5	1.6	4.5	1.4	2.5	1.2	1.3
Fuel use	1.7	4.6	1.4	3.1	1.2	1.8	1.2	1.4
CO_2 emissions	1.7	4.6	1.4	3.1	1.2	1.8	1.2	1.4
NO_x emissions	1.6	3.3	1.3	2.2	1.1	1.6	0.9	0.5

Table 44: Growth factors for aircraft km, fuel use, CO2 and NOx relative to 2000

Emission inventory

The AERO-model allows the calculation of emission inventories (5° x 5° horizontal grid plus 15 equidistant altitude bands of 1km) for the most important types of emissions from aviation (CO2, NOx, SO2, CxHy, CO, H2O).

Values for emissions of CO2, NOx and fuel have been presented for each of the CONSAVE scenarios and sub-scenarios. However, technology assumptions for the other CAEP-regulated emissions (i.e. unburned hydrocarbons (CxHy), CO and smoke) were not specifically assessed for each of the scenarios. If some estimation is required, it can be assumed - as a first order approximation - that HC and CO emissions will remain at current levels; i.e. similar emissions for similar size aircraft. Total HC and CO emissions therefore increase in line with increasing movements and aircraft size.

Similarly, SO2 emissions have not been specifically modelled within CONSAVE. SO2 emissions are directly proportional to the amount of sulphur in the fuel (kerosene only). If assumptions are made for fuel sulphur content in future fuels, then the total SO2 emissions can be calculated by multiplying the assumed future fuel sulphur mass content by the mass of fuel consumed and then by a factor of 2 (Molecular weight 64/32) to account for oxidation.

The calculated emission inventories can be made available on diskette and can be ordered from NLR and DLR.

As an example for the emissions at altitude, figure 45 shows the distribution of emissions by altitude band for the Unlimited Skies scenario. No special operational measures (such as flying lower and slower) are taken to reduce its environmental impact.

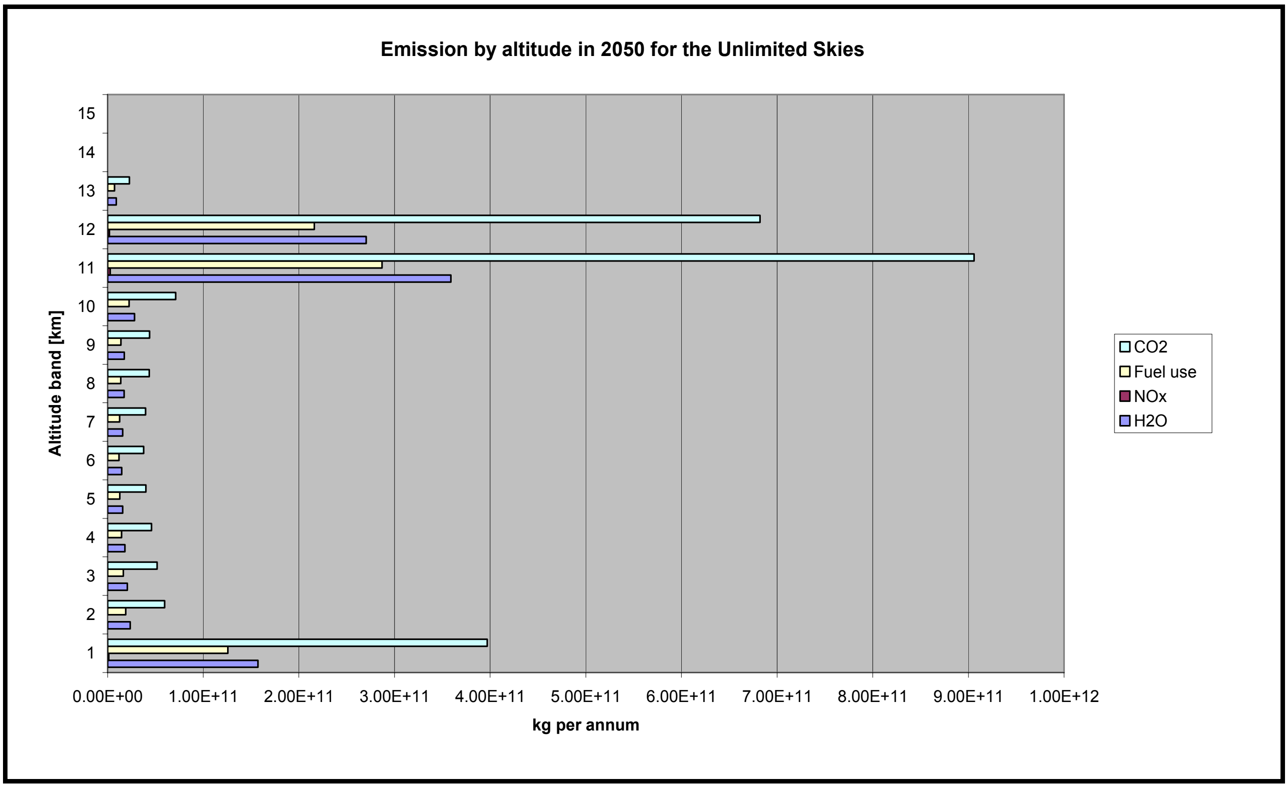


Figure 45: Emission by altitude band for 2050 in scenario ULS

Tables 45, 46 and figures 46, 47 show the contribution from aviation to global anthropogenic CO2 and NOx emissions by comparing respective scenario specific values of IPCC/SRES (delivering total global values for the emissions caused by man) and CONSAVE aviation scenarios. For the purpose of this comparison, findings from the RPP sub-scenario "Hydrogen rollover" (details see chapter 5.8.3) are also included, as the emission related results for this scenario are especially relevant in this context.

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

CO2 Emissions [MtC]	2000	2020	2050
IPCC SRES A1G-MESSAGE	7970	10910	21420
ULS Aviation	145	247	666
IPCC SRES A1T-MESSAGE	7970	10260	12260
RPP Aviation	145	204	451
IPCC SRES A1T-MESSAGE	7970	10260	12260
RPP H2 Aviation	145	204	21
IPCC SRES A2-MESSAGE	7970	11460	15910
FW Aviation	145	170	260
IPCC SRES B1-MESSAGE	7970	9160	8570
DtE Aviation	145	170	196

AC CO2 – contribution	2000	2020	2050
ULS	1.82%	2.27%	3.11%
RPP	1.82%	1.99%	3.68%
RPP H2	1.82%	1.99%	0.17%
FW	1.82%	1.48%	1.64%
DtE	1.82%	1.86%	2.29%

Table 45: Contribution from aviation to global anthropogenic CO2 emissions

It should be noted that some uncertainties in these figures result from the fact that the scenario assumptions from IPCC/SRES are not absolutely identical to the CONSAVE scenarios, specifically only with respect to the dominant aspects GDP and population. It my occur surprising that the contribution from air transport to the total CO2 emissions caused by men is higher for the RPP scenario (basic version) then for the ULS scenario. However, one has to bear in mind that within the RPP scenarios all kind of human emissions are regulated (not only those from aviation). Therefore, a much lower absolute CO2 emissions level in RPP (compared to ULS) corresponds nonetheless to a higher percentage on the total anthropogenic CO2 emissions. If the positive assumed emission characteristics of hydrogen could be realised at reasonable cost and negative side-effects can be avoided, a change to a cryoplane fleet could solve the CO2 problem for aviation.

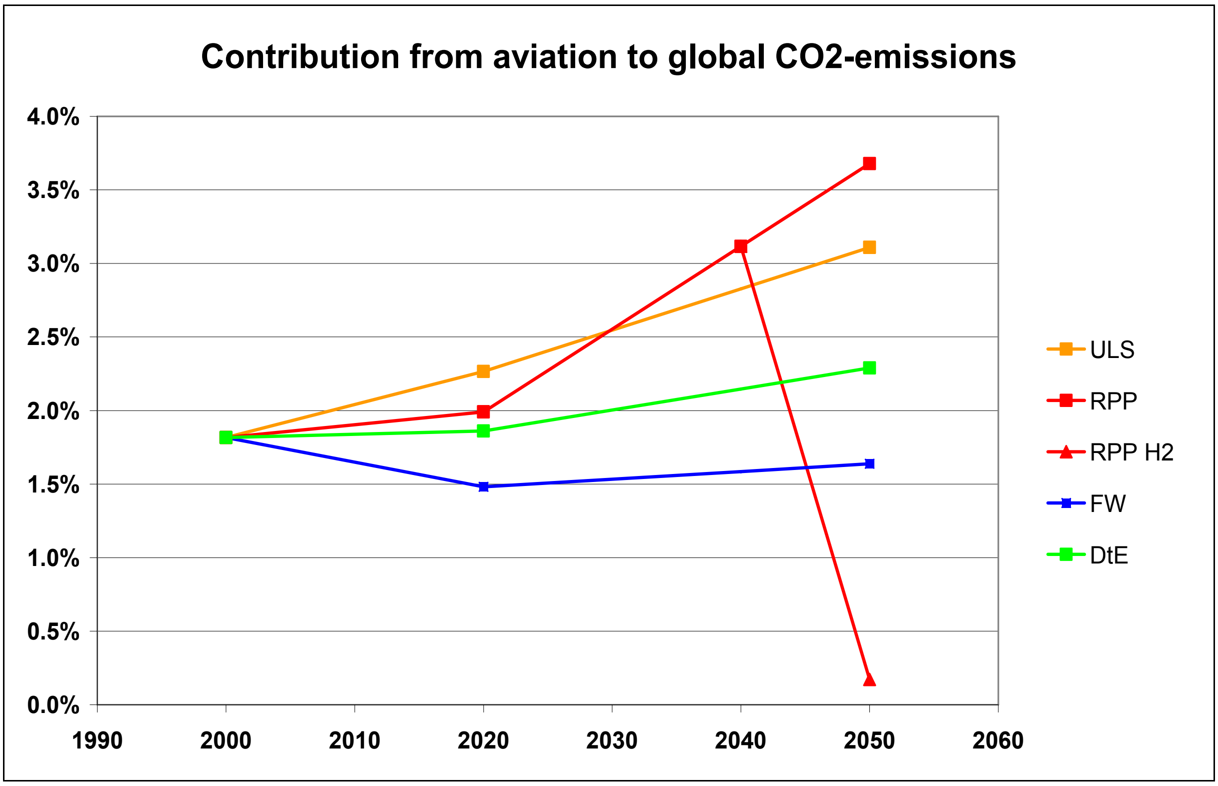


Figure 46: Contribution from aviation to global anthropogenic CO2 emissions

It is important to recognise that the percentage of total man-made CO2 and NOx emissions attributed to aviation in figures 46 and 47 assumes considerable technical progress in aviation as

NOx Emissions [MtN]	2000	2020	2050
IPCC SRES A1G-MESSAGE	32	46	89
ULS	0.68	1.06	2.23
IPCC SRES A1T-MESSAGE	32	46	61
RPP	0.68	0.87	1.50
IPCC SRES A1T-MESSAGE	32	46	61
RPP H2	0.68	0.87	0.42
IPCC SRES A2-MESSAGE	32	47	66
FW	0.68	0.72	1.05
IPCC SRES B1-MESSAGE	32	44	40
DtE	0.68	0.58	0.34

AC NOx contribution	2000	2020	2050
ULS	2.12%	2.31%	2.50%
RPP	2.12%	1.90%	2.45%
RPP H2	2.12%	1.90%	0.69%
FW	2.12%	1.53%	1.60%
DtE	2.12%	1.31%	0.85%

Table 46: Contribution from aviation to global anthropogenic NOx emissions

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 CO2 and NOx emissions for the ULS and RPP scenarios would rise to around 7% of total man-made emissions.

The differences in NOx emissions from a hydrogen fleet, compared to a kerosene fuelled fleet, emanate from three principal sources:

Firstly, dependent on scenario, a 10% to 15% lower NOx emissions index (based on mass of emissions per unit mass of fuel) is assumed from a hydrogen fuelled fleet, due to the potential for hydrogen combustion to operate at lower flame temperatures. Theoretically, hydrogen combustion offers greater benefits than this. However an allowance has been made for the relative in-service immaturity of hydrogen combustion technology compared to its kerosene equivalent.

Secondly, hydrogen has an energy per unit mass around 2.8 times that of kerosene. On an energy basis, hydrogen combustion therefore offers significantly better NOx emissions, partially offset by greater fuel consumption resulting from the increased aircraft drag, a consequence of the low energy per unit volume of liquid hydrogen.

Finally, in this particular scenario, a relatively rapid fleet rollover to hydrogen power is assumed form 2040 to 2050. As a result, in 2050 the fleet is an extremely young fleet compared to the 2050 fleet which would have existed in the pure kerosene-fuelled case. This in itself brings a “modernisation” and hence an emissions improvement to the fleet.

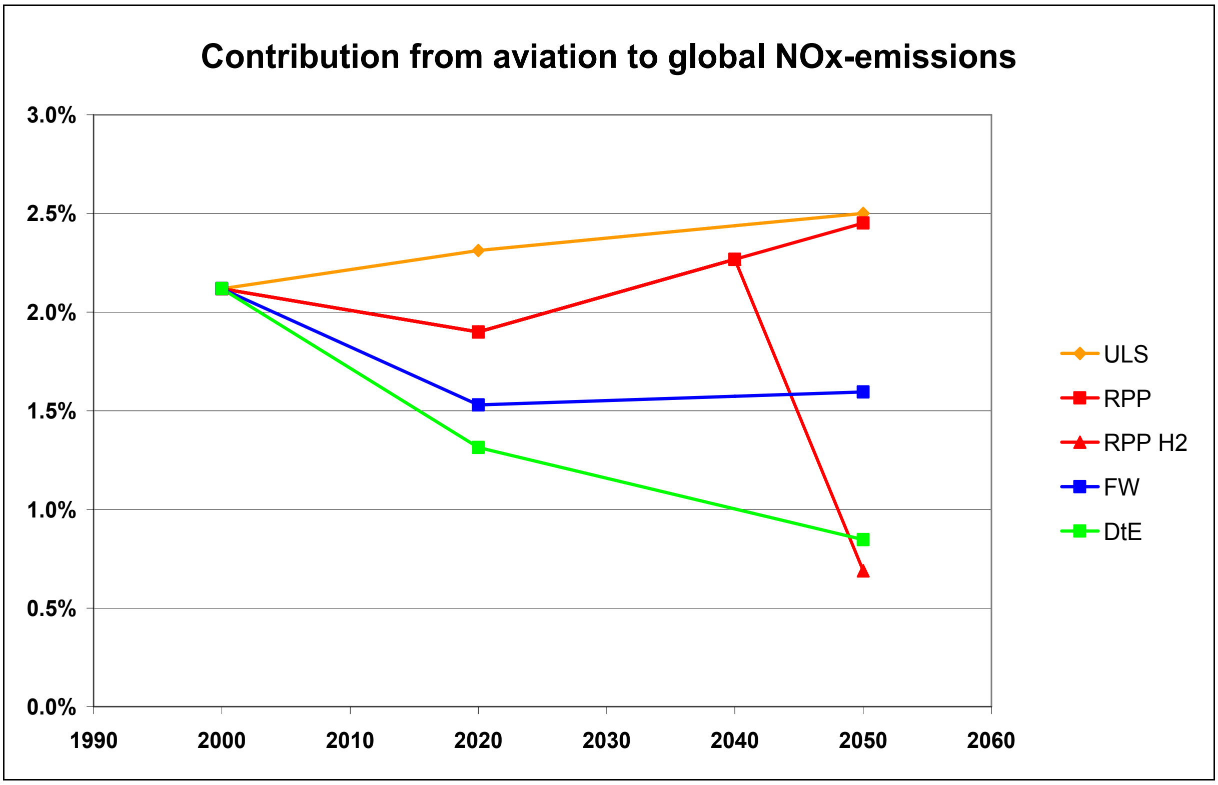


Figure 47: Contribution from aviation to global anthropogenic NOx emissions

Local air quality around airports and noise

Local air quality

The AERO-model was modified to provide results for the Airport Air Quality (AAQ) of which the main species of interest are CO2, 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 photochemical ozone formation) and PM (see AERONET [32]). Levels of airport PM emissions are estimated to be low, but significant uncertainties exist in understanding the complex PM formation process.

Around 65 cities are selected world wide, including a slight emphasis on the larger airports in the western hemisphere. For each of these cities (or airports) the average changes were calculated for fuel consumption, and nitrogen oxides NOx.

Since the AERO model cannot provide the level of detailed 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. The definition of standard deviation implies that 95% of all cities have an emissions factor lower than average plus standard deviation. A factor of 2 for an emission E implies that the volume of emission E around an airport has doubled.

For three of the four basic scenarios – ULS, RPP (kerosene), and FW - NOx emissions around airports will be enhanced up to 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 variance 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, (as it is the case for the total global NOx emissions for this scenario). In the RPP cryoplane sub-scenario aircraft NOx emissions around airports will also be significantly reduced up to 2050.

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

In the following figures 48-52 the detailed results are shown for the basic scenarios and their respective sub-scenarios.

In the Unlimited Skies scenario (figure 48), NOx-emissions will increase with factors 2.2. to 2.4 from 2000 to 2050, depending on the level of the Landing Charge, imposed. Apparently, the increase in air traffic cannot be compensated by a reduction of the emission-index of NOx (EI-NOx) by the NOx-related technology advances, assumed for this scenario.

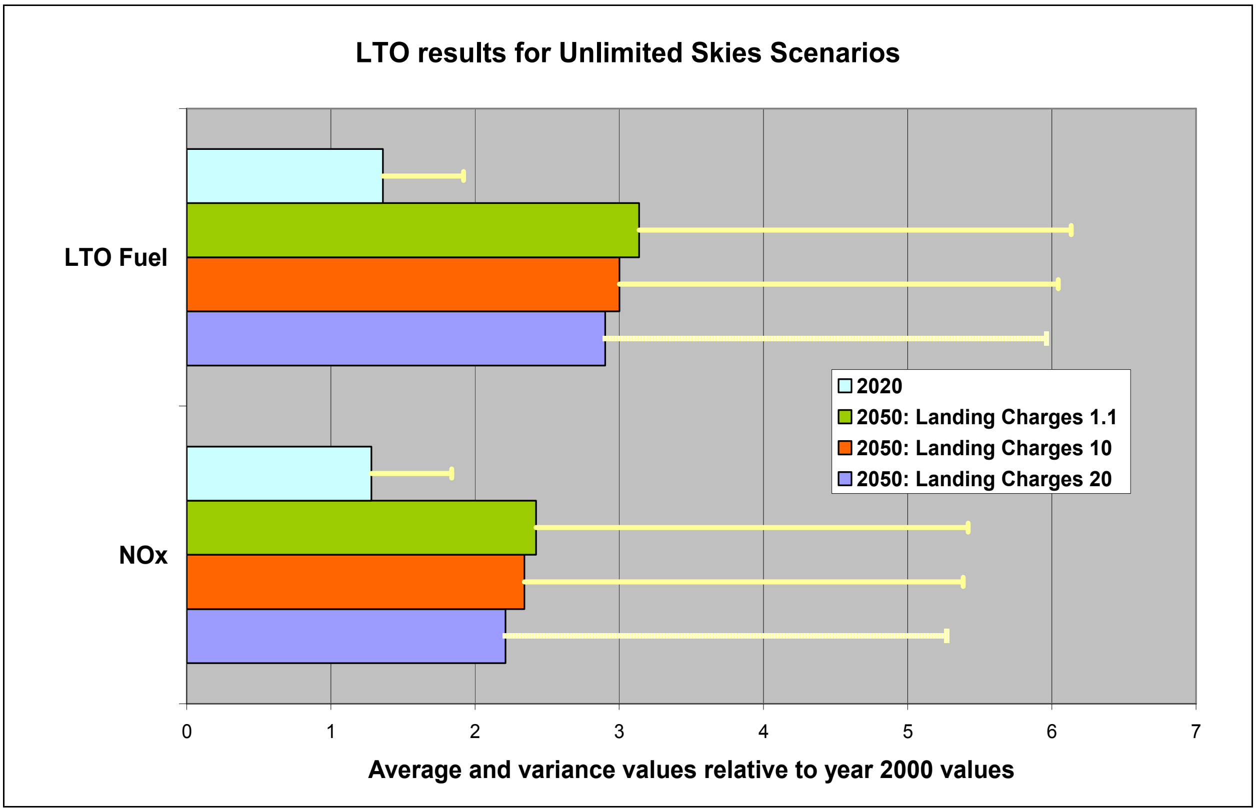


Figure 48: Local Air quality change Unlimited Skies scenario for 2050

In the Regulatory Push & Pull with the all kerosene powered fleet scenario (figure 49), aviations influence on local air quality obviously worsens as well, but at a lower pace than the unlimited skies. Also obvious, application of a kerosene tax (of the order of 10 % of the kerosene price) has only a small effect: Airlines and demand responses to taxes of this level are quite small.

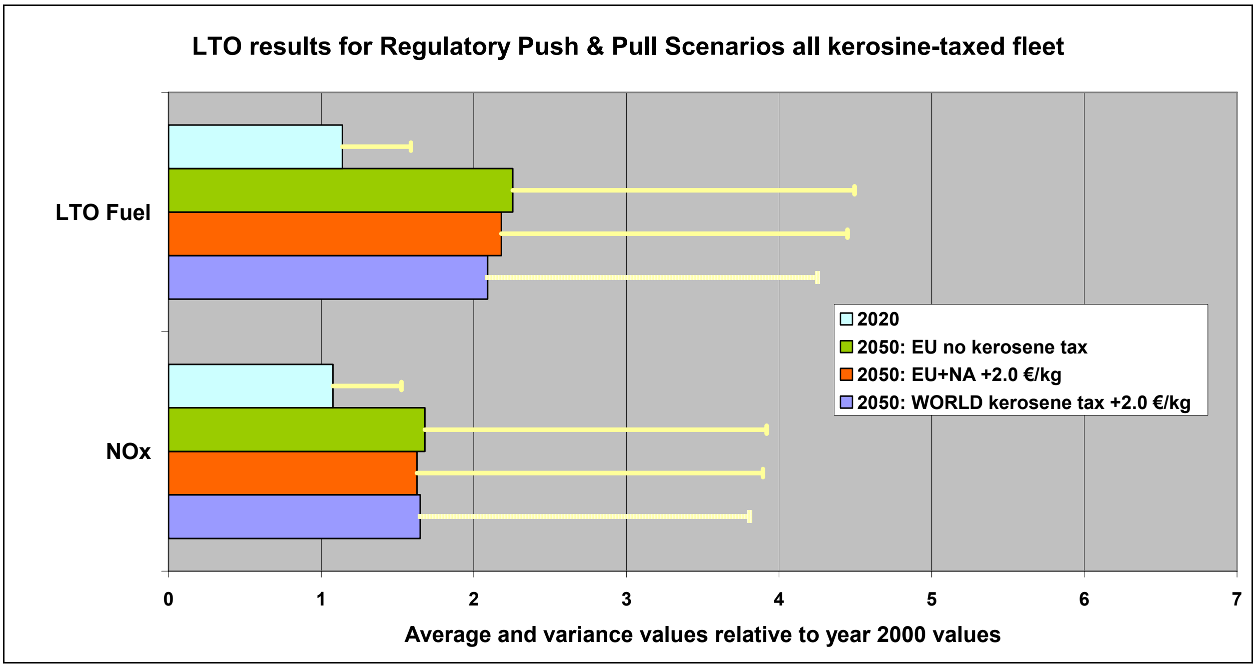


Figure 49: Local Air quality change Regulatory Push & Pull scenario for 2050

In the Regulatory Push & Pull scenario with the kerosene to hydrogen fleet roll-over (figure 50), there is a remarkably different situation:

- The fleet is quite young because of the early phase out of the older, kerosene powered air-craft, hence incorporating the latest technology.
- The fleet is hydrogen powered.

For this scenario factors of changes for other emissions are also shown.

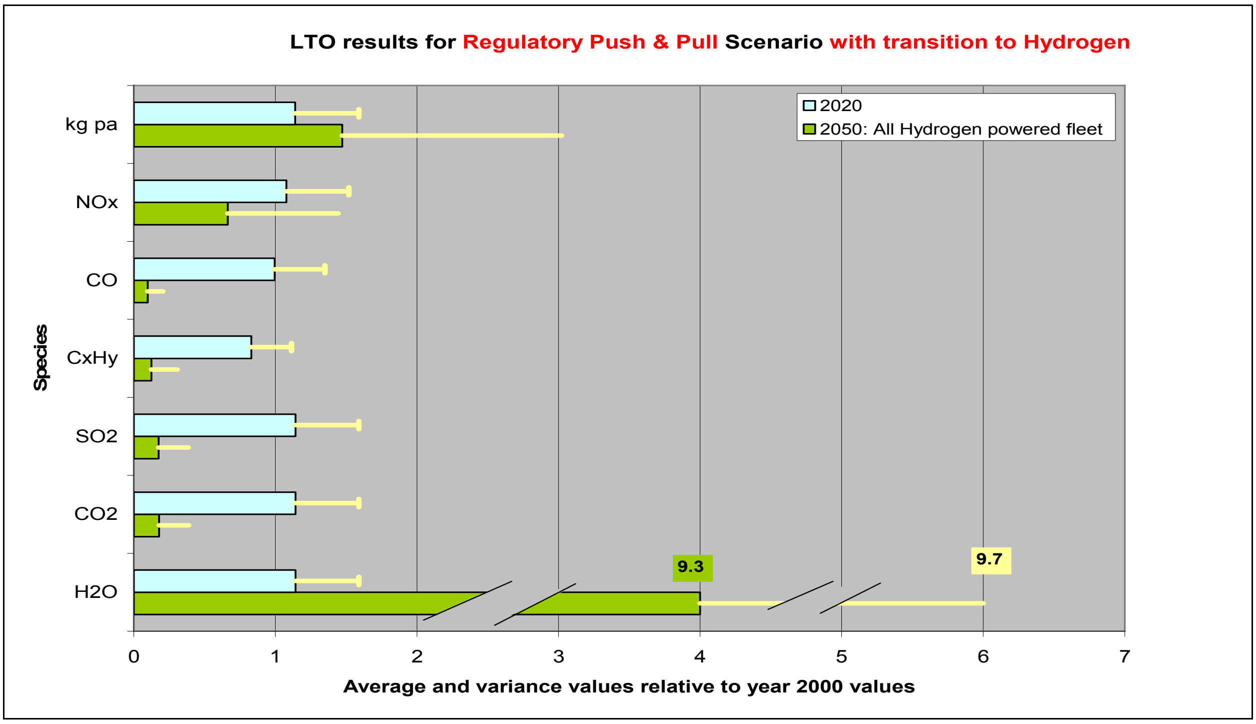


Figure 50: Local Air quality change - RPP cryoplane scenario for 2050

NOx-emissions will be remarkably reduced in the RPP cryoplane scenario. However, it must be recognised that aviation is not financially sustainable. Even, if only the costs of new aircraft are born by the airlines (infrastructure costs are not taken into account), the aviation industry is – without subsidies from the government - faced with heavy losses, even if they have sought the best possible position in setting fare levels. Note that the emissions of H_2O will be significantly increased - by an average factor of 9.3 (and a variance value of 9.7)

The Fractured World scenario (figure 51) has few long-range flights, with limited opportunities for the aviation system to grow. This is apparent from the following figure.

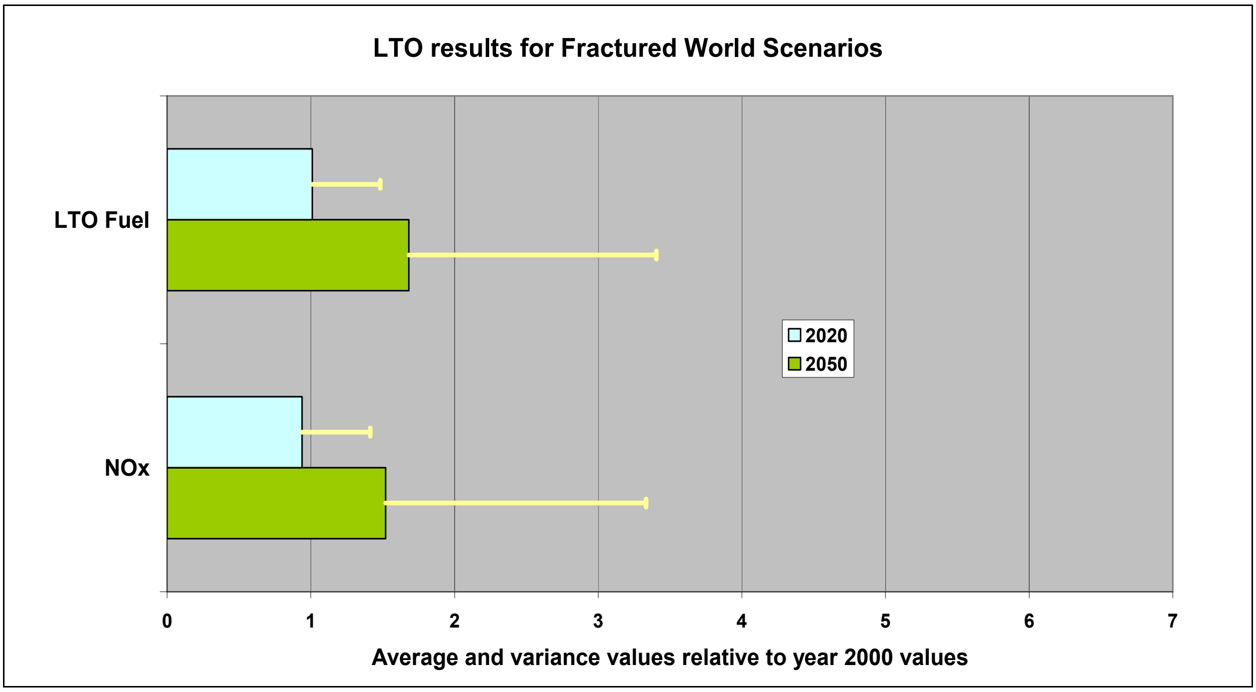


Figure 51: Local Air quality change Fractured World scenario for 2050

Like the Fractured World, aviation activity in the Down to Earth scenario (figure 52) is smaller. Furthermore, there is a high global emphasis on th reduction of NOx emissions. Hence airport air quality will be improved.

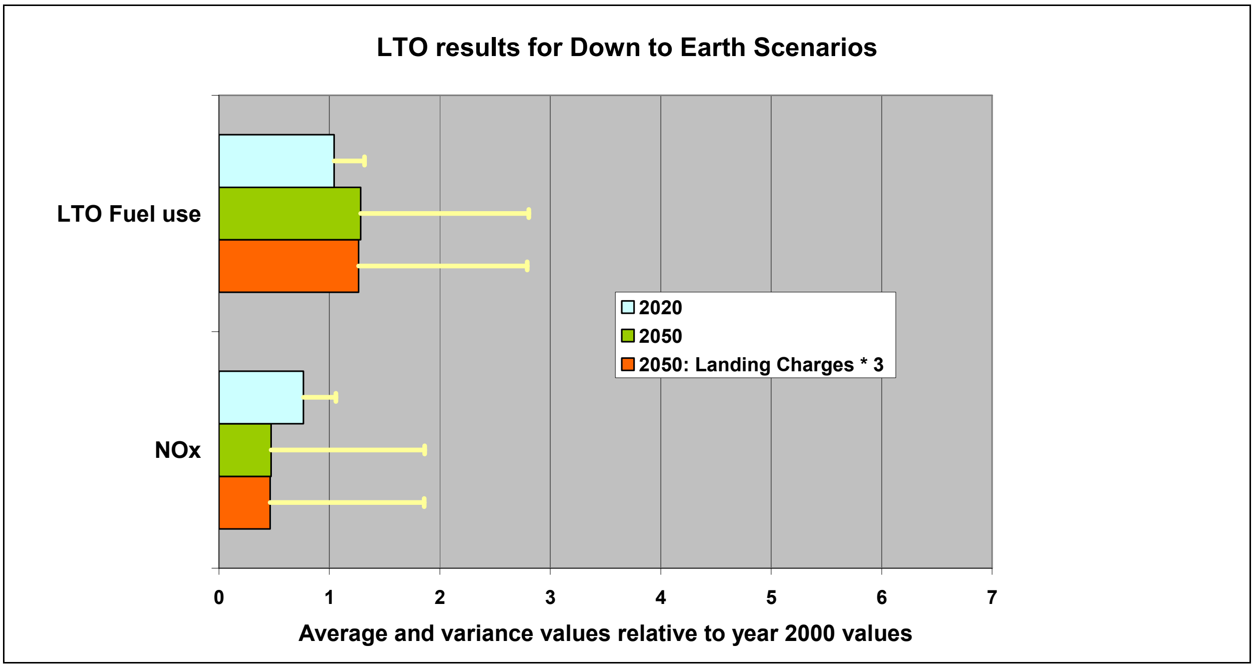


Figure 52: Local Air quality change Down to Earth scenario for 2050

Noise

There are many factors contributing to the noise levels and local air quality at a specific location near an arbitrary airport, among them the geographical location of ground sources, local weather conditions etc. Many of these factors are outside the scope of this project because of the level of detail required. However, some of the major factors can be estimated within the (high level) context of CONSAVE. These are:

- Technical advances of aircraft technology
- Fleet built-up
- Transport volume
- Traffic breakdown in flight frequency and aircraft size for the 'major' cities.

It must be stated that the higher the level of detail under consideration, the lower the fidelity will be.

For the purpose of CONSAVE, a noise factor is designed for noise assessment purposes. This noise descriptor is effectively a noise factor representing the change of impact relative to a reference noise, i.e. 1990 or 2000 situation, and accounts for the following aspects:

- Aircraft technology (source noise) and performance, as changing over time
- Traffic volume

The traffic volume contribution can be corrected for:

- Routes (flight distribution over routes depending on and airport runways and layout)
- Flight scheduling, i.e. the distribution of flights over the time-of-day
- Geographical position relative to routes and airport.

Although noise contours are very much dependent on local routes and aircraft performance, a noise descriptor is designed to take account of technological advances (engine source noise), traffic densities and of the ATM noise abatement efficiency.

The next figure shows the effect of the fleet built-up with the technology scenario alongside. In the case of the high growth scenario, aircraft tend to be on average younger and come with lower average noise levels. The 8 most recent years of technology are again under-represented: Aircraft production lines are assumed to deliver 'constant' technology for roughly 8 years. Hence the latest technology year is presented for only 1/8 of the latest year in aircraft purchases, the latest but one for 2/8 etc. etc.

For the various scenarios Unlimited Skies, Regulatory Push & Pull, Fractured World and Down to Earth, the noise change (reduction) is shown in the following table 47 including the contributing factors. The contributions of the fleet to noise reduction (Source weighted noise reduction) are approximately equal throughout the world, except for the Fractured World, with a 1.6 dB difference between EU and world-average values.

The traffic volume factors are numbers for the EU. The Traffic Technology factor compensates for the increase in runways to accommodate the traffic volume, thereby spreading the noise over larger area.

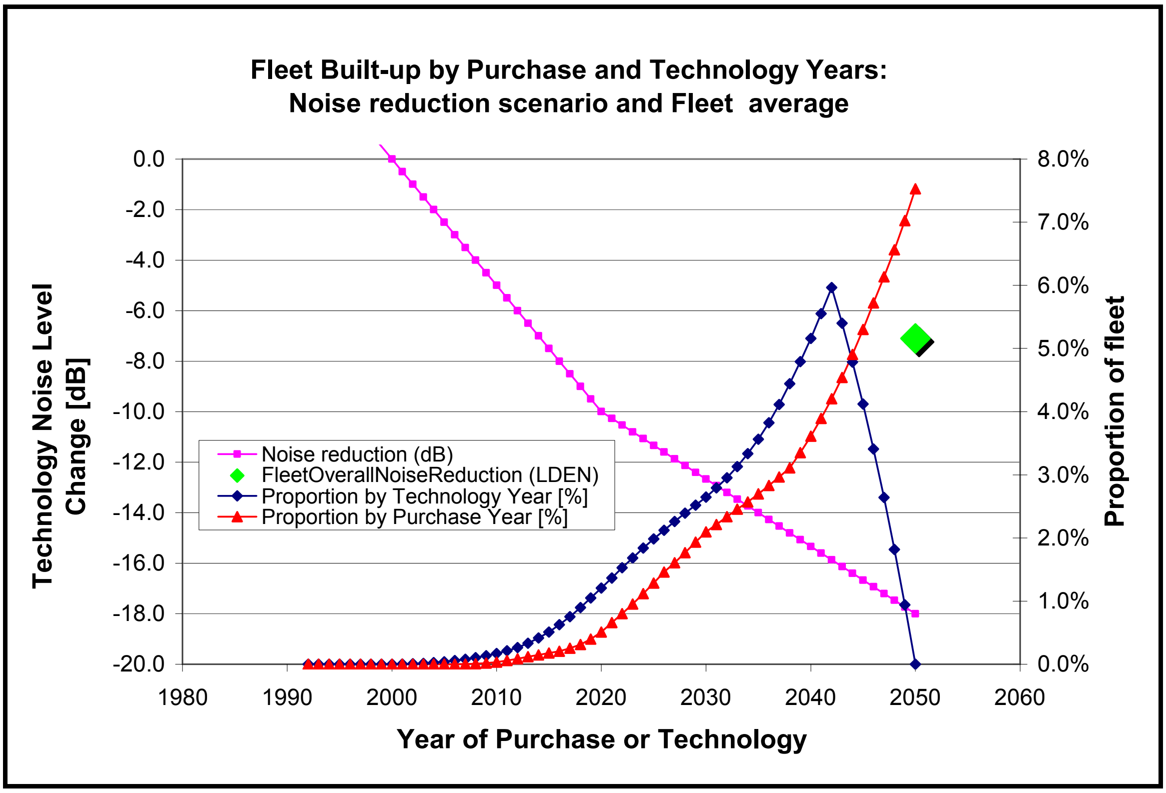


Figure 53: Fleet built-up by purchase and technology years: noise reduction and fleet average (typical for an expanding fleet)

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
Traffic technology factor	0.90	0.95	0.95	0.95	0.95	0.95
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).

Table 47: Lden* noise reduction compared to year 2000

The results indicate that (imposed) noise at ground level will be reduced significantly. However, there is a major pitfall here: Implicitly it is assumed that the sensitivity of the communities to aviation noise and the accompanying regulations are not different from today's standards! (Noise feeling has an objective and a subjective component.)

Economic effects on airlines and unit costs

Economic effects on airlines

The following part shows the cost effects for airlines and their profitability related to the scenarios. Table 48 and figure 54 explain the costs per revenue tonne kilometres in US $/tonne-km, until 2020, stagnating in ULS and slightly increasing in the other scenarios, while increasing in all scenarios after 2020. The lowest increase is quantified for ULS, covering a strong increase in technology development. DtE and RPP, with a slightly higher increase, are including a slower technology development and additional costs for regulations, while in FW higher costs for maintenance and security are causing the highest increase. It should be borne in mind that costs for regulation and security are assumed to be partly passed over to passengers, while maintenance costs are assumed to be covered by the airlines.

US-$/tonne-km	2000	2020	2050
ULS	0.71	0.75	1.15
RPP	0.71	0.88	2
FW	0.71	1.03	1.91
DtE	0.71	1	1.51

Table 48: Cost/RTK in US $/tonne-km

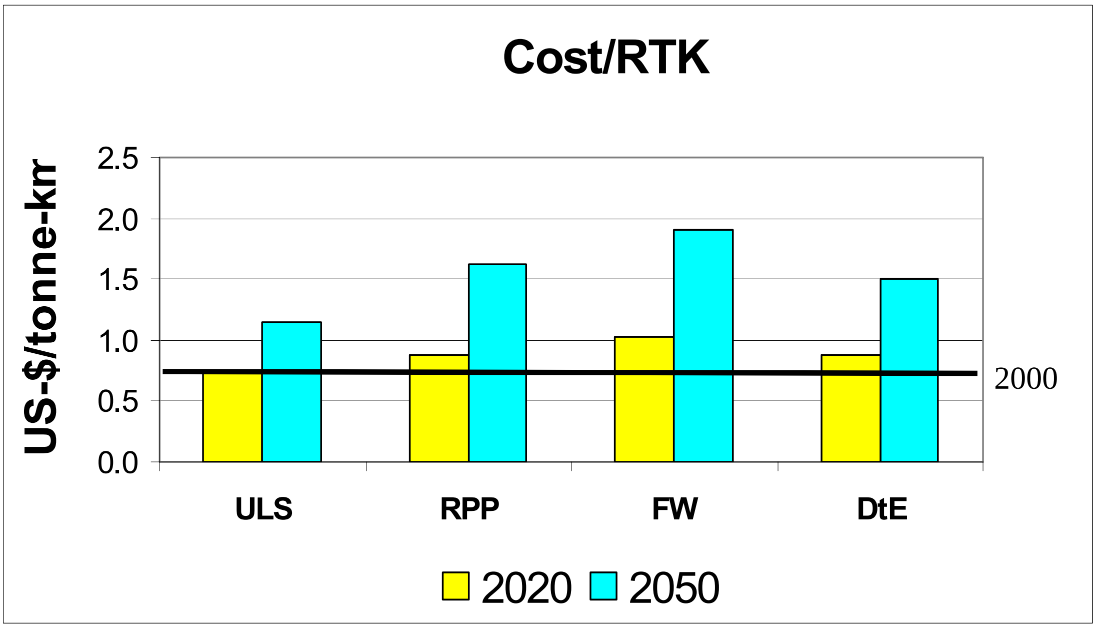


Figure 54: Cost/RTK in US $/tonne-km

Table 49 and figure 55 show the global totals for pax-km/seat-km. This ratio represents the average load factor of the global fleet. As a consequence of a change to larger aircraft especially beyond 2020 (to 2050) in all scenarios, this factor will - in the long-term - reduce in value.

(Note that load factors are an output of the AERO-model.)

Factor	2000	2020	2050
ULS	0.72	0.75	0.69
RPP	0.72	0.75	0.7
FW	0.72	0.71	0.69
DtE	0.72	0.74	0.74

Table 49: Pax-km/seat-km relative to 2000

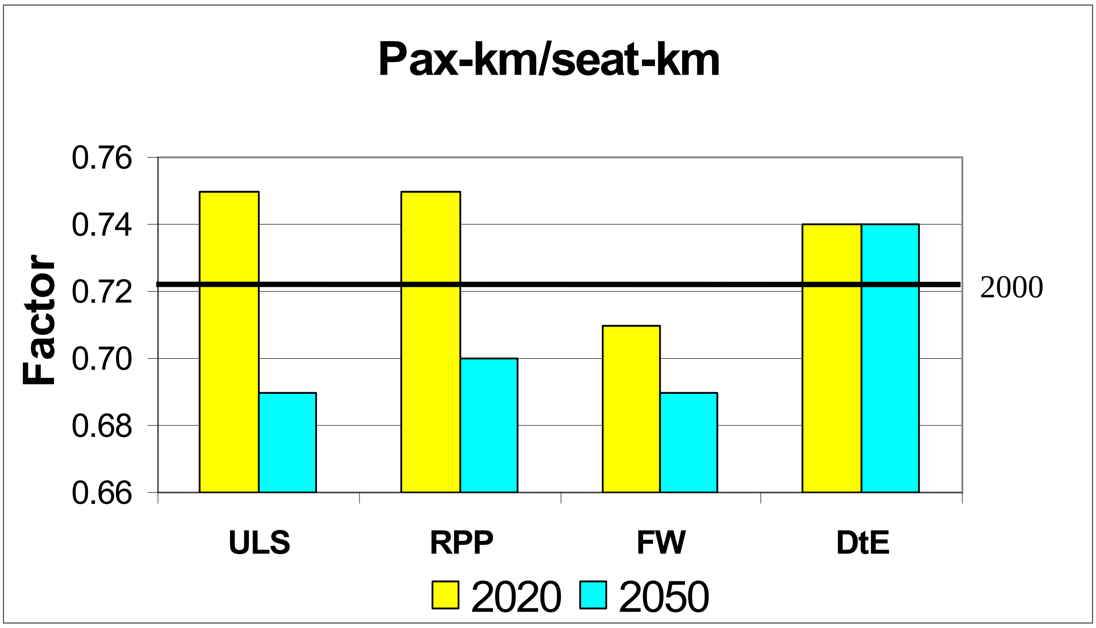


Figure 55: Pax-km/seat-km relative to 2000

Table 50 and figure 56 show revenue tonne kilometer/aircraft kilometer in tonne-km/ac-km, indicating for all scenarios except FW an increase in efficiency and technology compared to 2000.

Tonne-km/ac-km	2000	2020	2050
ULS	14.77	17.7	20.15
RPP	14.77	17.42	19.00
FW	14.77	14.62	13.27
DtE	14.77	17.00	17.12

Table 50: RTK/aircraft-km in tonne-km/ac-km

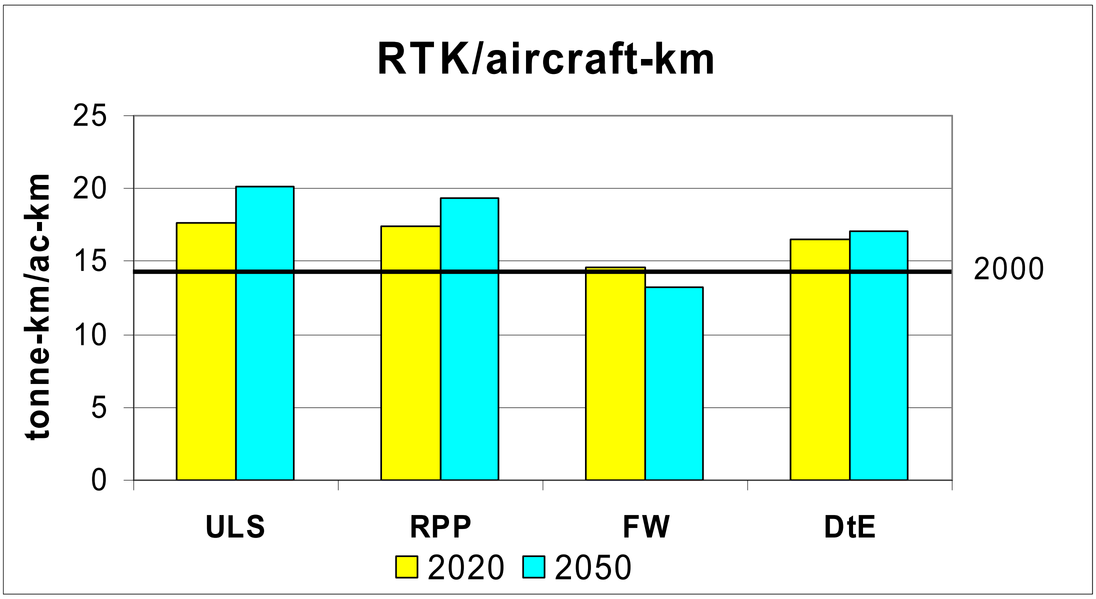


Figure 56: RTK/aircraft-km in tonne-km/ac-km

Table 51 and figure 57 show the operating costs and revenues, which are mainly dependent on flights and to a lower extent also on ticket prices.

Billion 1992 US $	ULS			RPP		FW		DtE	
	2000	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
Operating costs	324	803	4678	776	4351	665	1961	552	1049
Operating revenues	352	869	5000	815	4540	705	2079	564	1070

Table 51: Operating costs and revenues in billion pax-km p.a.

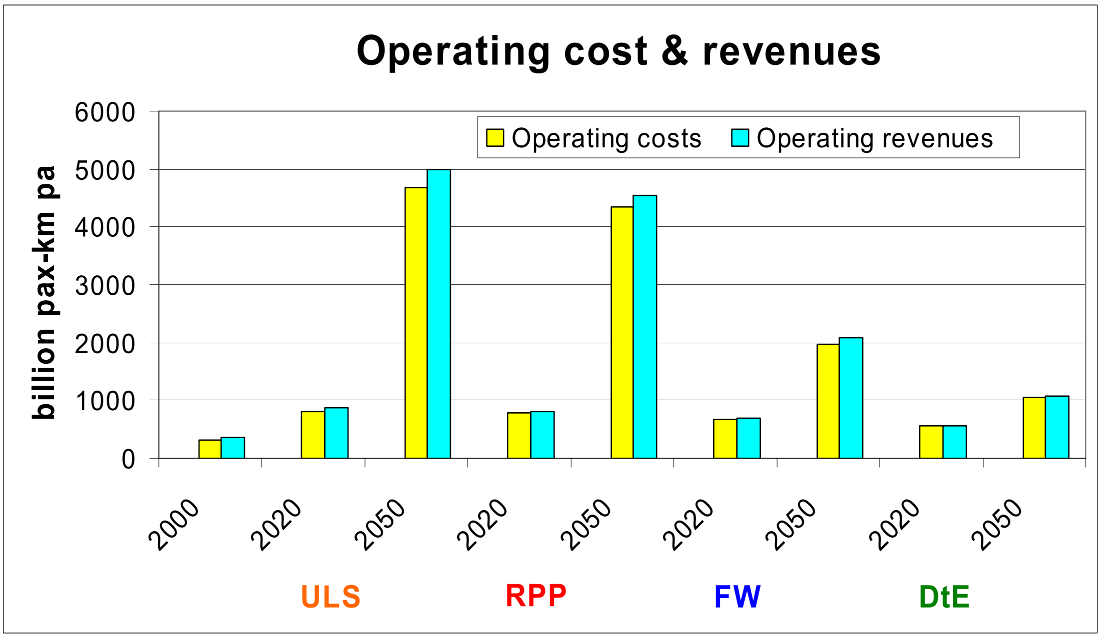


Figure 57: Operating costs and revenues in billion pax-km p.a.

Table 52 and figure 58 show the operating results, visualising the difference between costs and revenues.

Billion 1992 US-$	2000	2020	2050
ULS	27.75	65.41	321.79
RPP	27.75	39.17	189.13
FW	27.75	39.47	118.64
DtE	27.75	12.11	20.58

Table 52: Operating results in billion 1992 US $

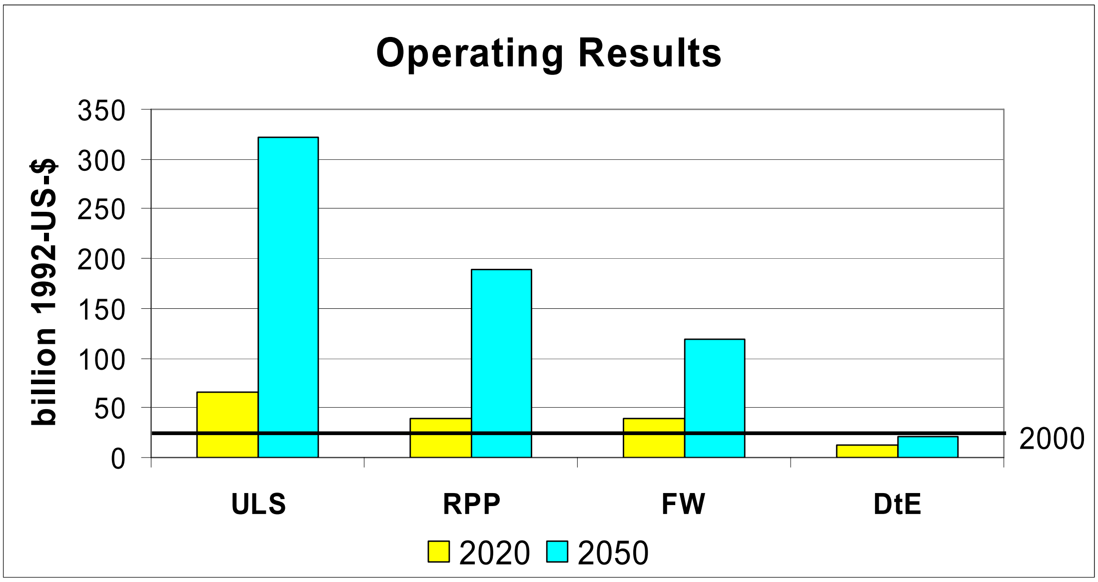


Figure 58: Operating results in billion 1992 US $

Consequently the lowest values are in DtE and the highest in ULS, were aviation is a big business. However, that does not automatically mean that aviation is an efficient business. Taking into account the unit costs and fares, the picture looks quite different. Table 53 and figure 59 show, that highest revenues per RTK are to expect in FW (caused by a larger proportion of short-distance trips) while lowest revenues per RTK are in ULS (caused by large costs to realise the high traffic volume). ULS has high competition and high traffic volumes.

US$/tonne-km	2000	2020	2050
ULS	0.77	0.81	1.23
RPP	0.77	0.93	1.70
FW	0.77	1.09	2.03
DtE	0.77	0.90	1.54

Table 53: Revenues/RTK in 1992 US $/tonne-km

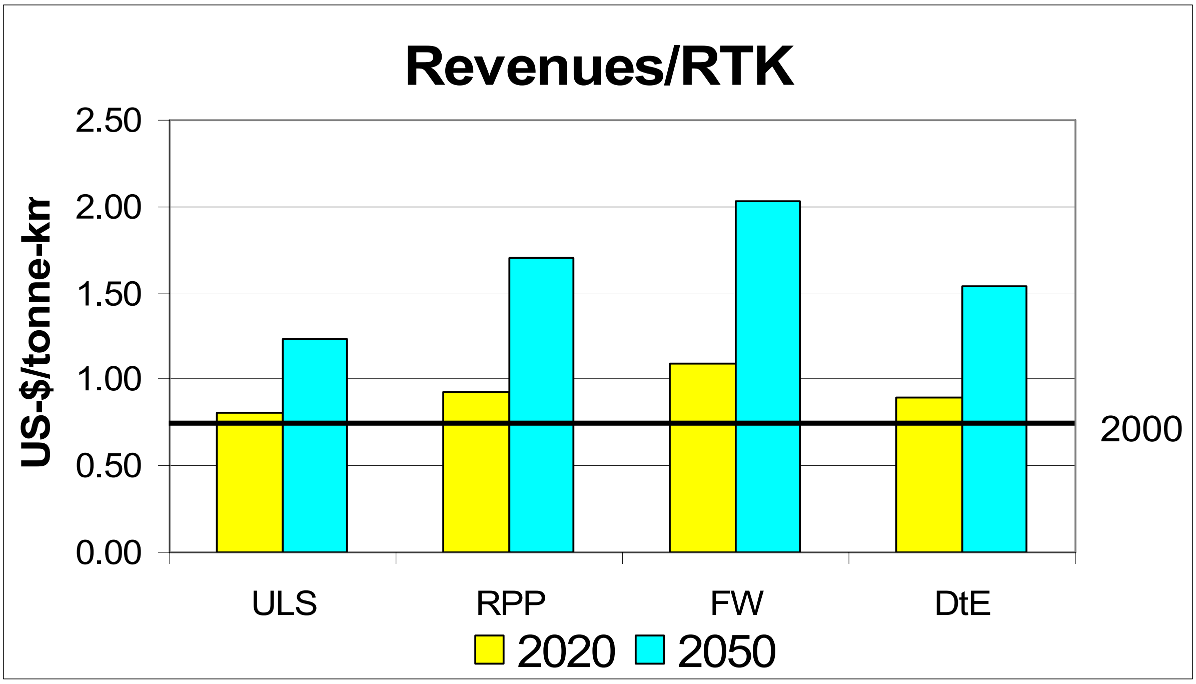


Figure 59: Revenues/RTK in 1992 US $/tonne-km

In the light of sustainability, the most important economic question is, whether aviation actors can keep up the supply in a profitable way. From this aspect, the AERO model can produce results for airlines, shown in table 54 and figure 60. For comparison, the figure also shows the profitability investigated by McKinsey for the years 1992-1996. The scenario results underline that, except for FW, profitability over time is decreasing because of the adjustment to the assumed challenges and constraints. However, in the time period to 2050, aviation is a very profitable business in ULS, while regulation is causing a slightly lower profitability in RPP, compared to today. Low demand plus regulation are strongly decreasing the profitability in DtE. The comparatively good profitability in FW is explained by differences in the regional development – some regions, especially North America and Eurasia seem able to adjust to the assumed fragmentation in the long run, dividing the world into winners and losers within the fractured world. One has to bear 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. This would require additional quantification, outside the scope of this project.

in Percentage	ULS	RPP	FW	DtE
2020	8.14%	5.05%	5.93%	2.19%
2050	6.88%	4.35%	6.05%	1.95%

Table 54: Profitability of airlines (revenues in percentage of invested capital)

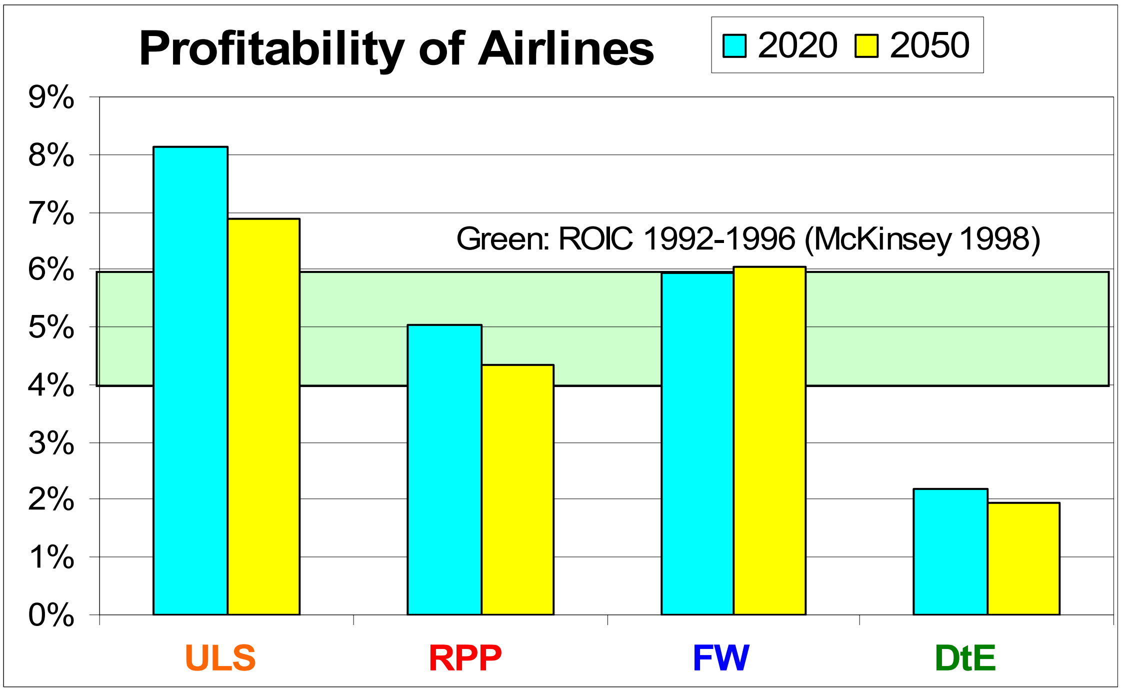


Figure 60: Profitability of airlines (revenues in percentage of invested capital)

Unit costs

Unit costs are means to assess the relative impact of costs components and at the same time are criteria for efficiency. A comparison across scenarios as well as a sensitivity analysis can also be made.

The following graphs show the unit costs in time for each scenario. The 'other costs' components in the Fractured World scenarios are the costs (only the relatively small part borne by the aviation sector) due to extra investments in hydrogen aircraft.

For the unit costs compositions, a number of observations can (already) be made:

- Costs with a large labour component (cabin crew, cockpit crew, maintenance) grow with GDP/capita.
- Some costs, notably volume costs reduce the operating costs considerably.
- Fuel price increases are compensated by fuel efficiency improvements per RTK. The latter is a combination of larger aircraft and overall improvement in fuel efficiency.

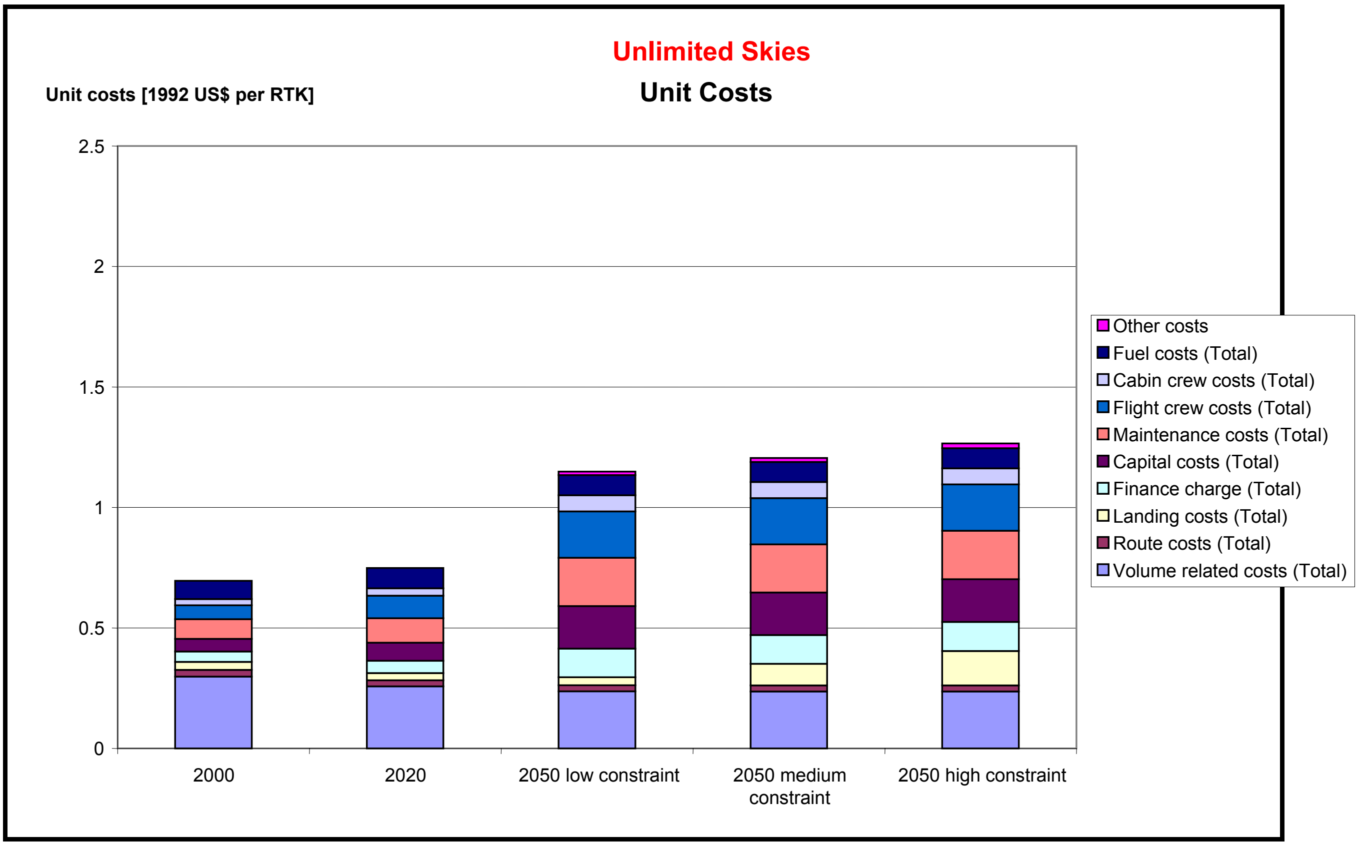


Figure 61: **Unit costs comparison for various scenario years for the Unlimited Skies scenario and different levels of landing charges (imposed constraints)**

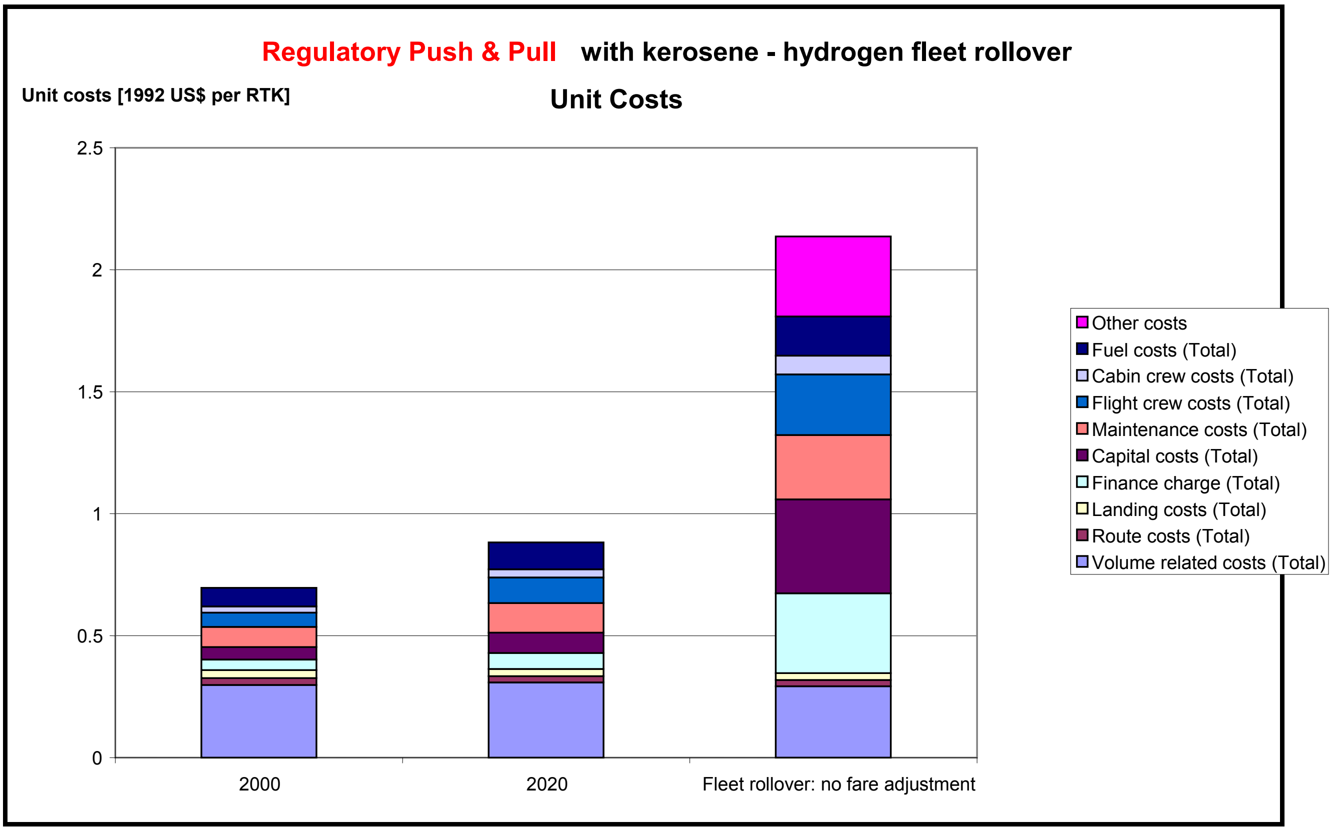


Figure 62: **Unit costs comparison for various scenario years for the Regulatory Push & Pull scenario with all hydrogen powered fleet. Aviation sector is a heavily loss making business.**

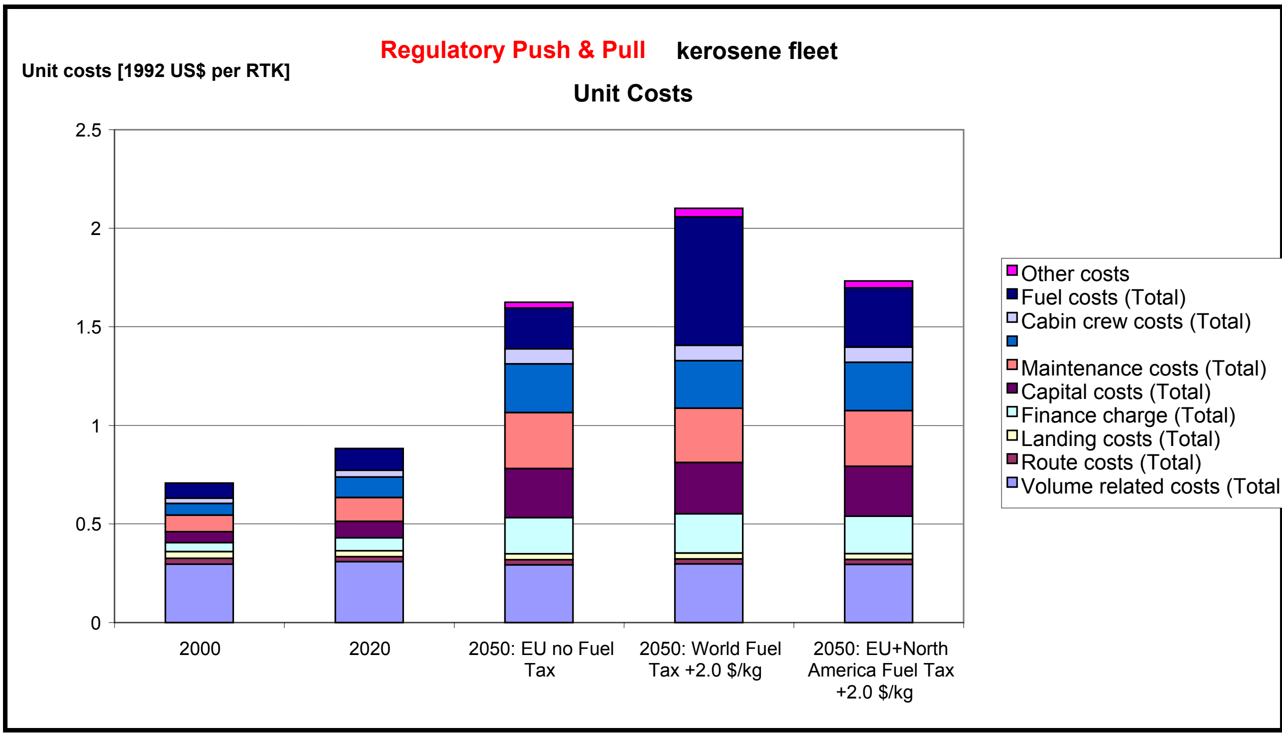


Figure 63: Unit costs comparison for various scenario years for the Regulatory Push & Pull scenario with an all kerosene powered fleet: For 2050 three different levels of fuel taxation are shown

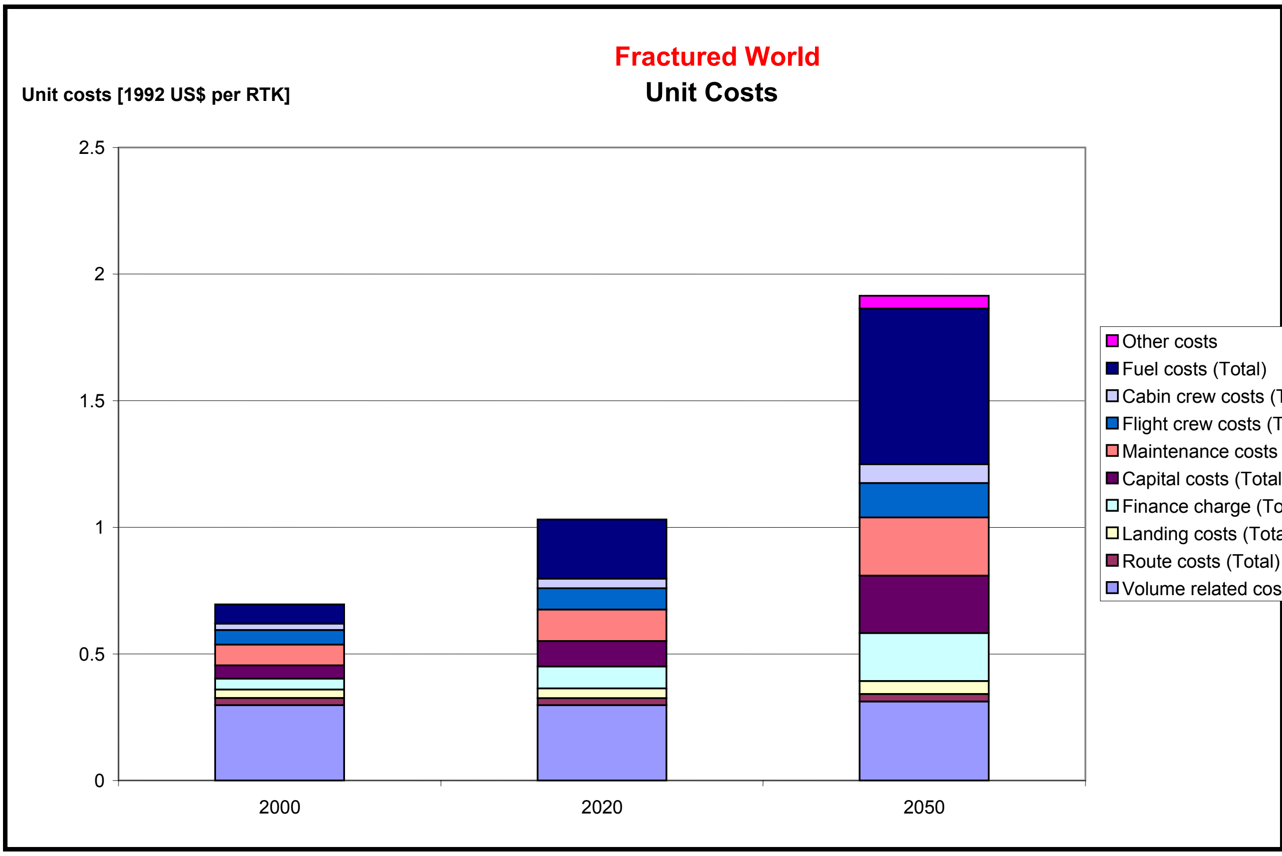


Figure 64: Unit costs comparison for various scenario years for the Fractured World scenario

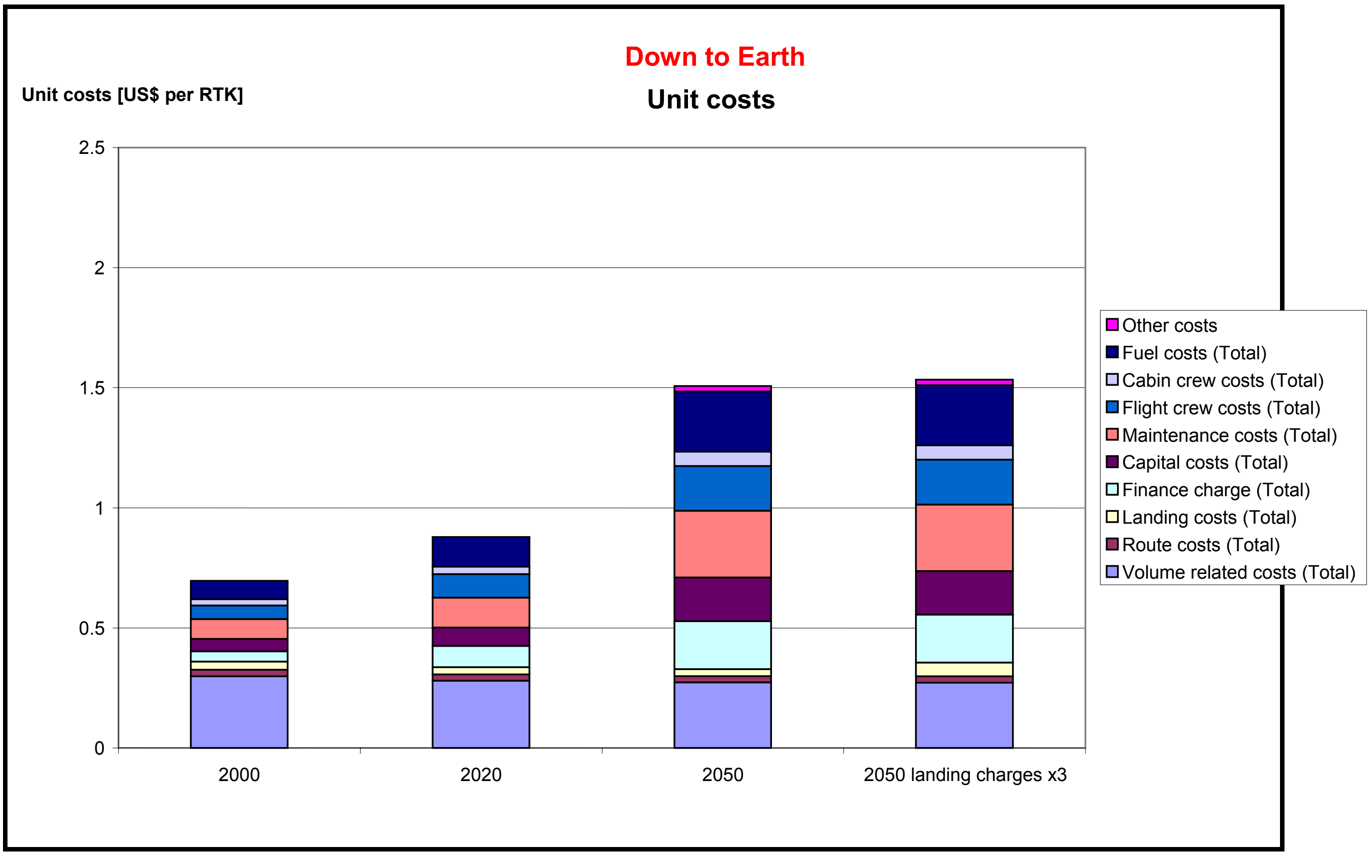


Figure 65: Unit costs comparison for various scenario years for the Down to Earth scenario

Airlines related employment

In the scenario ULS the airlines-related employment increases from 2.4 million employees in 2000 to 4.9 million in 2020 and to 16.6 million employees in 2050 (see table 55 and figure 66). In comparison to ULS, the increase of airline-related employees is a little lower in RPP and very low in FW and DtE. This development seems to be plausible in relation to the scenario specific aviation developments in general and the figures for relative growth in demand.

1000 employees	2000	2020	2050
ULS	2481	4919	16610
RPP	2481	4566	13065
FW	2481	3515	5906
DtE	2481	3183	3487

Table 55: Employees at airlines in 1000

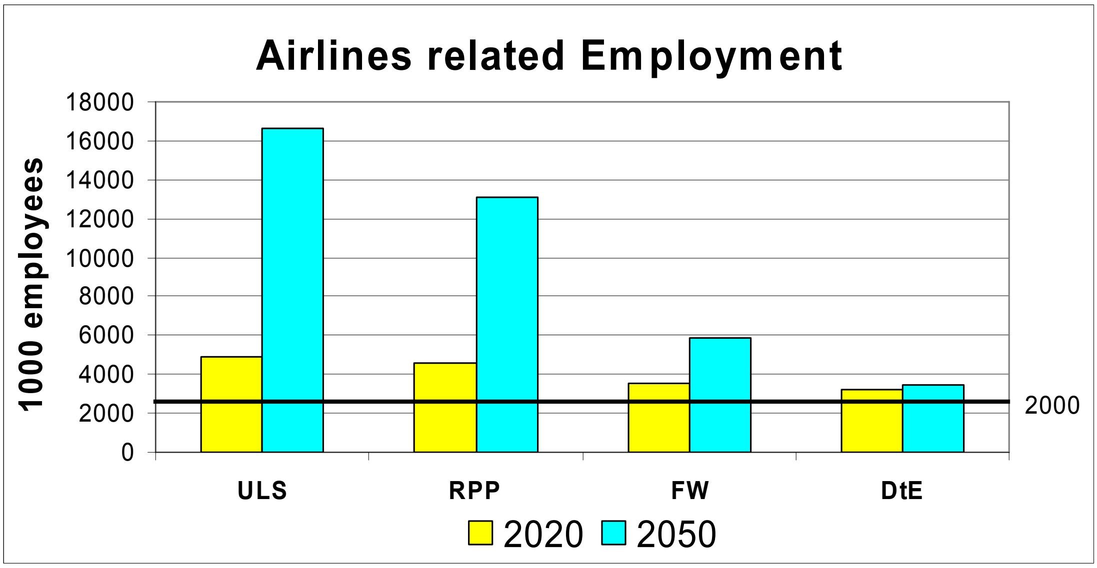


Figure 66: Employees at airlines in 1000

Effects for a typical major European airport

Based on the figures and tables above and assuming that the hub or spoke function within the aviation network is constant the following tables 56 and 57 give an overview of the consequences for a typical major European airport. Results show that in DtE passenger demand is decreasing, but more movements are expected, as DtE has many relatively small aircraft (with low NOx emissions).

			ULS		RPP		FW		DtE	
		2000	2020	2050	2020	2050	2020	2050	2020	2050
Pax demand	million pax pa	38.1	54.2	169.6	43.9	107	33.8	43.1	36.6	35.1
Cargo demand	million tonne pa	1.14	2.63	10.09	2.19	5.8	1.51	1.78	1.46	1.36
Movements	1000 mov. pa	427	608	1608	511	1106	432	607	442	480
Employment	billion 1992 US $	107	159	446	135	293	106	128	110	106

Table 56: Pax/cargo demand (in million pax p.a.), movements (in 1000), employment (in billion 1992 US $)

Growth in Percentage relative to 2000	ULS		RPP		FW		DtE	
	2020	2050	2020	2050	2020	2050	2020	2050
Pax demand	42%	345%	15%	182%	-11%	13%	-4%	-8%
Cargo demand	131%	785%	92%	409%	32%	56%	28%	19%
Movements	42%	276%	20%	159%	1%	42%	3%	12%
Employment	49%	317%	26%	174%	-1%	20%	3%	-1%

Table 57: Growth of pax/cargo demand, movements, employment relative to 2000

5.8.3 Sub-scenarios and scenario specific tests

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

Unlimited Skies - Additional runway requirements

The following figure 67 shows the effects of Landing Charges on air transport volume and the number of movements that can be accommodated due to new infrastructure, financed by Landing Charges.

Three costs levels (expressed as a landing charge factor) for infrastructure (expressed as the maximum capacity of the year 2000) and two levels of ticket price and effect on air transport volume (expressed as the maximum capacity of the year 2000) are shown. These cost levels demonstrate that a landing charge increase of approximately 3 to 6 times is required to accommodate all air traffic in the US and EU using additional infrastructure.

The number of additional runways needed to accommodate all flights (shown in figures 68 and 69) is based:

- On the aircraft movements of 2050 compared to 2000 by (major and aggregated minor) airports
- On an inventory of airports and number of runways available for the year 2000
- And on the effective level of runway capacity used in the year 2000

Note that only the cost levels are considered; the availability of the required space in term of land use planning is not assessed.

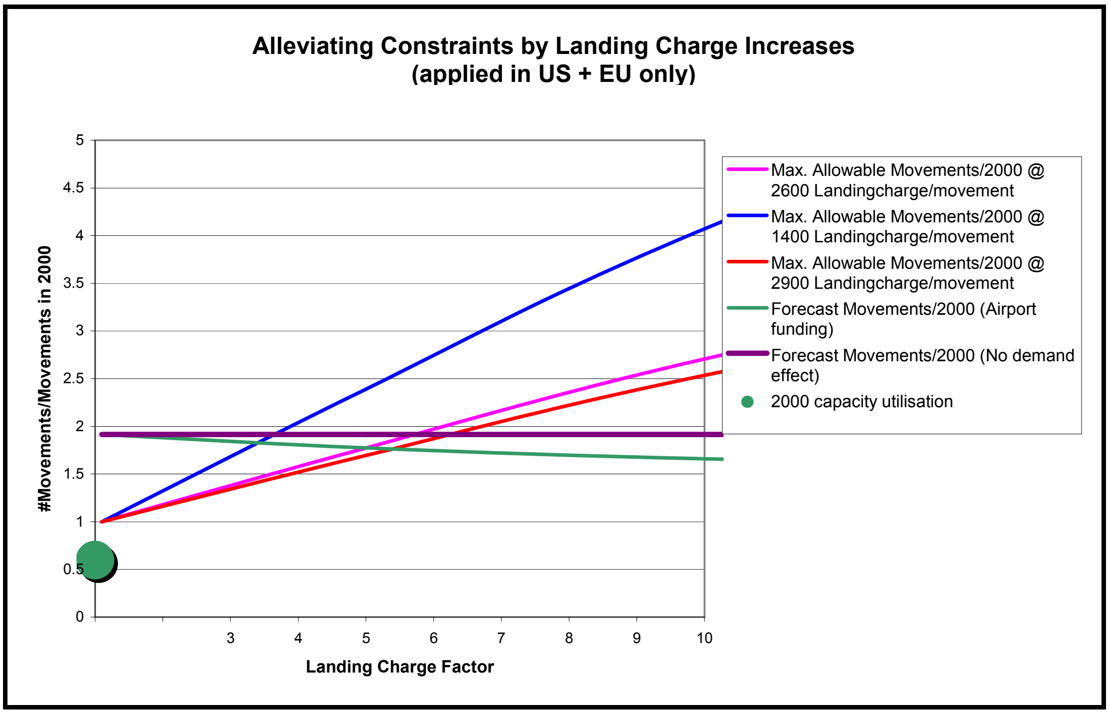


Figure 67: Landing charge increases for fund raising and effect on traffic volume

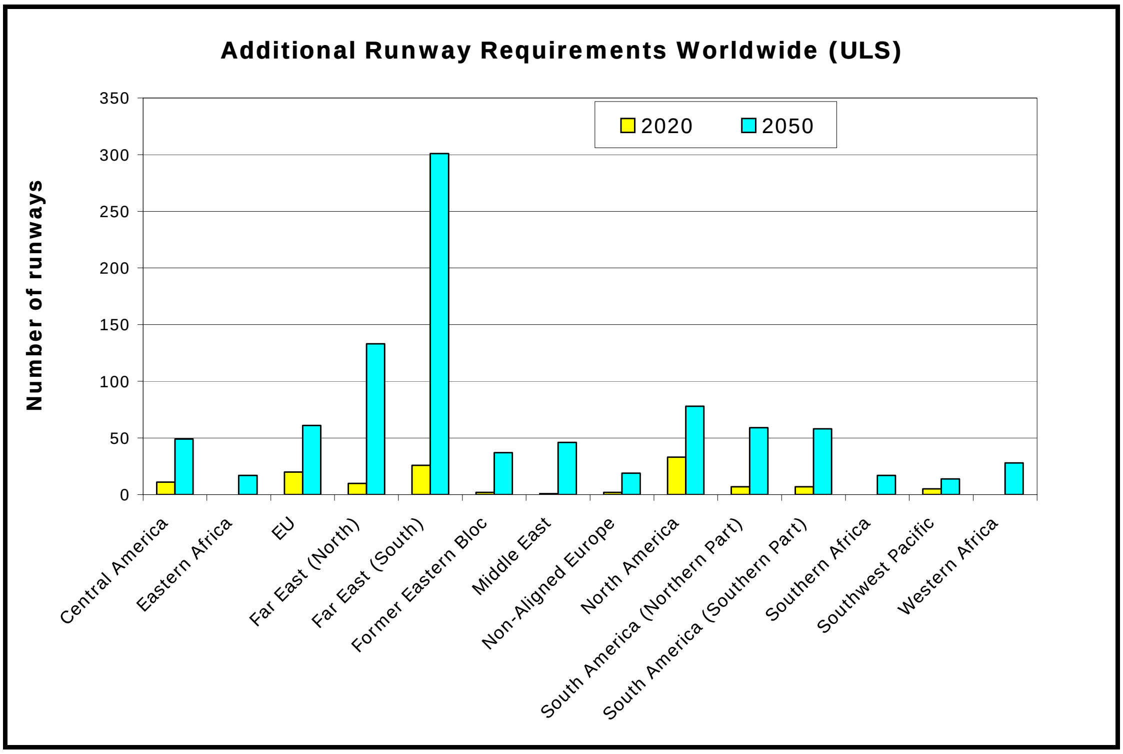


Figure 68: Additional runways needed (World) to accommodate future traffic in 2050 for the ULS scenario

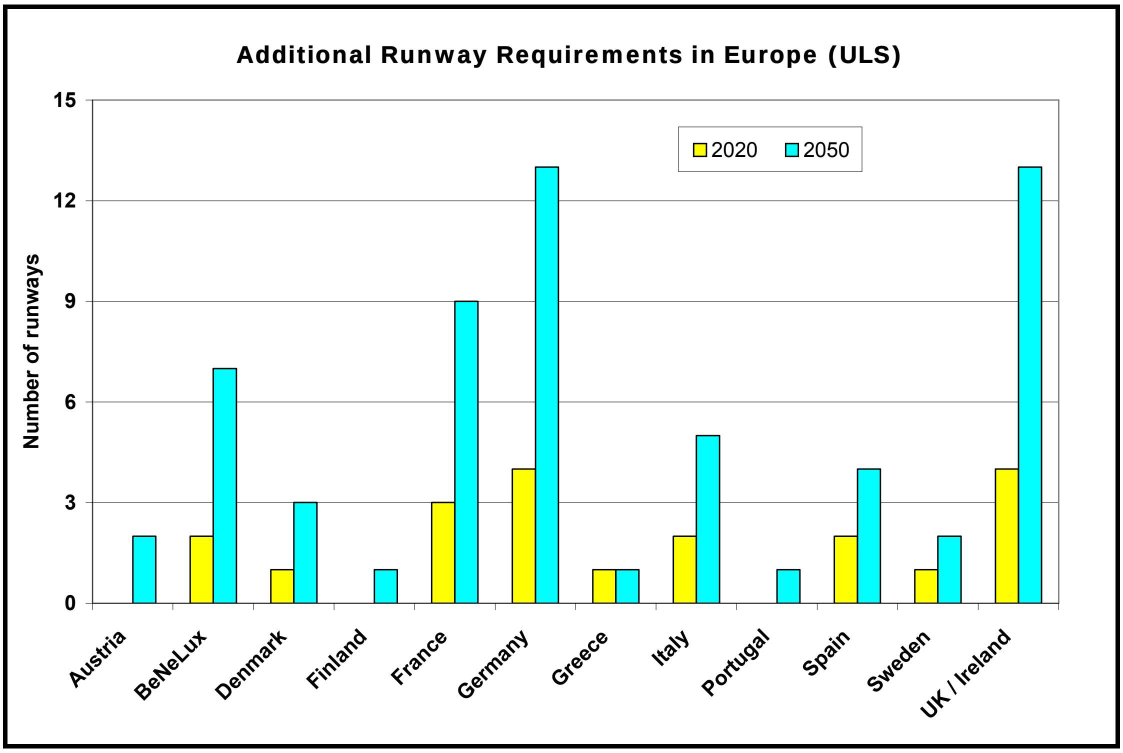


Figure 69: Additional runways needed (Europe) to accommodate future traffic in 2050 for the ULS scenario

Unlimited Skies - Landing Charges

Constraints in infrastructure (especially in Europe) and increasing local airport emissions brought up a discussion about landing charges as a possible solution. The following results deal with the question, how efficient this measure could be and which impacts can be estimated on demand, fleet, airline profitability and NOx-emissions.

Effects on demand

In table 58 and figure 70, the demand growth of ULS and two sub-scenarios are given. In two sub-scenarios, higher landing charges (by factors 10 and 20) are assumed, starting in 2020. These force airlines to use bigger aircraft and/or to pass additional costs to customers. In these cases, the increase of demand is 1.5% and 3.0% lower than in the scenario with today's landing charge (the "normal" increase being a factor of 1.1).

Billion pax-km p.a.	2000	2005	2020	2050
ULS (charge factor 1.1)	3308	4091	6505	21185
ULS (charge factor 10)	3308	4091	6505	20874
ULS (charge factor 20)	3308	4091	6505	20554

2020-2050	Reduction	%
14680	-	0
14369	311	1.5%
14049	631	3.0%

Table 58: Range of passenger demand for ULS sub-scenarios in billion pax-km p.a.

Table 59 shows the effects on movements, reflecting the use of bigger aircraft, which are strongly dampening the need for new infrastructure.

Movements – In 1000 flights p.a.	2000	2020	2050
ULS charge factor 1.1	393.6	608.3	1607.6
ULS charge factor 10	393.6	608.3	1383.2
ULS charge factor 20	393.6	608.3	1226.5

2020-2050	Reduction	%
999.3	-	0
774.9	224.4	14.0%
618.2	381.1	23.7%

Table 59: Range of movements for ULS sub-scenarios in 1000 mov. p.a.

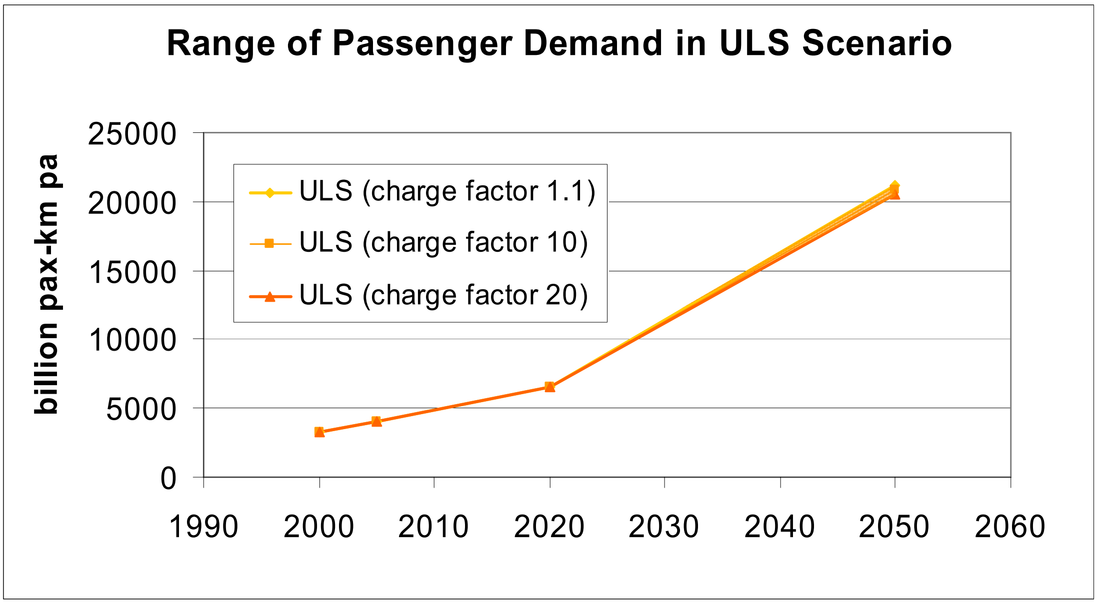


Figure 70: Range of passenger demand for ULS-sub-scenarios in billion pax-km p.a.

Effects on the fleet

In table 60 and figure 71 the ULS aircraft fleet are shown with two sub-scenarios. In the sub-scenarios, fleet growth is 3.1% (landing charge factor 10) and 5.1% (landing charge factor 20) lower than in the scenario with today's landing charge, causing a shrinking market for manufacturers.

Number of aircrafts	2000	2005	2020	2050	2020-2050	Reduction	%
ULS (charge factor 1.1)	18988	22992	34790	105570	70780	-	0
ULS (charge factor 10)	18988	22992	34790	102250	67460	3320	3.1%
ULS (charge factor 20)	18988	22992	34790	100200	65410	5370	5.1%

Table 60: Range of aircraft fleet for ULS-sub-scenarios

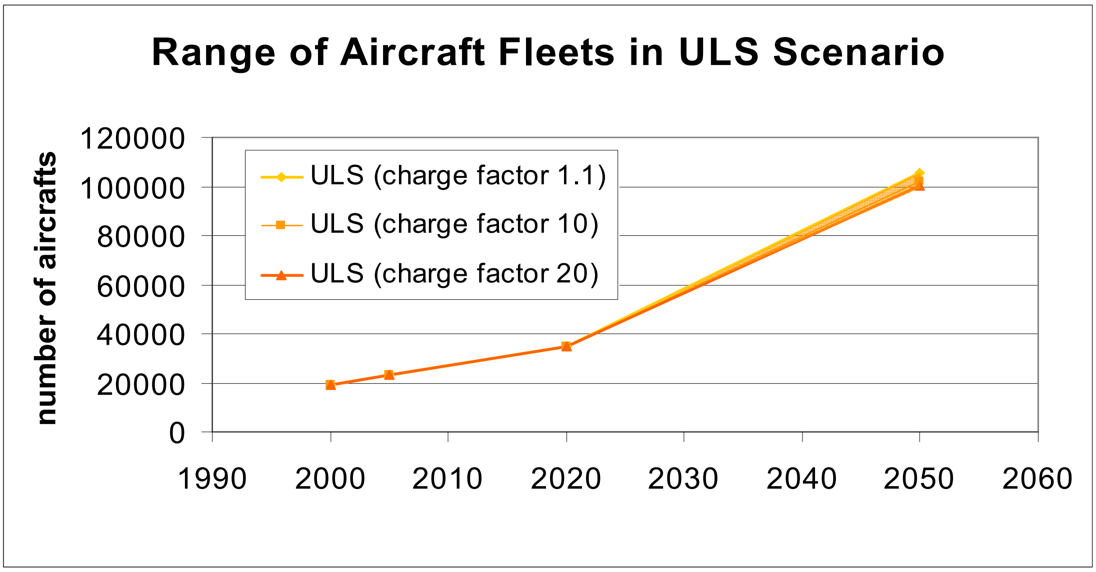


Figure 71: Range of aircraft fleet for ULS-sub-scenarios

Effects on the airlines profitability

Figure 72 shows the profitability of airlines for ULS (2020, 2050) and related sub-scenarios (2050). The results for increased landing charges are not of great concern. A landing charge factor of 20 shrinks airlines profitability to 4.2% while a charge factor of 10 leads to a profitability of 5.24%. With these rates airlines would remain in the same profitability range as today (4% - 6%).

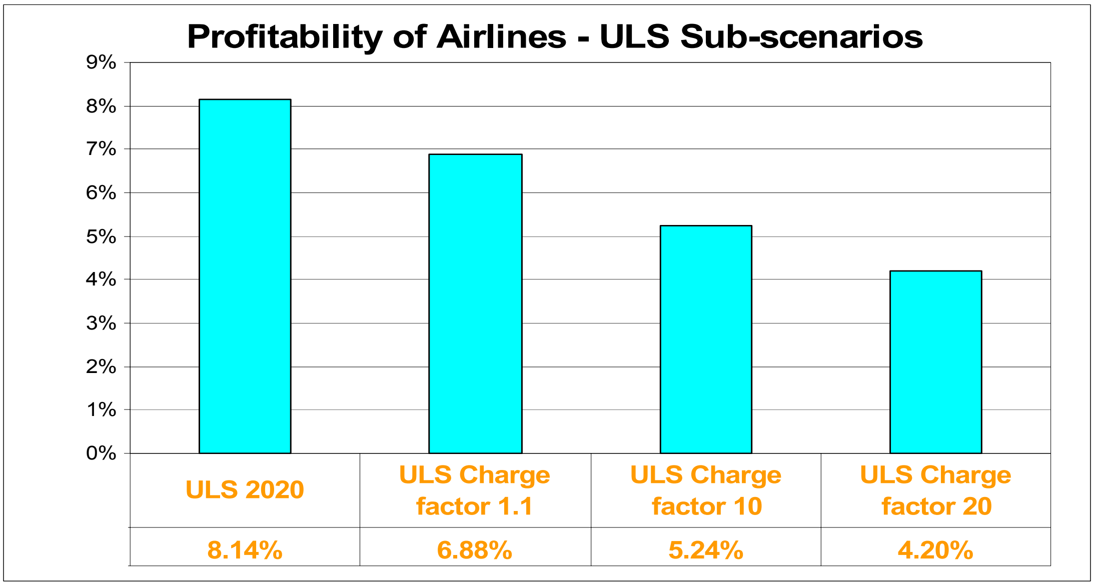


Figure 72: Profitability for ULS sub-scenarios (revenues in percentage of invested capital)

Effects on emissions

Table 61 and figure 73 show similar results for the development of NOx-emissions. In the sub-scenario with a landing charge factor of 10, NOx will be reduced by 0.7%, while a charge factor of 20 brings a reduction of 1.3%. One needs to bear in mind, that the reduction rates are based on the assumption, that in ULS more emphasis is given to reducing fuel consumption instead of NOx.

NOx – million kg pa	2000	2005	2020	2050	2020-2050	Reduction	%
ULS charge factor 1.1	2228	2637	3494.5	7312.6	3818.1	-	0
ULS charge factor 10	2228	2637	3494.5	7262.9	3768.4	49.7	0.7%
ULS charge factor 20	2228	2637	3494.5	7186.2	3691.7	126.4	1.3%

Table 61: Range of NOx emissions for ULS sub-scenarios

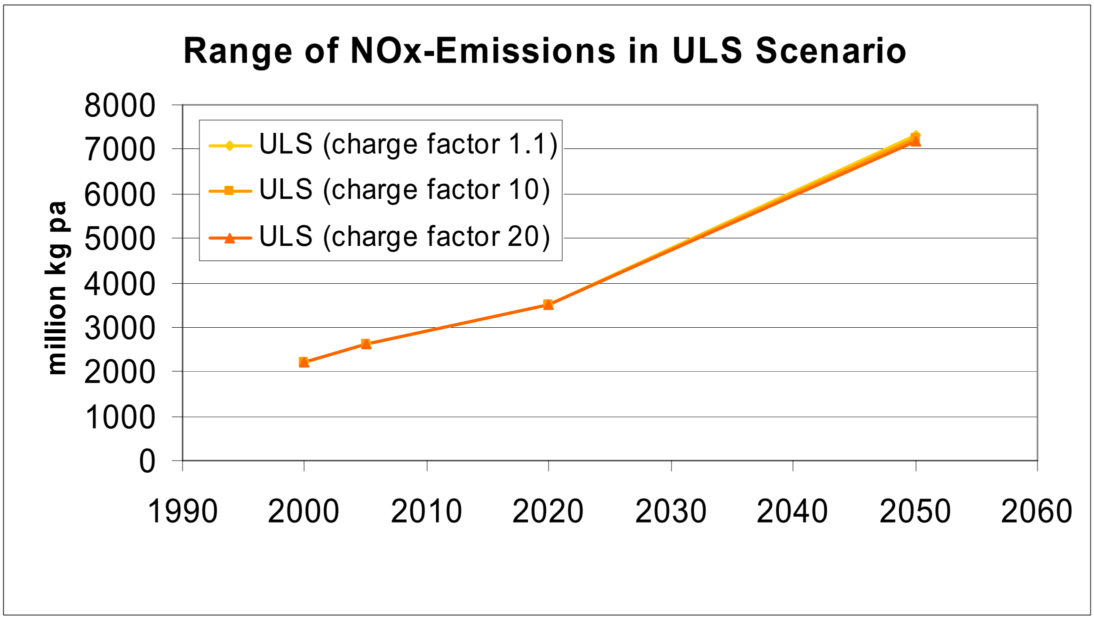


Figure 73: Range of NOx emissions for ULS sub-scenarios

Regulatory Push and Pull - Fuel tax and H2 fleet roll-over

In recent years, there has been an ongoing discussion about the introduction of fuel tax as a possible solution to reduce climate impacts of aviation and to foster engine and aircraft innovation. The following results deal with the question as to how efficient this measure could be and what impact can be estimated for demand, fleet and airlines profitability.

Effects on demand

In table 62 and figure 74, the demand growth of RPP and three sub-scenarios are given. In two sub-scenarios, a fuel-tax (1$/kg and 2$/kg) is assumed starting in 2020. This tax forces airlines to use more efficient aircraft and/or to pass additional costs to customers. In these cases, the increase of demand is 8% and 4% lower than in the scenario without tax. For comparison a reduction of 8% is also estimated for the sub-scenario which describes a fuel-change to hydrogen after 2020, although it should be noted that no infrastructure costs as part of the requirement for the use of hydrogen aircraft are considered in the quantification. Consequently, in the latter sub-scenario, the costs partly passed on to customers are only for new hydrogen aircraft.

Billion pax-km pa	2000	2005	2020	2050
RPP H2-fleet roll-over	3308	4091	5284	13886
RPP no tax	3308	4091	5284	14636
RPP fuel tax 1$/kg	3308	4091	5284	14259
RPP fuel tax 2$/kg	3308	4091	5284	13884

2020-2050	Reduction	%
8602	750	5.1%
9352	-	0
8975	377	2.6%
8600	752	5.1%

Table 62: Range of passenger demand for RPP sub-scenarios in billion pax-km pa

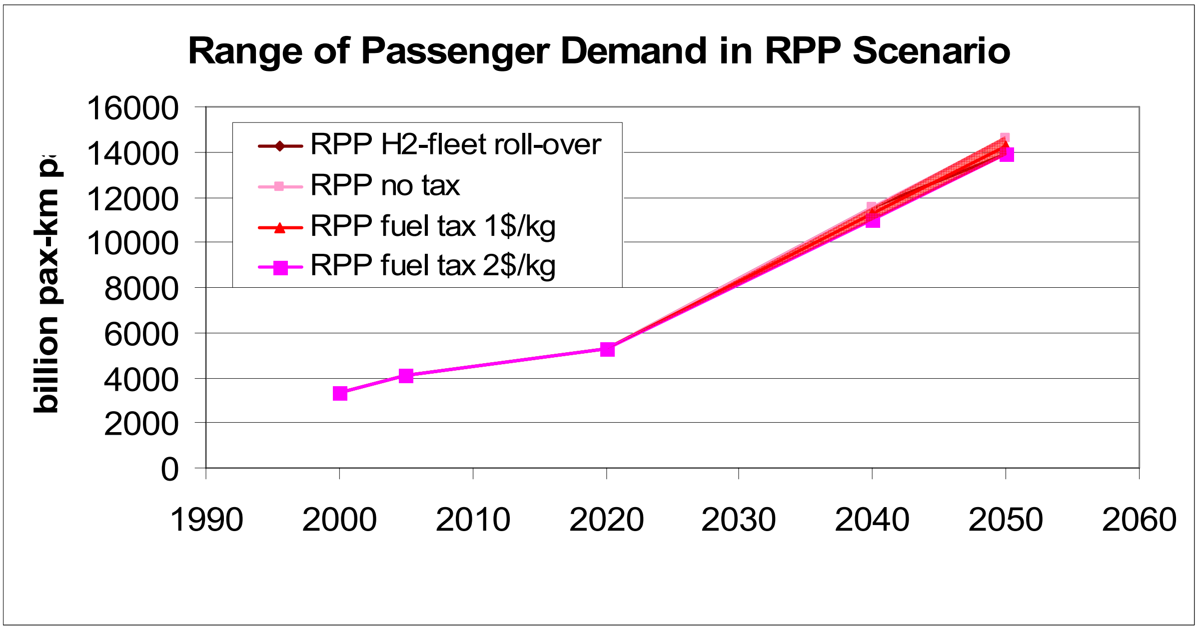


Figure 74: Range of passenger demand for RPP sub-scenarios in billion pax-km pa

Effects on the fleet

In table 63 and figure 75, the RPP aircraft fleet for the basic scenario and three sub-scenarios are given. In two sub-scenarios with fuel-tax the fleet growth is 14% and 24% lower than in the scenario without tax, causing a less rapidly growing market for manufacturers. As a fuel tax of

2$/kg is particularly high compared to fuel price, there is a dramatic change in direct operating costs, forcing the airlines to invest in highly efficient (mostly larger) aircraft.

A similar reduction of again 14% is estimated for the hydrogen sub-scenario, indicating that the production of new hydrogen aircraft leads to similar cost increases to a fuel tax of 1$/kg. Financial support by governments could help, but without a global approach, the competition in the manufacturer market is strongly affected.

number of aircrafts	2000	2005	2020	2050
RPP H2-fleet roll-over	18988	22992	29278	67957
RPP no tax	18988	22992	29278	74346
RPP fuel tax 1$/kg	18988	22992	29278	68114
RPP fuel tax 2$/kg	18988	22992	29278	63575

2020-2050	Reduction	in %
38679	6389	8.6%
45068	-	0
38836	6232	8.4%
34297	10771	14.5%

Table 63: Range of aircraft fleet for different RPP sub-scenarios

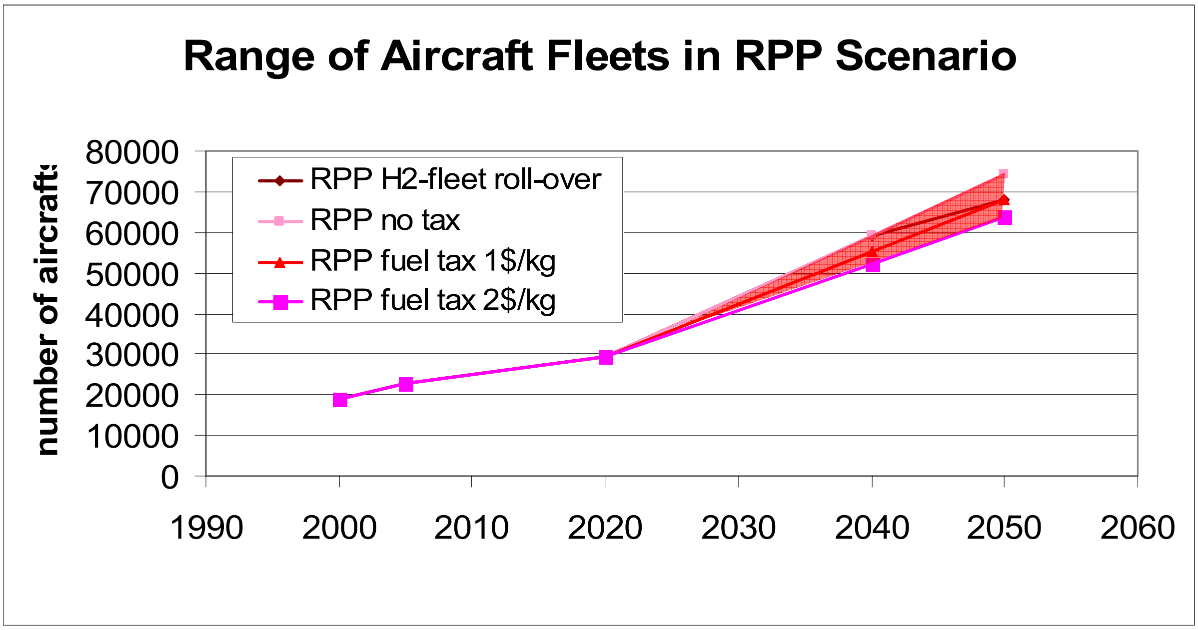


Figure 75: Range of aircraft fleet for different RPP sub-scenarios

Effects on airline profitability

Figure 76 shows the profitability of airlines for the RPP scenario (to 2020 and 2050) and for related sub-scenarios (2050). Because of limited ability to pass on additional costs to the customers, aviation is not a profitable business if a H2-fleet rollover is carried out without additional financial support. The resulting average value of ~-4% is just for orientation and depends heavily on the introduction speed. Future research might identify an optimal speed of introduction plus the necessary financial support (amount and timely distribution), taking into account the twin goals of profitability and emission reduction.

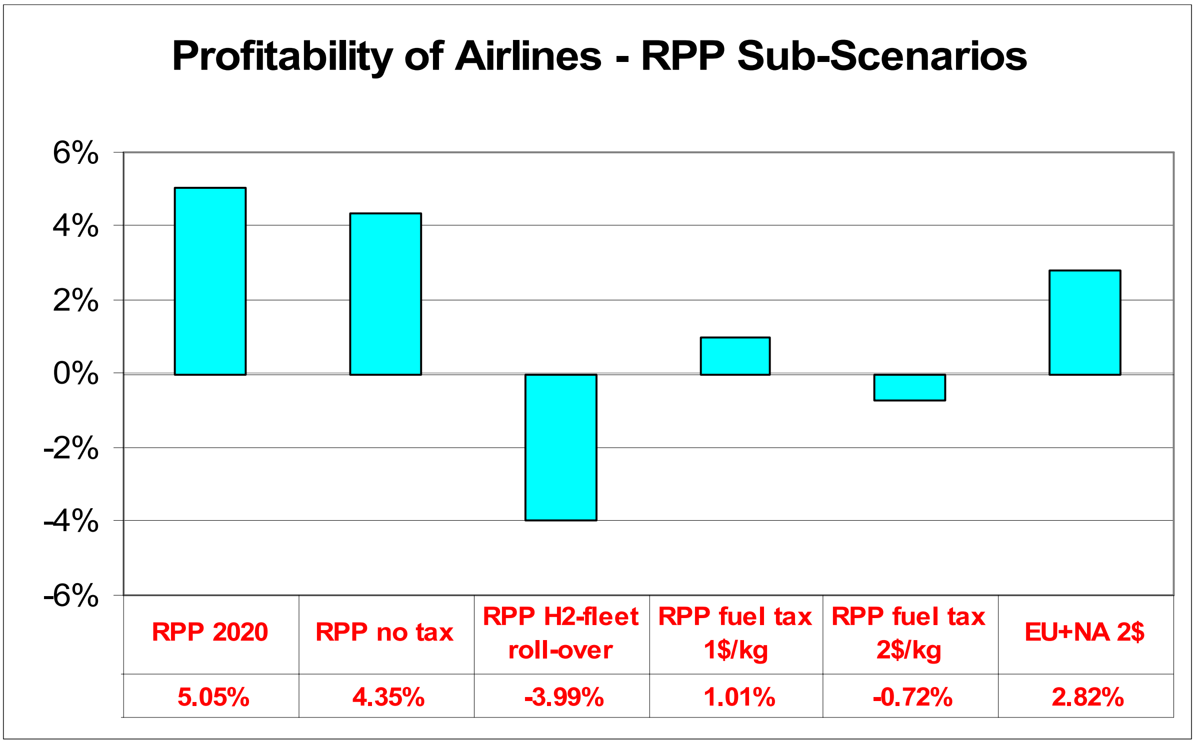


Figure 76: Profitability for different RPP sub-scenarios (revenues in percentage of invested capital)

Results for fuel tax are also cause for concern. A 2$/kg tax will cause heavy losses in the aviation business and even 1$/kg cannot operate satisfactorily with 1% profitability. These average numbers (2020-2050) do not consider that shortly after introduction of the fuel tax, profitability decreases significantly with recovery occurring only later. (It should also be noted that in recent years, business models have diversified and airlines increase their profitability with non-aviation activities. This may offer a solution to the reduced profitability estimated in this analysis) Future research might identify an optimal (maybe increasing with time) tax level, considering these profitability and emission reduction goals. It can be stated however, that in the case of a serious climate threat the efficiency of fuel tax in aviation is relatively ambivalent: comparatively (to other emission sources) high investments cause only medium emission reductions. Hence emission trading might be a better approach.

Regulatory Push and Pull - Transition from kerosene to hydrogen powered aircraft

In some of the Regulatory Push & Pull scenarios, one of the key assumptions is that an alternative fuel replaces kerosene. Alternative fuels could be hydrogen or bio-fuels. A transition from kerosene to bio-fuel is expected to have an impact that is limited to the production side and has very limited impact on the aviation industry. Contrarily, a scenario that includes a switch from kerosene to hydrogen will see a complete change of infrastructure, aircraft and operational procedures. Consultation by the CONSAVE team with EADS has lead a Regulatory Push and Pull scenario scheme that is dominated by a transition from an all kerosene to a 95% hydrogen powered fleet in only a short time frame of the order of 10 years. The following aspects are part of this kerosene-hydrogen fleet-roll over:

Production transition from kerosene to hydrogen

New aircraft need to be designed and certified for virtually all aircraft sizes and ranges. Production facilities need to be transformed by closing down the kerosene aircraft production, causing an early write off of capital costs. New productions lines will be set up for the hydrogen powered aircraft that will need considerable investments. A typical rate of transition is 8 years for an all new generation of aircraft. Other issues include:

- Replacement of kerosene by hydrogen aircraft in the fleet and operations. Older kerosene powered aircraft need to be phased out early, without the opportunity to use them somewhere else. It is assumed, because of the forced transition, that the government will buy the kerosene powered aircraft at residual, market prices.
- New hydrogen aircraft need to be bought in a hectic market with relatively low (hydrogen production) production volumes. This will increase new aircraft prices. These new aircraft will be financed by the airlines.
- The airport fuel infrastructures (installations etc.) need replacement by hydrogen related ones. This causes early write-off of kerosene installations and high costs of introduction of the hydrogen one. These costs are only partially reflected in the fuel prices. It should be noted that in this scenario aviation is assumed to be following a society that is changing towards hydrogen for other forms of transport and power generation.

In the following figure, the aircraft purchase behaviour of airlines is shown as a function of year of purchase. (The figure is almost to scale). The horizontal axis is the year of purchase. The vertical axis denotes the number of aircraft purchased or the number of aircraft in the fleet. The difference between the two is the attrition (phasing out of the fleet) of aircraft, becoming important for the older aircraft in the fleet (toward the left side). The effects of a kerosene-to-hydrogen transition are visualised, noting that:

- The origin to the right is the current year of consideration (20XX).
- The fleet consists of a number of purchases over the years. The older aircraft are to the left, the newer to the right.
- The production line transitions over the period from all-kerosene to all-hydrogen production. This transition starts at the start of rollover and is roughly 95% complete at the end of rollover. The vertical bar shows and intermediate year with some of the production line still producing kerosene powered aircraft, while most production lines already produce hydrogen powered aircraft.
- The fleet volume (contributions per purchase year), with the kerosene portion, the hydrogen portion and the hydrogen for kerosene replacement portion shown. The kerosene and the replacement fleet volumes have the same size (aircraft numbers).
- The number of kerosene aircraft that need to be scrapped (and replaced).
- The increase in production of new (hydrogen) aircraft (partially due to early replacement of kerosene powered ones).
- Natural phase out (business as usual).
- After rollover is completed, production rates drop dramatically to pre rollover values.
- The natural phase out is shown namely that aircraft are taken out of active service and being replaced by new ones after many years of service (this is the default, business as usual, situation).

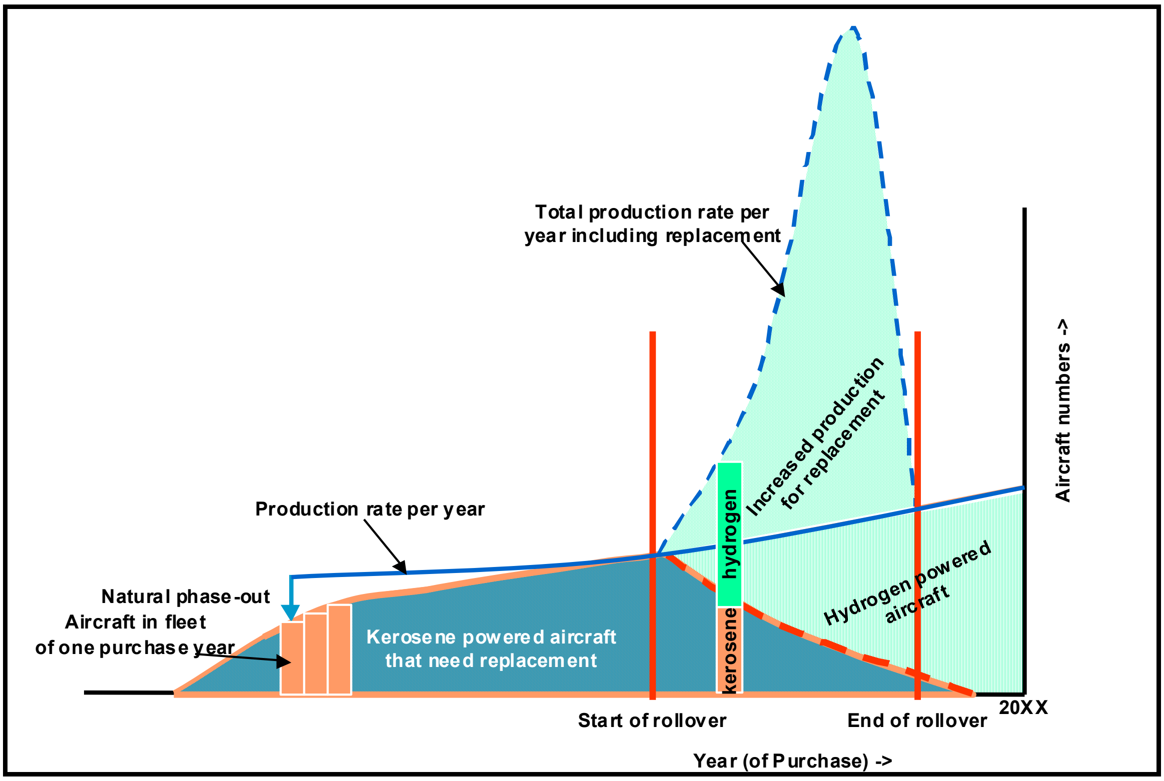


Figure 77: Accelerated kerosene to hydrogen fleet rollover

Logically, there are considerable costs involved in such a fleet roll-over.

- The government (society) has a stake in a reduction of emissions. In the current relevant scenarios it is assumed that the aviation sector (airline, aircraft and engine industries) are successful in negotiating a significant contribution in (transition) cost from the government.
- The costs of scrapping the kerosene-powered aircraft will be compensated fully by the government. The (capital) costs of acquiring new hydrogen powered aircraft are fully borne by the airlines and costs will be passed on, as far as possible, to the passengers.
- The new ground-based fuel infrastructure capital costs and early write-off of the kerosene fuel installations is an external factor, compensated by the government and not included in the fuel prices.

Aircraft new prices will rise as a result of two factors:

- High demand for new aircraft and a production rate that will need significant expansion
- New aircraft (engine) technology associated with increased technological risks will lead to increased development costs

In the case of a switch from kerosene to bio-fuels, aircraft probably do not need replacement. Minor modifications to engines and systems will do. In addition, (airport) infrastructure will probably do not need significant adjustment either. If the time period for the fleet roll-over is of the order of an average aircraft lifetime, costs and effects will be considerably lower.

Emissions

In table 64 and figure 78, the CO2-development of RPP and three sub-scenarios are given. In two sub-scenarios a fuel-tax (1$/kg and 2$/kg) is assumed (starting 2020), forcing airlines to use more efficient aircraft and/or to pass additional costs to customers. In these cases the increase of CO2-emissions is 10% and 18.7% lower than in the scenario without tax. A significant reduction of more than 174% is achieved in the sub-scenario which describes a fuel-change to hydrogen after 2020. It should be noted that CO2-emissions as a result of the production of the hydrogen are not considered in this sub-scenario.

CO2 - billion kg pa	2000	2005	2020	2050	2020-2050	Reduction	%
RPP H2-fleet roll-over	530.7	618.5	748.9	75.8	-673.1	1578	95.4%
RPP no tax	530.7	618.5	748.9	1653.8	904.9	-	0
RPP fuel tax 1$/kg	530.7	618.5	748.9	1563.1	814.2	90.7	5.5%
RPP fuel tax 2$/kg	530.7	618.5	748.9	1484.9	736	168.9	10.2%

Table 64: Range of CO2-Emissions for RPP-sub-scenarios in billion kg p.a.

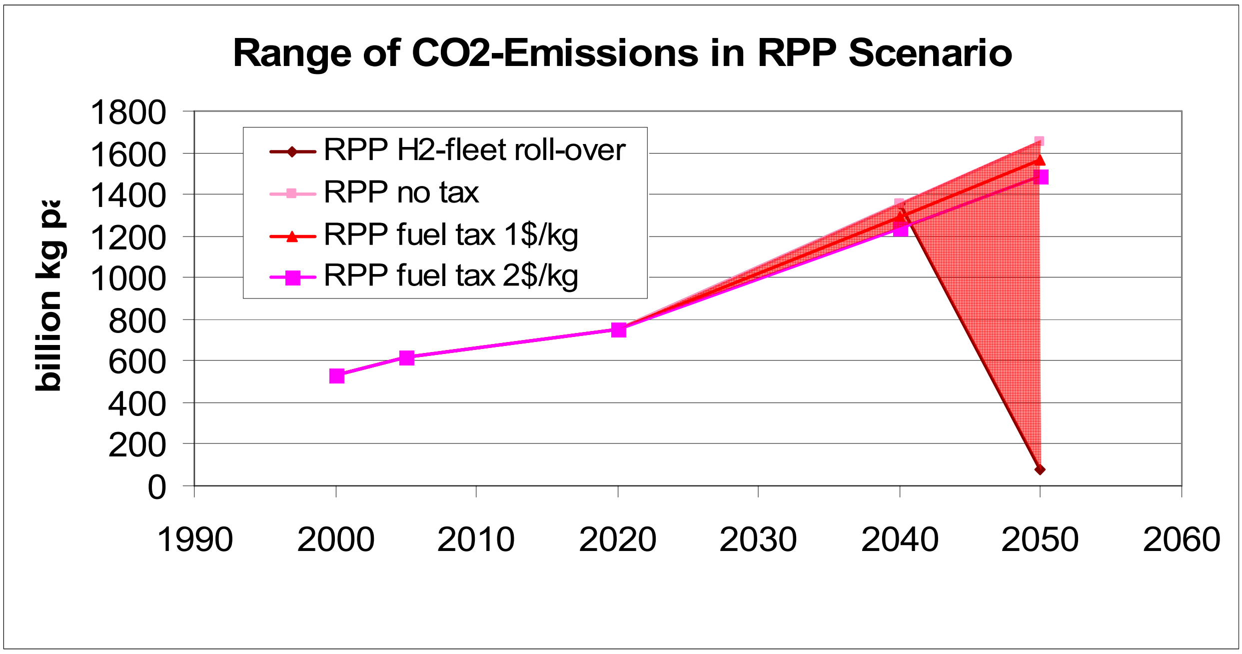


Figure 78: Range of CO2-Emissions for different RPP-sub-scenarios in billion kg p.a.

Table 65 and figure 79 show similar results for the development of NOx-emissions. In the sub-scenario with a fuel tax of 1$/kg NOx will be reduced by 13%, while a fuel tax of 2$kg brings a reduction of 24%. The hydrogen sub-scenario again has the highest decrease of NOx-emissions of 173% in comparison to the year 2020 because of the lower production of NOx basis emissions, as already mentioned above:

NOx - million kg pa	2000	2005	2020	2050	2020-2050	Reduction	%
RPP H2-fleet roll-over	2228	2637	2871	1382	-1489	3532	71.9%
RPP no tax	2228	2637	2871	4914	2043	-	0
RPP fuel tax 1$/kg	2228	2637	2871	4650	1779	264	5.4%
RPP fuel tax 2$/kg	2228	2637	2871	4419	1548	495	10.1%

Table 65: Range of NOx-Emissions for different RPP-sub-scenarios in million kg p.a.

As already described above, it should be noted that the differences in NOx emissions from a hydrogen fleet, compared to a kerosene fuelled fleet, emanate from three principle sources.

Firstly, dependent on scenario, a 10% to 15% lower NOx emissions index (based on mass of emissions per unit mass of fuel) is assumed from a hydrogen fuelled fleet, due to the potential for hydrogen combustion to operate at lower flame temperatures. Theoretically, hydrogen combustion offers greater benefits than this. However an allowance has been made for the relative in-service immaturity of hydrogen combustion technology compared to its kerosene equivalent.

Secondly, hydrogen has an energy per unit mass around 2.8 times that of kerosene. On an energy basis, hydrogen combustion therefore offers significantly better NOx emissions, partially offset by greater fuel consumption resulting from the increased aircraft drag, a consequence of the low energy per unit volume of liquid hydrogen.

Finally, in this particular scenario, a relatively rapid fleet rollover to hydrogen power is assumed form 2040 to 2050. As a result, in 2050 the fleet is an extremely young fleet compared with the 2050 fleet which would have existed in the pure kerosene-fuelled case. This in itself brings a “modernisation” and hence an emissions improvement to the fleet.

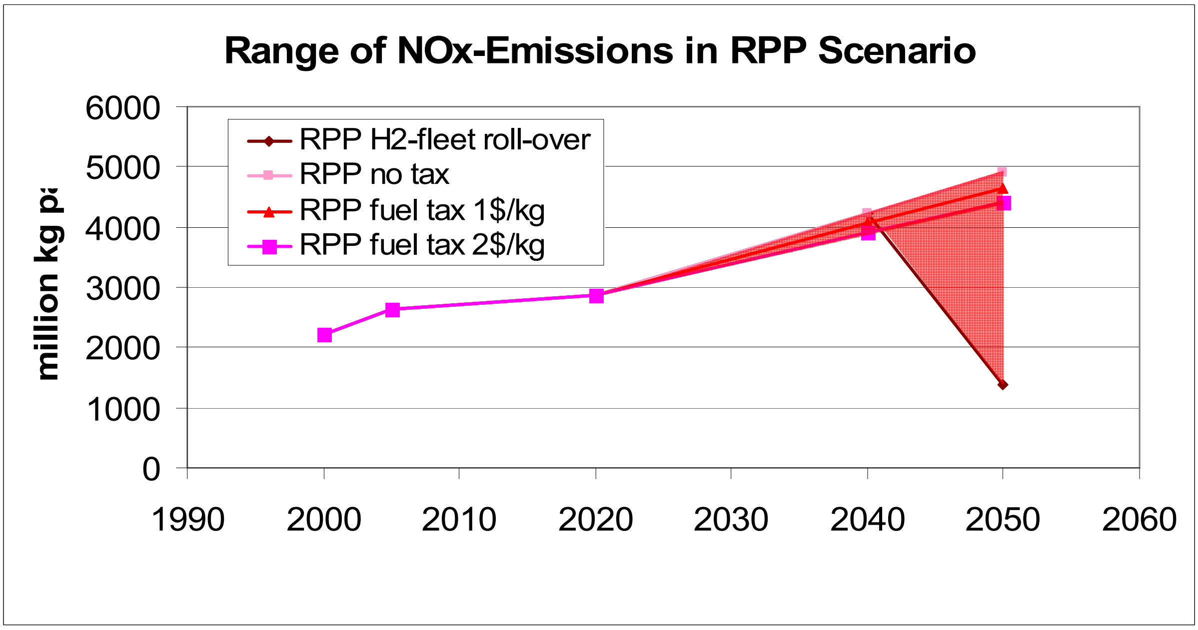


Figure 79: Range of NOx-Emissions for different RPP-sub-scenarios in million kg p.a.

<u>Fractured World</u>

No sub-scenarios were designed for the Fractured World. It would be of interest to study the dependency on the results for this scenario on the selection of number and structure of the blocks of the fractured world.

<u>Down to Earth – Landing charge</u>

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 - with a decrease of 1% compared to the scenario without additional charges - very small.

5.8.4 Outlook to the year 2100 for the world passenger demand

Using the characteristics of the AERO-model system it was possible to produce quantified results for the various scenarios up to the year 2050. A calculation of figures for the time horizon year 2100 is, however, outside the framework of the system. Therefore, an outlook to year 2100 needs to be developed based on alternative means. For CONSAVE, a rough estimate of the main aspect of such an outlook, that is the development of the global demand in the second half of the century, was developed in the following way, using a combination of available information:

The starting information for this estimation was the set of the scenario-specific GDP values for the years 2020 and 2050 used as input data for the AERO-model and a respective set of the calculated figures for air transport demand - given in passenger kilometres (see columns 6,7 and 3,4 of table 66). Based on these values for each scenario, the ratio of the relative growth in passenger kilometres between the years 2020 and 2050 (column 8) and the relative growth of GDP in the same time period (column 9) were calculated. The results (column 10) can be interpreted as an approximation for the overall GDP elasticities (epsilon) for air transport demand (in passenger kilometres) for 2020 to 2050. Applying parametric assumptions of the development of this factor between 2050 and 2100 and using the relative growth for GDP within this period - as given from IPCC/SRES (column 11), allowed for the "calculation" of the scenario specific relative growth for the development of air transport between 2050 and 2100, and eventually for the estimation of the scenario-specific passenger kilometres in 2100 (columns 12 and 13). The elements of this estimate and the results are given in table 66 and figure 80.

The results correspond to a range of average annual growth rates for air transport demand (in Pkm) between 2050 and 2100 of 0.1% for DtE up to 2.2% for the higher version of ULS.

	1	2	3	4	5	6	7	8
	Billion pax-km pa				**GDP (mer) trillion US$ 1990**			**relative growth PKM 2020-2050**
	2000	**2005**	**2020**	**2050**	**2020**	**2050**	**2100**	
ULS	3308	4091	6505	21185	56.48	181.32	528.53	2.26
RPP Kero	3308	4091	5284	14636	54.79	175.88	512.67	1.77
RPP H2	3308	4091	5284	13886	54.79	175.88	512.67	1.63
FW	3308	4091	4157	6990	40.50	81.57	242.78	0.68
DtE	3308	4091	3920	4164	52.14	135.64	328.35	0.06

	9	10	11	12	13
	relative growth GDP 2020-2050	**ε = colum-ne'8/9'**	**relative growth GDP 2050-2100**	**Billion pax-km ε = const**	**Billion pax-km ε = -20%**
				2100	**2100**
ULS	2.21	1.02	1.91	62600	54300
RPP Kero	2.21	0.80	1.91	37100	32600
RPP H2	2.21	0.74	1.91	33500	29600
FW	1.01	0.67	1.98	16300	14400
DtE	1.60	0.04	1.42	4400	

Table 66: World passenger demand – outlook to year 2100

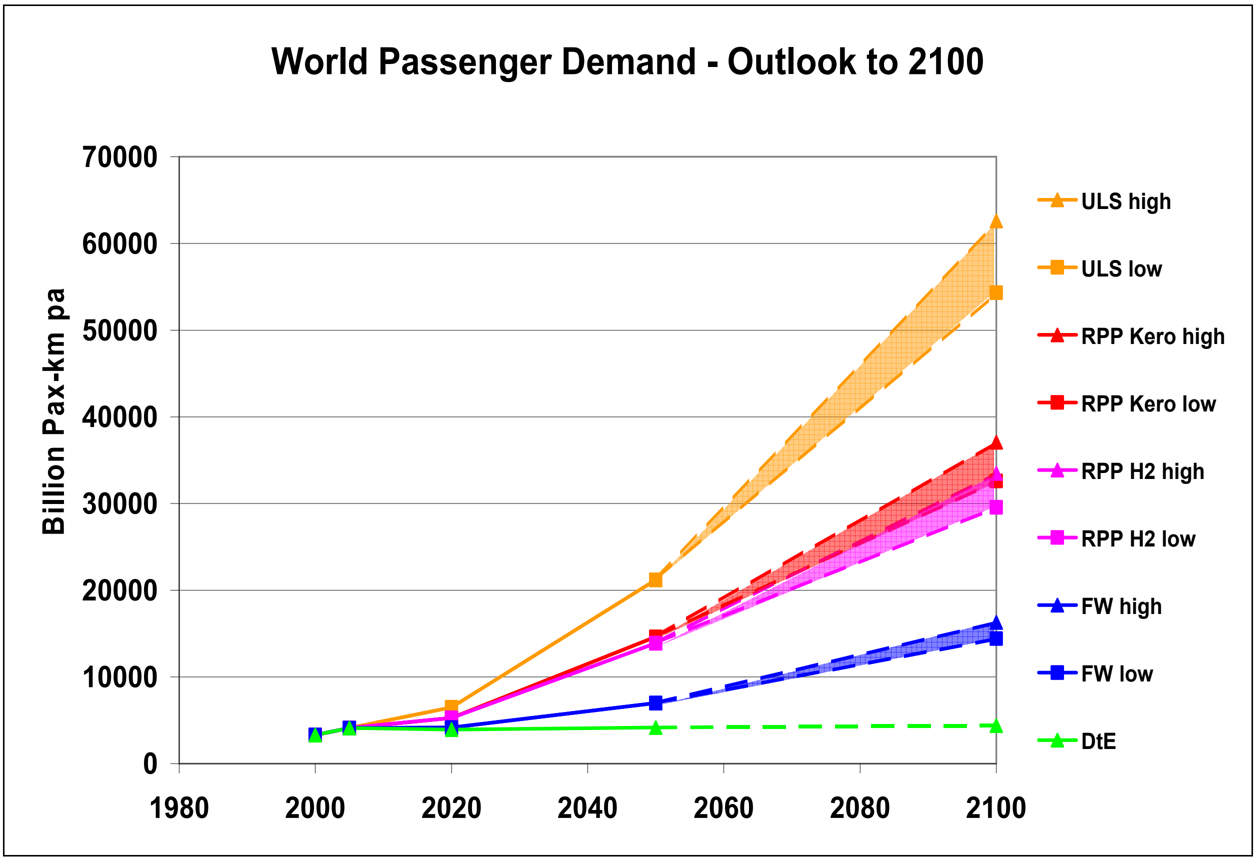


Figure 80: World passenger demand – outlook to year 2100

6. COMPARISON OF INITIALLY PLANNED ACTIVITIES AND WORK ACTUALLY ACCOMPLISHED

In the following the comparison between the initially planned activities and the work actually accomplished is carried out on the level of sub tasks[13] (as formulated in the contract).

In this chapter summarizing descriptions are given. More details are reported – where adequate – in chapter (5) together with the presentation of the results. For a comprehensive documentation of the work performed the intended set of deliverables was produced and submitted to the EC. The complete catalogue of the deliverables of the CONSAVE 2050 project is listed in chapter (7.6).

WP 1 – Key factors and qualitative background scenarios

Sub task WP 1A.1

Choice of scenario descriptors which are of key interest as strategic information for customers and which should be quantified in the study.

Work actually accomplished

Taking into account the findings from preceding activities of the EU-funded Thematic Network AERONET and based on the results of additional questionnaire action and its subsequent review of the team and the CONSAVE Advisory Committee, a catalogue of key scenario descriptors was identified to be applied to the storyline description, the quantification of the Background scenarios, and the qualitative description of the scenarios on aviation and its emissions and to be used as (part of the) input for the quantification exercise of the aviation scenarios with the AERO-model. In addition a list of those features was elaborated which are of key interest for the stakeholders in aviation because they are assumed to have the potential to be effective as the most relevant challenges and constraints for the long-term development in aviation. (Documentation in D5)

Sub task WP 1A.2

Determination of factors needed as input for the AERO-model.

Work actually accomplished

The list of factors *needed* as input for the AERO-model as well as of those scenario features which *should be considered* by the model as of relevance for the project was compiled. Some aspects (noise, air quality, infrastructure/capacity, security) were found to be of interest for the stakeholders, which are not or not fully addressed within the version of the AERO-model at the hand at the beginning of the project. (For the consideration of these features within CONSAVE a number of improvements and extensions have been added to the AERO-model (see WP 3).

Sub task WP 1B.1

Check of the „background“ scenarios developed during two AERONET workshops, especially with respect of the completeness of the list of key descriptors which should be quantified in the study, following the findings of WP 1A and with respect to internal consistency – using information from the results of the IPCC/SRES work.

[13] Not discussed in this chapter are the sub tasks referring to the (fully accomplished) respective contributions to the final reports.

Work actually accomplished

Under WP 1B the completion, adaptation and modification of the outline qualitative scenarios elaborated from AERONET were performed. The work on the sub task has also included a comparison of the background scenarios developed within the AERONET activity with the latest findings/developments of the IPCC/SRES macro-economic scenario process. Also comprised in this work were consistency checks and regularising for regional differences. (Documentation in D6)

Sub task WP 1B.2

Design of additional qualitative „background“ scenarios underpinning constrained aviation scenarios using the outcomes of a project workshop on this topic.

Work actually accomplished

The planned project workshop was held at IIASA in Laxenburg, Austria to agree upon a representative set of (constrained qualitative) scenarios. At the workshop a selection of six scenarios was made, which was finally modified to an agreed group of four CONSAVE scenarios (from three scenario families). The development and completion of the storylines for the individual scenarios has necessitated consultation with some of those involved in the AERONET scenario workshops and was performed by the subcontractor IIASA, leader of the author team of the IPCC Working Group III Special Report “Emissions Scenarios” (2000). The draft was intensively reviewed by the CONSAVE team, the Advisory Committee and additional external experts. Taking into account the review recommendations, IIASA elaborated the final scenario storylines. The storylines include first general features for air transportation, developed in line with the characteristics of the background scenarios, to be used as a proposal for a starting frame for a set of more detailed scenario assumptions on the long-term development on aviations and its emissions, to be developed in WP 3. (Documentation in D6/M)

Result of the comparison for WP 1

As intended, a broad discussion on the key drivers of interest for the project was performed. The findings gave the basis for a successful further work of the following work packages.

WP 2 – Quantification of background scenarios

Sub tasks WP 2.1 and WP 2.2

- Investigation of the IPCC/SRES work to find those respective SRES-scenarios closest to the different „background“ scenarios designed in WP 1B.

- Quantification of the projection of those key factors/features which are affecting – following the results of WP 1A – those main descriptors of scenarios of aviation and its emissions of interest for possible customers and are needed as input for the models used in WP 3. The quantification of the long-term development of reductions in aviation emissions should be based on the respective scenarios 2050, developed for IPCC/2000.

Work actually accomplished

Selecting the appropriate background scenarios, drawing upon IPCC/SRES knowledge was the first element of this task. In turn this has led to quantification of the background scenarios for 2050 (and the identification of related factors for 2025 and 2100) as the foundation upon which to build the aviation specific elements. The involvement of the IPCC expertise, external to the aviation sector, has promoted consistency with broader macro-economic scenario work, avoiding duplication of effort and ensures robustness in the main underlying assumptions. (Documentation in D7)

Result of the comparison for WP 2

As planned, quantified Background Scenarios which are in line with the findings of the IPCC/SRES exercise could be elaborated.

WP 3 – Quantification of scenarios on aviation and its emissions

Sub task WP 3.1a – not explicitly defined in the original catalogue of sub tasks[14]

Final determination of quantified input data for the AERO-model, which include detailed assumptions on the – scenario dependent – development in aviation technology.

Work actually accomplished

As originally planned findings from WP 1 and WP 2 were used to define scenario characterizing input assumptions for the AERO-model. Caused by changes in the leadership of QinetiQ, a partly rearrangement of the Work Plan of CONSAVE 2050 was agreed on, resulting in the elaboration by QinetiQ of a comparably much more detailed set of quantified assumptions on the long-term development of the aviation technology to be applied as input for the AERO-model. DLR and NLR elaborated additional quantified inputs to be used by the AERO-model, characterizing further factors and features also relevant for the aviation scenarios. For scenario independent input assumptions which needed no update “default” values were taken, which were already derived for the AERO-model from historic data during earlier applications. Compared to the original intention, with the inclusion of these work steps the quality of the work performed in WP 3 could be substantially further improved.

Sub task WP 3.1

Use of the AERO-model to calculate quantitative projections of key descriptors of scenarios on aviation and its emissions: calculation for relevant aviation demand factors, relevant aviation supply side factors, and related emissions features.

Work actually accomplished

On the base of developed sets of input for the AERO-model, characterizing the different scenarios, quantification for the four selected CONSAVE scenarios for the long-term development of aviation and its emissions were calculated with help of the AERO-model. The outcome of the calculations is presented in a catalogue of outputs (for the years 2020[15] and 2050) which are assumed - based on the findings of the CONSAVE questionnaires and additional contacts to external aviation experts - to be of key interest for the various stakeholders, including results for aviation demand and supply, and emissions from aviation. A 5° x 5° x 1km emission inventory (for fuel use, CO, H2O, SO2, NOx, CO, UHC) for years 2050 and 2020 is available. Preliminary results were presented to be checked within a broad European review, finished by a review workshop. The outcome and feed-back of the review process have been analyzed carefully and used – if appropriate – as input for final modifications of the quantification procedure.

[14] For reasons described in detail in (7.4) these sub tasks was added during the life of the project.
[15] As modified during the life of the project (see chapter 7).
For reasons explained in detail in (7.4) the first time horizon for CONSAVE was shifted from the originally planned year 2025 to the year 2020.

Sub task WP 3.2

Analysis of the effects of relevant external factors – not be taken into account by the AERO model - on key features of scenarios on aviation and its emissions.

Work actually accomplished

Some aspects of the CONSAVE 2050 scenarios have been recognized to be "transparent" to the (starting version) AERO model. Within CONSAVE it was finally possible to proxy at least some of the effects of the non-modelled factors by adjusting model inputs, and thus ultimately obtaining quantified and consistent model results of the factors in combination.

Sub task WP 3.3

Modification of the unconstrained IPCC/1999 scenarios

Work actually accomplished

The unconstrained IPCC/1999 scenarios have been modified for comparison reasons by replacing the "old" inputs for GDP (being the key driver for global air transport demand in the IPCC/1999 scenarios) from the IPCC/1992 background scenarios on the long-term development in economy with the new values used in the IPCC/SRES/2000 work.

Result of the comparison for WP 3

The core objective of the CONSAVE 2050 project could be fully achieved: As intended a representative set of quantitative scenarios of aviation and its emissions was constructed. Compared to the original plans the work could be further remarkably improved with respect to some important aspects: Instead of 2-3 scenarios (as originally planned), four scenarios were designed, resulting in an improved taxonomy for the selected CONSAVE scenarios and representing a broad range of possible futures. Secondly, the scenario assumptions on the long-term development of aviation technology were determined with a substantially higher level of detail then originally foreseen. Furthermore, the original AERO-model version could be extended to be able to quantify at least some of the effects of relevant external factors which were in the starting version "transparent" to the AERO model as noise, air quality, infrastructure/capacity issues. (The complete work of WP 3 is documented in D9)

WP 4 – Organization of a European review on preliminary study results and contacts to external activities

Sub tasks WP 4A.1 – 4A.4

A1. Development of a detailed concept for the performance of the review

A2. Distribution and necessary explanation of the preliminary Report on the study findings among a representative group of European experts on aviation and other interested specialists

A3. Handling reaction to comments of the review

A4. Organisation of a workshop to summarise the outcomes of the Review process and to develop recommendations for modifications of the preliminary findings of the study.

Work actually accomplished

In month 18 the preliminary results of the study have been reported. The task of *WP 4A* has been to organize a broad review of this material among a representative group of European experts and stakeholders in aviation. This review process has been ongoing from an early stage within the project as it was necessary to secure technical verification of elements within the scenarios before these were too advanced. The first part of the review process was based on a questionnaire action. The review has been culminated with a workshop that has been explained the composition of the scenarios, has been exposed these to critical assessment and has been provided for the modification as necessary of preliminary study results. About 40 persons participated in the Review Process (questionnaire action and review workshop), representing a broad spectrum of expertise of the European aviation community. This process substantially contributed to the fulfillment of the intension to ensure that the scenarios produced in the project are robust, that they will reflect the key perspectives of the stakeholder community and are geared to use by the industry, the scientific community and the policy and regulatory communities. (Documentation in D11)

Sub tasks WP 4B.1 – 4B.4

B1. Contact to ACARE with the goal to harmonise its work-plans with the work-plan for this study.
B2. Contact with EUROCONTROL, aviation sector groups and scientific and regulatory bodies participating in scenario activities bearing upon the conduct of CONSAVE 2050.
B3. Contact with the EC/AERO2K, TRADE-OFF, and various other relevant external projects to ensure that the results of the studies are of added, mutual and complementary value.

Work actually accomplished

To elaborate ensuring valuable output from CONSAVE 2050 has required continuing and close interaction with a number of related activities taking place within Europe and cognizance of other activities occurring in the broader international community. This process was assessed as critical to the success of the project and to its acceptance and application in the aviation community. From the commencement of the project the CONSAVE team has involved linkages with a number of activities to promote consistency, information exchange, efficiency of effort and avoidance of duplication. Key linkages have been with the EC/AERO2K and TRADE-OFF projects, the EC/AERONET thematic network, the industry ACARE (Advisory Council for Aeronautics Research in Europe) scenario activity, EUROCONTROL scenario work and with a number of national or collaborative scenario projects that bear upon aviation and its emissions. With CONSAVE 2050 scenarios intended to be a significant European contribution to the international debate on aircraft emissions impacts, scenario activity taking place internationally has been monitored and appropriate linkages have been established. (Documentation in D10)

Result of the comparison for WP 4

The initially planned activities of work package WP 4 were fully accomplished: The close linkages involved to all relevant groups ensured that on the one hand the work of CONSAVE 2050 was continuously reviewed by aviation stakeholders and key information from external activities could be taken into account for the CONSAVE project, on the other hand the findings of the CONSAVE exercise were intensively considered by other European groups actually working on scenarios. Especially ACARE/ASTERA and EUROCONTROL referred to the CONSAVE project.

WP 5 – Management and co-ordination

Sub tasks WP 5.1 and WP 5.3

1. Co-ordination of project and overall project management
3. Compilation of the mid-term and final reports and dissemination of the final study results

Work actually accomplished

The proposed work has been supported by management and co-ordination activities led by DLR. An important task has been to organize internal assessment of preliminary results of the various work packages by the consortium. The work has included the development of a – continuously updated - Project Management Plan and the preparation of four administrative reports. Project meetings were held on a regular basis (6 months) and additional working conference have been organized bringing together all partners for a discussion of the state of the ongoing work and the future activities. The final contributions from the work packages WP 1 – WP 4 are integrated in this Final Technical Report for the production of Deliverable D4 as a part of the work of WP 5. A major action has been and will be further on the dissemination of the results, as of paramount importance to the work is the broad distribution and acceptance of the results. Thus emphasis has been given to the preparation of "public domain" reports, the CONSAVE (experts) Review and the web-based communication of results. (For further details see following chapter 7 on "Management and co-ordination aspects. For full documentation see Periodic Reports I – III, respectively D1 – D3, and Periodic Report IV)

Sub task WP 5.2

Formation and organisation of the work of the advisory committee

Work actually accomplished

An Advisory Committee of stakeholders/customers has been organized as part of WP 5 by DLH supported by DLR. Permanent information on the actual status of the work has been established and two meetings have been performed for an assessment of the outcomes of WP 1 and the results of the project, respectively, to ensure that the results are well in line with the requirements of users.

Result of the comparison for WP 5

The planned work could be effectively performed.

As a result of the comparison of this chapter it can be stated that all initially planned tasks could be successfully performed.

7. MANAGEMENT AND CO-ORDINATION ASPECTS

The tasks for the management and co-ordination work for CONSAVE within WP 5 has been described in chapter (6), the details of the work performed were given in the Periodic Reports I – IV (see Annexes 1-4, Part II). The following expositions concentrate on giving an overview on relevant general aspects:

7.1 Members of the Project Management

The project work was supported by management and co-ordination activities led by DLR, with Ralf Berghof and Alf Schmitt as project – co-ordinators.

The day-to-day management for a quick reaction to arising problems during the project work, consisted out of Ralf Berghof and Alf Schmitt (both DLR; for the overall Co-ordination), and one representative from each partner: Karlheinz Haag (DLH), Jan Middel (NLR) and Chris Eyers (as successor for David Lee, who left QinetiQ for a full/residential Chair in Atmospheric Science at the Manchester Metropolitan University). Ralf Berghof (DLR) was nominated to be the Exploitation Manager.

The Advisory Committee, chaired by DLH (Karlheinz Haag), was composed of representatives from a broad range of stakeholders in aviation, including airlines, air traffic control, manufacturers, politics, and research (for the complete list of the AC-members see Annex I, Part II).

7.2 Planning and management

To achieve the goals set for the project work, it was necessary to develop a detailed project planning with a continuous up-dating of the work plans, ensuring that the team had a permanent solid overview on content and time schedule of the next steps and their role within the total project. The central instrument for the organisation of the discussion of open questions and demands for support was an intensive e-mail communication, lead by the project co-ordinators. The - achieved - intention was to minimise the need for time-consuming team-meetings. Nonetheless, team meetings and other meetings between partners were held on a regular (half year) basis and before starting new phases of the work, when it was necessary to review the completed parts of the work and to get a well founded common understanding of the details of the next tasks and their performance.

To ensure that the ongoing work was in line with the requirements of the possible consumers of the CONSAVE results and to be able to take into consideration the work of related external groups, a broad range of discussions with various stakeholders were organised. Furthermore, the co-ordinators have taken, whenever useful, the opportunity to inform other groups on the actual status and findings of CONSAVE 2050, especially by participating in externally organised conferences and workshops.

A list of the conferences, referring to the project is given in (7.3).

For communication within the team and for information for interested scientists and stakeholders an Internet Website (http://www.dlr.de/consave) was created to give an overview about the project goals and results. The Homepage includes a member area with download opportunities as a platform for exchanging files such as protocols and reports.

Beside the organisation and management of the "normal work", the co-ordinators, supported by the team, had to decide on several "special issues", in reaction on new experiences or new information get during the performance of the project. A summary of the most project relevant agreements with respect to these "special issues" is given in (7.4), details are reported in the Periodic Reports I – IV (see Annexes 1-4, Part II).

7.3 List of conferences and special activities

The following meetings were held in the years 2002 to 2004 in preparation and during the performance of the CONSAVE 2050 project, respectively were visited to inform external groups: (Agendas and minutes of these events are given in the Periodic Reports I – IV):

Project Team Meetings

26 Sep 2002	Kick-off-meeting to discuss relevant principal aspects of the performance of the project and discuss and agree on necessary details for the realization of the work and on related responsibilities at DLR, Cologne, DE
21 Nov 2002	Team-Meeting to discuss the catalogue of key factors to be quantified at NLR, Amsterdam, NL
23 Jan 2003	Team-Meeting to discuss further activities after the Background Scenario Workshop at IIASA, Vienna
05/06 Mar 2003	Team-Meeting (regular 6-month meeting) at DT, London, GB
15/16 July 2003	Team-Meeting (in month 10) at DLR, Cologne, DE
23 Sep 2003 16 Feb 2004 15/16 June 2004	Mid-term meeting at Airbus, Toulouse, FR Team-Meeting at DLR in Cologne, to discuss with the necessary technical detail the next steps of the project, especially the organisation of the work on the quantification of the four CONSAVE scenarios on aviation and its emissions with the AERO-model Team-Meeting (at DLR in Cologne), to perform an internal review of the findings and recommendations from the CONSAVE Review Process and external contacts (see Deliverables D10 and D11) and to agree about modifications for the scenario assumptions (Agenda and minutes attached as Annex 3.)

Advisory Committee Meetings

31 Oct 2002	1. Advisory Committee Meeting to review the catalogue of key factors to be quantified at DLH, Frankfurt, DE
19 Mar 2003	2. Advisory Committee Meeting to review the scenario storylines to be quantified at DLH, Frankfurt, DE

Workshops

22/23 Jan 2003 29/30 April 2004	Background Scenario Workshop with external experts at IIASA, Vienna, AU CONSAVE Review Workshop with European experts at NTUA in Athens

Further meetings among partners and with the EU-Project Officer

25 Jun 2002	Meeting with IIASA at IIASA, Laxenburg, AU on the performance of a „Workshop on Discontinuities and Surprises in Air Transport Scenarios to 2050“
20 Aug 2002	Meeting with NLR - main emphasis on WP 1 at Amsterdam, NLR, NL
03 Sep 2002	Meeting with DLH at DLH, Frankfurt, DE to discuss, which stakeholders should be in the Advisory Committee

02 Dec 2002	Meeting with DLH at DLH, Frankfurt, DE on the performance of the Advisory Committee. Meeting combined with the Lufthansa Workshop on Emissions.
27 July 2004	Meeting with DLR-Subcontractor IIASA at IIASA in Laxenburg, AU for a discussion on possible modifications of the preliminary results, especially as far as the Background scenarios and their interpretation were concerned, and on possible contribution from IIASA to follow-up activities.
30 July 2004	Meeting with the EU-Project Officer at the EU-Commission in Brussels for a discussion of the status of CONSAVE 2050, on the last phase of the project and possible follow-on activities/projects

Contact meetings to external experts and groups

14 Jan 2003	Meeting with ACARE to establish contacts and identify possible synergies with the ACARE-project, Brussels, BE
21 Aug 2003	Meeting with ACARE to discuss the scenarios created by ACARE and CONSAVE plus further co-operation at DLR, Cologne, DE
20 April 2004	Review Meeting with a group of experts from DLH at DLH in Frankfurt, DE to discuss the preliminary results of the scenario quantification, to ensure that the special aspects of an airline will be taken into account
14 April 2004	Meeting with Prof. Szodruch, DLR, Vice-president of ACARE at DLR in Cologne, DE to discuss the possible inclusion of ACARE in the CONSAVE Review Process
12 Aug 2004	Meeting with DaimlerChrysler, Forschung und Technologie at DaimlerChrysler in Berlin, DE for a discussion on the CONSAVE 2050 project and on scenario activities of DaimlerChrysler Forschung und Technologie; and for a comparison between the scenario approaches, methods of both groups.

Informational contacts – Participation in conferences

12 Dec 2002	Participation in the Scenario Workshop on Future Transport Emissions (DLH and BMW) at BMW, Berlin, DE
	Participation in the AERONET workshop at DLR, Berlin to present the CONSAVE project and to announce the questionnaire for the AERONET experts
	Participation in the “Scenario on mobility – Workshop” at BMW, Berlin to check similar activities in transport scenario development
13 Jan 2004	Participation in the AERONET II Final meeting in Garmisch-Partenkirchen (Contribution: presentation of the actual status of the CONSAVE 2050 project)
17 Jan 2004	Participation in the workshop of the “Tremove contact group”, organised by EUROCONTROL (Contribution: explanation of the CONSAVE project).

7.4 Special issues

Beside the "normal" work of the co-ordination and project management some arising questions required additional actions and decisions to ensure the progress of the project. Most relevant for the performance of the work of CONSAVE 2050 were the following issues:

Shift of first time horizon of CONSAVE from 2025 to 2020

While for the CONSAVE project it was planned to quantify the year 2025, the IPCC has developed quantifications for the decades between 2000 and 2100, using ten year steps (8). Consequently, in the storylines, developed for CONSAVE, IIASA used the IPCC numbers for the year 2020 instead of 2025. The ACARE project with similar goals as CONSAVE focuses on 2020. With the exception of AERO2K, other external work is dominantly related to a time-horizon year 2020 as well. As a result of the team discussion it was eventually agreed, to shift the first time horizon of CONSAVE to the year 2020. Main reason was that in any case it will be necessary for CONSAVE 2050 as an accompanying measure project, to perform intensive comparison work of its results with findings from other related work, especially with those from ACARE. At the same time it would be also helpful for the distribution and application of the project results to deliver the quantifications of the aviation scenarios for a time–horizon year, which might have a preference of possible users of the CONSAVE results: As it was strongly stated by the AC, aviation industry would like to have numbers for 2020. The EC Project Officer has agreed on the shift of the time horizon.

Partly rearrangement of work

Caused by changes in the leadership of QinetiQ, a partly rearrangement of the Work Plan of CONSAVE 2050 was agreed on, resulting – without any change in total manpower – in an improvement of the quality of the project work. It was concluded that QinetiQ should give more emphasis on the development of quantified aviation technology scenarios as part of WP 3, which are – beside the background scenarios, developed in WP 1 and WP 2, a key input for the AERO-model. In compensation the efforts going to WP 4 could be reduced, as the tasks to establish contacts to external groups could be diminished without loss in quality, because some of the team members are at the same time members of related external project groups. While QinetiQ reduced its work for WP 4, DLR took over additional effort for this work package and decreased at the same level its work in WP 3. DLR became now responsible for the performance of the Review Workshop.

Decision to have the planned Review Workshop back-to-back with AERONET in April 2004

As part of the agreement of between AERONET and CONSAVE for a mutual support of the work, there was an early announcement of the intention to perform the CONSAVE Review Workshop together with an AERONET conference, because both parties have expressed their high interest that AERONET should be intensively included in the CONSAVE Review Process. Originally the CONSAVE Review Workshop was foreseen to be held in February 2003. It was only in late 2003 when AERONET decided to split the planned combined conference of a Final Meeting of AERONET II and Kick-Off Meeting for AERONET III into its two parts. The first one was settled to be in January 2004, the second one to be in April 2004. It turned out that the best date for the April meeting would be on the 28th and 29th. Because the January date was to early for a Review Workshop as the final step for the CONSAVE Review Process, it was decided to have the Review Workshop back-to-back with the AERONET III Kick-OFF meeting, as the alternative to have a meeting without AERONET seemed to be linked with to many negative aspects. Therefore, eventually, the CONSAVE Review Workshop was shifted by about three months to April 2004 and started in the afternoon of the 29th.

As a consequence, some other milestones and deliverables were shifted to dates different from those, originally planned, as well.

There were no negative effects on the time table for the remaining milestones (M3, M13, M14) and deliverables (D4, D9) of the last phase of the project, because already at the CONSAVE Kick-Off Meeting a time buffer within the original time schedule could be identified: To be in time, the final results of the two-years project CONSAVE 2050 have to be presented (using D9) in month 24 of the project (September 2004) and the concluding Final Report (D3) of the project should be submitted 2-3 month later, i.e. until the end of the year 2004. (The original time table was based on the assumption that the Final Report should be already submitted in month 24 of the project.)

Decision to assume a harmonized development of all scenarios until the year 2005

As a consequence of the September 11th event of the year 2001, the “normal” continuation of the development in aviation was heavily disturbed. It is assumed that at least for some years after 2001 these disturbances will have a larger impact on the further development in air transport than possible first differentiations for the four CONSAVE scenarios within this period. As ICAO/CAEP has offered a new forecast for the development of air transport until the year 2005, it was decided to start the differentiations of the different paths of the four CONSAVE scenarios on aviation and its emissions in 2006 and to adjust the AERO-model to be in line with the forecast of ICAO/CAEP of 2005.

Contact to ANOTEC

A contact to the ANOTEC project was started, with the hope to get support for the use of a noise model for CONSAVE. However it turned out, that no model design is planned within this study.

7.5 Project reporting

During the Kick-off Meeting content and dates for the Periodic Reports were discussed. The respective draft of the co-ordinators was accepted by the Scientific Officer of the EC, Mr Ronaldo Simonini, with the following modifications:

a) All reports should be send to EC additionally on CD-Rom;
b) Project Report II (mid term assessment report) should also include a draft for the technological report (correct versions of the slides are attached);
c) as far as necessary the project reports will be structured in a public and a non-public part.

To document the work of CONSAVE 2050 – beside this Final Technical Report - 11 deliverables, listed in (5.4) were prepared during the project life by the respective work packages owners, supported by work package partners and the other team members, and submitted to the EC. The Periodic Reports I – IV included as essential parts management reports, given by the co-ordinators.

7.6 List of Deliverables

WP	Title and Nature of the Deliverables	Del. No.	Comments, Dissemination Level	Presented in Part II Annex No.
5	Periodic Report I (6 months report)	**D1**	CO	1
5	Periodic Report II (Mid-Term Progress Report)	**D2**	CO	2
5	Periodic Report III	**D3**	CO	3
5	Periodic Report IV	**-**	CO	4
5	Final Technical Report (this report)	**D4**	RE	-
1	Catalogue of key factors to be quantified for CONSAVE	**D5**	RE	5
1	Representative set of qualitative “background” scenarios (inclusive storylines)	**D6**	Version 1, RE	6a
1	Representative set of qualitative “background” scenarios (inclusive storylines). Modified Version	**D6/M**	Version 2, RE	6b
2	Quantification of “background” scenarios: data and report	**D7**	RE	7
3	Quantification of scenarios on aviation and its emissions – Preliminary results for review	**D8**	RE	8
4	Quantification of scenarios on aviation and its emissions – Final results	**D9**	RE	9
4	Findings and proposals from the review process and the related concluding workshop	**D10**	RE	10
4	Report on the contact to external activities	**D11**	RE	11

Dissemination levels:

PU: Public

RE: Restricted to groups specified by the consortium depending on the deliverable, including the Commission services

CO: Confidential, only for members of the consortium including the Commission Services

The Summaries of the deliverables can be used for Web-information (PU).

8. RESULT AND CONCLUSIONS

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

1. 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 latest information for the "Background Scenarios" for those fields which set the framework for the long-term development of 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.

2. 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 to 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.

3. 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 EUROCONTROL forecast for 2020, as input information for many discussions within AERONET III, and for comparison within the AERO2K project.

4. 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 project, as some key developments for the future of aviation will become relevant only beyond 2020.

Two examples of such developments in two key driver fields are:

- Within the time period from 2020 – 2050 in the energy sector, there is an expectation of a significant increase in fuel prices or, dependant on scenario, even an availability problem, enforcing a 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 climate impacts of emissions from human activities (including those from aviation) and their resulting effects on the habitat of human beings, has reached a high enough level of accuracy and precision, and that this would be followed – if the results indicate a high enough level of danger for man - by significantly increased 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 reason 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 concurrent scenario developments. However, particularly 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.

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

6. Technological developments require a considerable time for implementation. With the help of the robust, detailed, and quantified scenarios developed by CONSAVE, there is a 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.

7. 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.

8. The concept of the project to develop Background Scenarios for CONSAVE closely consistent with scenarios in 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 its related emissions, which are embedded in the “complete” scenarios for emissions from all human activities, thus supplementing and strengthening the work of IPCC/SRES.

9. 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.

10. A wide range of open questions have been addressed by CONSAVE. Nonetheless, during the performance of the project it became clear that various complimentary additional aspects should also be studied in the near future. These could not be dealt with by CONSAVE, as they were outside the given funding and time frame for project. Based on what has already been achieved within CONSAVE, a set of proposals for future work has been developed, described in the following chapter, which should follow the CONSAVE project to further enhance the value of the study and to further contribute to achievement of the objectives for European aviation.

9. PROPOSALS FOR FUTURE WORK

9.1 Proposals for activities at the European level

(1) The CONSAVE project has developed a quantified set of scenarios on aviation and its emissions as support for the strategic planning of stakeholders up to the year 2050, on the way to a sustainable aviation system. However, in an always changing world, preferred and alternative strategies have to permanently reflected and - if necessary – modified, requiring a system which continuously monitors the strategy-relevant scenario aspects and factors. Following this view, CONSAVE is just a start, and the implementation of a monitoring system on aviation scenarios for a continuous update of information, relevant for strategic planning in aviation is an urgent follow on activity of CONSAVE. Such a system is currently not available. The use of the CONSAVE 2050 results for the strategic planning of stakeholders in aviation will be much more of interest for the applicants if a continuous update of relevant features of the scenarios would be guaranteed for the future. If no adequate monitoring system were established, the danger could be that the impact of CONSAVE 2050 will be reduced to a single, possibly quickly outdated event. Therefore, to achieve lasting improvements for the aviation community with respect to the strategic planning, a high priority proposal for future work is to perform an:

- EU-supported and -funded pilot study on the development and 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 principals for the organisational structure. (Willingness to co-operate within such a project and for some financial support after the pilot study has already been declared by various stakeholders).

(2) The set of CONSAVE scenarios consists of four distinct scenarios. In addition, a number of sub-scenarios have been assessed using the AERO-model. Nevertheless, there are numerous sub-scenarios of special interest which could not be addressed, as it was not possible within the given frame of the project, to discuss a larger number of scenarios. Therefore - as a follow on to CONSAVE - it is proposed to consider a range of selected further (sub-) scenarios. Especially

- more detailed scenarios studying additional alternative long-term developments in the fields of energy / fuel technology / aircraft emissions (e.g. addressing air quality aspects around airport)

would be of high importance for EU projects such as ECATS.

(3) The CONSAVE scenarios were quantified with help of the AERO-model. The model has again proven its usefulness and its flexibility for further improvement. During the project time the model was able to be substantially extended to be able to deal with a much higher level of detail concerning infrastructure capacity, noise, and air quality aspects. Now, it would it be highly useful

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

(4) It is known from experience that visual media can contribute to a higher understanding, especially of complex interrelationships and features (like scenarios) e.g. by a more intensive involvement of the subconscious. Therefore it is proposed, that

- The scenarios storylines should be visualised by producing video-movies to further enhance the understanding and acceptance of the main messages of the outcomes from CONSAVE 2050.

(5) It was beyond the framework of the project to address in detail the topic of "Wild Cards". However, as expressed by various stakeholders in aviation, it would be of significant interest for them to have a study on potential (aviation related) wild card events, including, for example, evaluation of the range of possible (sector specific) effects, on initial ideas for adequate reactions aiming to minimize negative impacts, and on possible precautionary measures (such as the organisation of an early warning system, perhaps as part of the monitoring system proposed in (1)).

(6) With respect to the important topic of the further development in the field of energy supply, some interesting results have already been described on the possible introduction of the hydrogen technology as aviation fuel. However, many aspects need further consideration. Therefore it is proposed

- To further clarify critical aspects of a possible introduction of the hydrogen technology for aviation

including for example:

(a) The investigation of the realistic potential of this alternative energy technology for emission reduction and of the environmental balance (especially with respect to CO2, H2O). Should the result be positive, (b) studying further details on cost, financing and introduction; (c) estimating prices for new aircraft depending on the details of introduction of (hydrogen) technology; (d) studying costs and benefits and ways to finance the roll over; (e) assessing the option to explore the cost effects of kerosene-to-hydrogen rollover if airlines have to cover all of the costs, including the early retirement of kerosene powered aircraft; (f) studying the effects of allowing a mix of kerosene-hydrogen aircraft in selected parts of the world; (g) selection of an adequate time for an introduction of hydrogen as an energy source in aviation; (h) study the impact of hydrogen-aircraft design on typical flight operations (e.g. flying lower and slower) and effects on emissions and costs.

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

9.2 Proposals for activities with/for individual stakeholders

(7) The concept of CONSAVE was to develop constrained scenarios in order to be able to discuss the most critical challenges which might affect the future of aviation and its emissions.

- It is proposed that more detail on special aspects, on alternative scenarios, on combination of scenarios, etc. of particular interest for the different stakeholders within the aviation community, should be studied in follow-on projects with the respective appliers of the scenario results, taking their specific point of view and strategy design requirements.

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

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12. GLOSSARY

12.1 Definitions and Terms

Acid deposition

Acidic air pollution that falls to the ground as either particles (dry deposition), or solutions in rain (wet deposition). The latter is commonly known as "acid rain". Produced from the atmospheric build-up of NOx and SO2.

Aerosols
Airborne suspension of small particles.

Aircraft kilometres
Aircraft kilometres equal the sum of the products obtained by multiplying the number of flight stages by the airport-to-airport distance for each stage.

Air pollution
A term used to describe any unwanted chemicals or other materials that contaminate the air that we breathe resulting in the degradation of air quality.

Alternative Energy
Energy derived from non-fossil fuel sources.

Annex I Countries
Annex I to the Climate Convention (UNFCCC) lists all the countries in the Organization of Economic Cooperation and Development (OECD), plus countries with economies in transition, Central, and Eastern Europe (excluding the former Yugoslavia and Albania). By default the other countries are referred to as Non-Annex I countries. Under Article 4.2 (a&b) of the Convention, Annex I countries commit themselves specifically to the aim of returning individually or jointly to their 1990 levels of GHG emissions by the year 2000.

Annex II Countries
Annex II to the Climate Convention lists all countries in the OECD. Under Article 4.2 (g) of the Convention, these countries are expected to provide financial resources to assist developing countries comply with their obligations such as preparing national reports. Annex II countries are also expected to promote the transfer of environmentally sound technologies to developing countries.

Annex B Countries
Annex B in the Kyoto Protocol lists those developed countries that have agreed to a target for their GHG emissions, including those in the OECD, Central and Eastern Europe, and the Russian Federation. Not quite the same but similar to Annex I, which also includes Turkey and Belarus, while Annex B includes Croatia, Monaco, Liechtenstein, and Slovenia.

Anthropogenic Emissions
Emissions of greenhouse gases (GHGs) associated with human activities. These include burning of fossil fuels for energy, deforestation, and land-use changes.

Biofuel
A fuel produced from dry organic matter or combustible oils produced by plants. Examples of biofuel include alcohol (from fermented sugar), black liquor from the paper manufacturing process, wood, and soybean oil.

Bunker Fuels (International)
Fuels consumed for international marine and air transportation.

Capital costs
Annual costs of aircraft depreciation and financing.

Carbon dioxide
A naturally occurring gas, CO2 is also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic GHG that

affects the earth's temperature. It is the reference gas against which other GHGs are measured and therefore has a "Global Warming Potential" (GWP) of 1.

Carbon monoxide (CO)
A highly poisonous gas, consisting of molecules of carbon (1) and oxygen (1) atoms, produced when fuel is burnt during incomplete combustion. It is emitted mainly from car exhausts.

Chlorofluorocarbons
Chlorofluorocarbons (CFCs) are GHGs covered under the 1987 Montreal Protocol and used for refrigeration, air conditioning, packaging, insulation, solvents, or aerosol propellants. As they are not destroyed in the lower atmosphere, CFCs drift into the upper atmosphere where, given suitable conditions, they break down ozone. These gases are being replaced by other compounds, including hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), which are GHGs covered under the Kyoto Protocol.

Cirrus
High, thin clouds composed of mainly ice particles.

City pair
Two cities between which travel is authorised by a passenger ticket or part of a ticket or between which freight and mail shipments are made in accordance with a shipment document or a part of it (air waybill or mail delivery bill).

Climate Change (UNFCCC definition)
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability over comparable time periods.

Combustion Efficiency
Ratio of the heat released in combustion to the heat available from the fuel.

Cost-effective
A criterion that specifies that a technology or measure delivers a good or service at equal or lower cost than current practice, or the lowest cost alternative for the achievement of a given target.

Decarbonisation
A decrease in the specific carbon content of primary energy or of fuels.

Direct Radiative Impact
Radiative forcing of aerosols or gases by scattering and absorption of solar and terrestrial radiation.

Distance
Great circle distance flown by aircraft between city pairs (not allowing for detours or ATC).

Domestic flight stage
A flight stage not classifiable as international. Domestic flight stages include all flight stages flown between points within the domestic boundaries of a State by an air carrier whose principal place of business is in that State.

Ecosystem
A system of interconnected habitats and their species of flora (plants) and fauna (animals), usually defined by a specific geographical area and/or climatic regime, e.g. mountain, polar, forest ecosystems.

Economies in Transition
National economies that are moving from a period of heavy government control toward lessened intervention, increased privatization, and greater use of competition.

Elasticity
Elasticities are applied in AERO-MS to govern the sensitivity of changes in dependent variables to changes in independent variables.

Emissions
Engine emitted remains of the fuel burning process into the jet plume.

Emission Index
The mass of material or number of particles emitted per burnt mass of fuel (for NOx in g of equivalent NO2 per kg of fuel; for hydrocarbons in g of CH4 per kg of fuel).

Emissions inventory
Information concerning the distribution of pollution sources in a certain area, and the amount and types of pollutants being emitted.

Energy Efficiency
Ratio of energy output of a conversion process or of a system to its energy input; also known as first-law efficiency.

Equivalence Ratio
Ratio of actual fuel-air ratio to stoichiometric fuel-air ratio.

Fleet mix
Proportion of the total number of global aircraft movements made by each aircraft type.

Flight
The operation of an aircraft on a flight stage or number of flight stages with the same flight number.

Flight stage
Direct flight segment between two cities.

Fossil Fuels
Carbon-based fuels, including coal, oil, and natural gas and their derived fuels such as gasoline, synthesis gas from coal, etc.

Global Warming
The hypothesis that the earth's temperature is being increased, in part, because of emissions of GHGs associated with human activities, such as burning fossil fuels, biomass burning, cement manufacture, cow and sheep rearing, deforestation, and other land-use changes.

Greenhouse Gas
A gas that absorbs radiation at specific wavelengths within the spectrum of radiation (infrared) emitted by the Earth's surface and by clouds. The gas in turn emits infrared radiation from a level where the temperature is colder than the surface. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planetary surface. Water vapor (H2O), carbon dioxide CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3) are the primary greenhouse gases in the Earth's atmosphere.

Greenhouse Effect
The trapping of heat by an envelope of naturally occurring heat-retaining gases (water vapour, CO2, nitrous oxide (N2O), CH4, and ozone) that keeps the earth about 30°C (60°F) warmer than if these gases did not exist.

Gross Domestic Product (GDP)
The total market value of goods and services produced in that region within a given period after deducting the cost of goods utilised in the production.

IATA
International Air Transport Association, the organization of international commercial aviation with headquarters in Geneva.

IATA region
Region in its interpretation of the total of airlines which are based in a region.

ICAO
International Civil Aviation Organization, a United Nations agency with headquarters in Montreal. Develops internationally binding norms for civil aviation.

Immission
Remains of fuel injected from the exhaust plume into the atmosphere.

Indirect Radiative Impact
Radiative forcing induced not directly but by changing other scattering or absorbing components of the atmosphere (clouds or gases).

Intergovernmental Organization (IGO)
Organizations constituted of governments. Examples include the World Bank, the OECD, and the International Civil Aviation Organization. The UNFCCC allows accreditation of these IGOs to attend the negotiating sessions.

International flight stage
A flight stage with one or both terminals in the territory of a State, other than the State in which the air transport operator has its main place of business.

International Institute for Applied Systems Analysis (IIASA)
Non-governmental, international, interdisciplinary research institute located in Laxenburg, Austria. IIASA is supported by the Academy of Sciences and similar learned societies from 15 countries. Its research focuses on the human dimensions of global change.

IPCC
Intergovernmental Panel on Climate Change. An international UN panel on climate change, founded in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP). In 1999, the IPCC published a special report on issues related to air transport, entitled "Aviation and the Global Atmosphere." (www.ipcc.ch), in 2000 a special report on "Emission Scenarios" (SRES).

Kyoto Protocol
The Protocol, drafted during the Berlin Mandate process, that, on entry into force, would require countries listed in its Annex B (developed nations) to meet differentiated reduction targets for their GHG emissions relative to 1990 levels by 2008-2012. It was adopted by all Parties to the Climate Convention in Kyoto, Japan, in December 1997.

Landing/Take-Off (LTO)
A reference cycle for the calculation and reporting of emissions, composed of four power settings and related operating times for subsonic aircraft engines [Take-Off - 100% power, 0.7 minutes; Climb - 85%, 2.2 minutes; Approach - 30%, 4.0 minutes; Taxi/Ground Idle - 7%, 26.0 minutes].

Load factor
Unit of Demand divided by unit of Capacity.

Long-haul
Traffic flow, for which every airport-to-airport distance is more than to 4000 km.

Medium-haul
Traffic flow, for which every airport-to-airport distance is more than 1500 km and less than or equal to 4000 km.

Methane
One of the six GHGs to be mitigated under the Kyoto Protocol, it has a relatively short atmospheric lifetime of 10 ± 2 years. Primary sources of CH_4 are landfills, coal mines, paddy fields, natural gas systems, and livestock (e.g., cows and sheep). It has a GWP of 21 (100 year time horizon).

Mitigation
An anthropogenic intervention to reduce the effects of emissions or enhance the sinks of greenhouse gases.

Nitrous Oxide
One of six GHGs to be curbed under Kyoto Protocol, N_2O is generated by burning fossil fuels and the manufacture of fertilizer. It has a GWP 310 times that of CO_2 (100 year time horizon).

NOx
Oxides of nitrogen, defined as the sum of the amounts of nitric oxide (NO) and nitrogen dioxide (NO_2) with mass calculated as if the NO were in the form of NO_2.

Organic Carbon
The carbonaceous fraction of ambient particulate matter consisting of a variety of organic compounds.

Ozone
Ozone (O3) in the troposphere, or lower part of the atmosphere, can be a constituent of smog and acts as a GHG. It is created naturally and also by reactions in the atmosphere that involve gases resulting from human activities, including nitrogen oxides (NOx), from motor vehicles and power plants. The Montreal Protocol seeks to control chemicals that destroy ozone in the stratosphere (upper part of the atmosphere), where the ozone absorbs ultra-violet radiation.

Ozone Hole
A substantial reduction below the naturally occurring concentration of ozone, mainly over Antarctica.

Particulate Mass Emission Index
The number of grams of particulate matter generated in the exhaust per kg of fuel burned.

Particulate Number Emission Index
The number of particles generated in the exhaust per kg of fuel burned.

Passenger kilometer (PKT)
Measure for the actual transport performance in passenger transport (number of passengers multiplied by distance flown). To determine this value, one does not use the actual length of the flown route, with its air traffic control related detours, but the great circle distance between the cities of origin and destination. One distinguishes between available transport performance (PKO, passenger kilometers offered) and actual transport performance (PKT, passenger kilometres transported). Another commonly used term for available transport performance is SKO (seat kilometers offered).

Perfluorocarbons
Among the six GHGs to be abated under the Kyoto Protocol. Perfluorocarbons (PFCs) are a by-product of aluminium smelting and uranium enrichment. They also are the replacement for CFCs in manufacturing semiconductors. The GWP of PFCs is 65009200 times that of CO2 (100 year time horizon).

Personnel costs
Personnel costs are defined as the total remuneration, in cash or in kind, payable by an employer to an employee (regular and temporary employees as well as home workers) in return for work done by the latter during the reference period. Personnel costs also include taxes and employees' social security contributions retained by the unit as well as the employer's compulsory and voluntary social contributions.

Plume
The region behind an aircraft containing the engine exhaust.

Policy variable
Input variable of which the value may be changed as a result of a policy measure, used in AERO-MS.

Pollutant
Strictly too much of any substance in the wrong place or at the wrong time is a pollutant. More specifically, atmospheric pollution may be defined as 'the presence of substances in the atmosphere, resulting from man-made activities or from natural processes, causing adverse effects to man and the environment'.

Pressure Ratio
The ratio of the mean total pressure exiting the compressor to the mean total pressure of the inlet when the engine is developing take-off thrust rating in ISA sea level static conditions.

Primary Energy
The energy that is embodied in resources as they exist in nature (e.g., coal, crude oil, natural gas, uranium, or sunlight); the energy that has not undergone any sort of conversion.

Radiative Forcing
A change in average net radiation (in W m-2) at the top of the troposphere resulting from a change in either solar or infrared radiation due to a change in atmospheric greenhouse gases concentrations; perturbance in the balance between incoming solar radiation and outgoing infrared radiation.

Region pair
The summation of flight stages between two IATA regions or within an IATA region.

Regulatory Measures
Rules or codes enacted by governments that mandate product specifications or process performance characteristics.

Renewables
Energy sources that are, within a short timeframe relative to the earth's natural cycles, sustainable, and include non-carbon technologies such as solar energy, hydropower, and wind as well as carbon-neutral technologies such as biomass.

Revenue passenger
A commercial passenger for whose transportation an air carrier receives commercial remuneration.

Revenue tonne-kilometres (RTK)
A metric tonne of revenue load carried one kilometre. Tonne-kilometres performed equals the sum of the products obtained by multiplying the total number of tonnes of each category of revenue load carried on each flight stage by airport-to-airport distance.

Route network
The aggregate of Air Transport System routes (airways), itineraries defined in terminal areas and other airspace structure elements (e.g. holding areas) defines for the use of the Navigable Airspace by Aircraft Operators.

Scheduled air service
A commercial air service operated according to a published timetable, or with such a regular frequency that it constitutes an easily recognisable systematic series of flights.

Scenario
A plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions ("scenario logic") about key relationships and driving forces (e.g., rate of technology change, prices). Note that scenarios are neither predictions nor forecasts.

(Scenario) Storyline
A narrative description of a scenario (or a family of scenarios) highlighting the main scenario characteristics, relationships between key driving forces and the dynamics of their evolution.

Scenario variable
Input variable of which the value may be changed as a result of autonomous developments following from the scenario specification.

Short-haul
Traffic flow, for which every airport-to-airport distance is less than or equal to 1500 km.

Socio-economic factor
Any characteristic of a group of people that is interpreted from either a social or economic perspective.

Soot
Carbon-containing particles produced as a result of incomplete combustion processes.

Specific Fuel Consumption
The fuel flow rate (mass per time) per thrust (force) developed by an engine.

Stakeholder
Person or entity holding grants, concessions, or any other type of value which would be affected by a particular action or policy.

Stratosphere
The stably stratified atmosphere above the troposphere and below the mesosphere, at about 10- to 50-km altitude, containing the main ozone layer.

Sulfur Hexafluoride
One of the six GHGs to be curbed under the Kyoto Protocol. Sulfur hexafluoride (SF6) is largely used in heavy industry to insulate high-voltage equipment and to assist in the manufacturing of cable-cooling systems. Its GWP is 23,900 times that of CO2 (100 year time horizon).

Surface competition
This is the potential for some air transport demand to be lost to or gained from surface modes when fare and freight increases or decreases occur.

Susceptibility
Probability for an individual or population of being affected by an external factor.

Sustainable
A term used to characterize human action that can be undertaken in such a manner as to not adversely affect environmental conditions (e.g., soil, water quality, climate) that are necessary to support those same activities in the future.

Technical Potential
The amount by which it is possible to reduce GHG emissions or improve energy efficiency by using a technology or practice in all applications in which it could technically be adopted, without consideration of its costs or practical feasibility.

Ton kilometres (TKT)
Measure of transport performance (payload multiplied by distance). One distinguishes between available transport performance (TKO, ton kilometres offered) and the actual transport performance (TKT, ton kilometres transported). In calculating payloads, passengers are taken into account by means of a statistical average weight.

Transport demand
The number of passengers or weight of freight or mail or baggage wanting to be carried, or having been carried.

Trip Purpose
There are three purposes of passenger trips used for air transport development analysis: business, leisure and vacation/holidays. In AERO-MS passenger trips are only disposed in business or leisure trips.

Tropopause
The boundary between the troposphere and the stratosphere, usually characterized by an abrupt change in lapse rate (vertical temperature gradient).

Troposphere
The layer of the atmosphere between the Earth’s surface and the tropopause below the stratosphere (i.e., the lowest 10 to 18 km of the atmosphere) where weather processes occur.

Ultraviolet Radiation
Energy waves with wavelengths ranging from about 0.005 to 0.4 μm on the electromagnetic spectrum. Most ultraviolet rays coming from the Sun have wavelengths between 0.2 and 0.4 μm. Much of this high-energy radiation is absorbed by the ozone layer in the stratosphere.

Unit cost
Direct operating cost per unit of capacity (for one flight).

Volatiles
Particles that evaporate at temperatures less than about 100°C.

Water vapour
Even ahead of carbon dioxide, water vapor is the most important greenhouse gas. Without water vapor from natural sources, the earth's surface would be around 22 degrees Celsius cooler. This makes water vapor responsible for two-thirds of the natural greenhouse effect of 33 degrees Celsius. Unlike carbon dioxide, man-made water vapor emissions are too insignificant in comparison with natural sources (e. g. evaporation) to have an influence on the earth's climate.

Yield
The ratio of revenues to passenger-kilometres. Yield is reported net of taxes and other government fees, including fees for border inspections and airports.

12.2 List of Abbreviations

AC	Advisory Committee – Circle of aviation stakeholders advising the CONSAVE 2050 project work
AERO2K	Global Aircraft Emissions - EC - data project for climate impacts evaluation
AERO-MS	AERO Modelling System – tool for the quantification of aviation scenarios within the CONSAVE 2050 Project
AERONET	Thematic network of the European Commission on Aircraft Emissions and Reduction Technologies
ACARE	Advisory Council for Aeronautics Research in Europe
ACOS	Aviation Cost Model (Part of AERO-MS)
ADEM	Aviation demand and Air Traffic Model (Part of AERO-MS)
ASTERA	Aeronautical Stakeholders Tools for the European Research Agenda – including Scenario Activities for 2020
ATC	Air Traffic Control
ATEC	Aircraft Technology Model (Part of AERO-MS)
ATK	Aircraft tone kilometers
ATM	Air Traffic Management
CAEP	ICAO Committee for Aviation Environment Protection
CONSAVE 2050	EC-Project for Constrained Scenarios on Aviation and Emissions with quantification until 2050
DECI	Direct Economic Impacts Model (Part of AERO-MS)
DLH	Deutsche Lufthansa AG
DLR	German Aerospace Centre
EC	European Commission
FLEM	Flights and Emissions Model (Part of AERO-MS)
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IGO	Intergovernmental Organisation
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LTO	Landing/Take-Off
NGO	Non-Governmental Organisation
NLR	National Aerospace Laboratory
OECD	Organisation of Economic Cooperation and Development
ppbv	Parts per billion by volume
ppmv	Parts per million by volume
pptv	Parts per trillion by volume
PKT	Passenger Kilometer
RTD	Research and Technological Development
RTK	Revenue ton kilometers
SRES	IPCC Special Report on Emission Scenarios
TKT	Ton Kilometer
TRADEOFF	Aircraft Emissions: Contribution of Different Climate Components to Changes in Radiative Forcing-Tradeoff to Reduce Atmospheric Impact (EC-Project)
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization
WP	Work Package

12.3 List of Prefixes

Name	Symbol	Factor
Yotta	Y	10^{24}
Zetta	Z	10^{21}
Exa	E	10^{18}
Peta	P	10^{15}
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Hecto	h	10^{2}
Deca	da	10^{1}

ANNEXES

Annex 1

Open list of proposals for topics to be addressed by the AERONET Workshop on long- term aviation scenarios (2050) –
Analysis of results from a AERONET questionnaire (performed in the year 2000)

Environment/ Emissions/ Climatology

- What means „sustainability" for the aviation system?
  How to define sustainability determinants?
  How can the environment benefit from sustainable mobility?

- What are the most important timescales for scenarios for atmospheric modelling and assessment purposes?

- What atmospheric sensitivities exist which suggest the need to alter the pattern of aviation, in terms of altitude, latitude, route concentration, etc.?

- With respect to impacts on climate change and/or air quality: What will be the most critical emissions from aviation during the next fifty years? Which additional (beyond the currently regulated) species may become environmentally important in the future (up to 2050)?
  - Clear answers, remaining uncertainties
  - Ranking, relative importance of emissions

- What are possible principal strategies to obtain sustainability (general targets, part/role of aviation)? What are the most effective levels for the strategy options: global, regional, national, local level(s)?

=>> Definition of different scenarios

- What might be the quantitative environmental targets during the next fifty years? How to define limits/caps for each of the important emissions (affecting climate change, local air quality)
  - based on detailed research or
  - based on political decisions/agreements like Kyoto-protocol, (precautionary principles)
  - setting standards following the „Californian way"?

  In which way will aviation be included?

- How to account for whole environmental problems (noise and emissions)? How do we arrive at the best balance between environmental impacts – noise, air quality, climate change – local vs. global etc?

- What might be „acceptable" global scenarios?

- Is there public support for radically different forms of air transport which could have reduced environmental impacts? If so, how should the funding for the development of this be generated?

- What is the potential to contribute to the reductions of emissions from aviation by means of
  - improvements in technology
    - -- engine / airframe technology

  - -- fuel technology
  - -- ATM/ATC/airport technology
- possible new aviation technologies
- improvements in aircraft operation
- feasible MBO's (market based options)?

Are the reduction scenarios and estimates developed for the IPCC report still valid?

- What will be the regulations, charges/taxation and restrictions for air traffic to fulfil the goals (ICAO, regional, local)?
- By what means (technological and/or operational) can certain effects of aircraft emissions on the atmosphere (changes in chemical composition, contrails, cirrus clouds) be minimized? How large would be the potential for a reduction of emissions by avoiding „dangerous" regions?

- What are the pros and cons for an in-flight mission monitoring in view of current and future regulations? For local air quality how will it be possible to take into account the new technologies (EIS) and how to phase them in?

- To what extent should we rely on (further, faster) technology developments or on economic/regulatory tools to meet the targets? Should economic tools be focused on demand management or on incentivising faster take up of improved technology?

- For a strategy to avoid/minimize policy restrictions, what would be the requirements on technological (engines, airframes, fuel, ATC) and operational improvements? What will be the related costs to finance the improvements?

Engines

- What rate of improvement in fuel efficiency and reduction of emissions can be expected over the time period? Are the scenarios developed for the IPCC report still valid?

- If the strategy is to avoid/minimise policy restrictions, which improvements in engine technology would fit to the requirements of „acceptable" scenarios?

- What are the prospects for new technologies to reduce atmospheric impact?

Fuel (availability, price, alternative fuels)

- How long is kerosene fuel expected to be available, in general, for aviation? Will we see a decrease in availability for aviation during the next fifty years? At what time could we expect (partial, total) substitution of kerosene, if any?

- What might be the development in fuel prices over the next fifty years and to which extent will this increase in price affect air traffic demand? To which extent will an increase in fuel prices stimulate technological improvements or new inventions?

- Can the specification of fuel be changed to reduce environmental impact? What is the situation in 50 years? Which will be the most feasible alternative to kerosene, if kerosene is no longer available? What would be the time frames for the introduction of alternative fuels?

Aircraft/Airframe/Fleet

- What are the technological improvements in airframe efficiency during the considered time horizon? Are the scenarios developed for the IPCC report still valid?
- How will the structure of the air traffic network develop over time? More hub & spoke, more point-to-point connections? What will be the related effects on the fleet mix and on aircraft design/seat capacity/load factor?
- In order to transport the same number of passengers, is it better for environment to increase the number of small aircraft which could be more adapted to the demand but increase the traffic density, or to limit the number of in-flight aircraft by an increasing of their size ? It is possible to quantify the benefit?
- Will the future fleet have more/less turboprops, more/less business jets? What will be relative importance of general aviation, military air movements?
- Which new aircraft types can we expect during the next decades: Cryoplane, high speed aircraft, „green“ aircraft, new very large aircraft types?
  - To which scenario would the introduction of a cryoplane fit? What would be a realistic time frame for introduction, if any?
  - To which scenario would the introduction of a SST fleet fit? How large would the fleet be? What are realistic time frames for introduction, if any?
- What improvements in airframe efficiency are needed to contribute to „acceptable“ scenarios?
- What is the role of airframe manufacturers to contribute to the effort to attain sustainability?

Airports

- Do we expect new airport design technologies? What would be the potential effects on demand on emissions?
- What will be the impacts of new aircraft types, changes in the fleet mix and the structure of the air traffic network (e.g. with respect to more/less hub & spoke, more/less point-to- point connections) on the airport design?
- What are the options for airports to reduce emissions?
- To what extent, at what time during the next decades do we expect infrastructure/airport capacity constraints in Europe and other parts of the world? What will be the related impact on demand?
- Is the concept of determining an „environment capacity“ for airports a feasible approach? To what extent will it be realized?
- During the next decades, what will be – for airports – the relative importance of air quality and noise aspects?

ATM/ATC

- What will be the ATM/ATC concepts at the time horizon being considered? What will be the impacts of changes in the structure of the air traffic network (e.g. with respect to more/less hub & spoke, more/less point-to-point connections) on ATM/ATC?

- What are the contributions of GATE to Gate concept, free route (and others) to the reduction of fuel consumption? (Can the information given by the IPCC report still be used or are there new developments?) Is ATM/ATC flexible enough to allow for a (feasible) concept for an „ecological“ routing?

- Which are the obstacles to achieve more effective ATM/ATC, and how to remove them in the considered time horizon? Are the limiting human factors for the further development of ATM/ATC? What will be the future role of computers?

- What will be the capacity constraints caused by bottlenecks in ATM/ATC and how will they affect demand?

Airline/ Airline operation

- To what extend will airline concentration/alliances be affected by globalisation? Will most of the airlines will become or be linked to international carriers? How will that affect the organisation of the air traffic? Are new international rules needed, e.g. to ensure efficient operation? Will the importance of regulations increase again?

- What rate of improvement in operational efficiency can be expected over the time period considered?

- Can airlines still operate economically if demand will be reduced?

- Is aviation growth financially viable in the long run? Does poor financial performance of some carriers allow for continuing growth or will this potential diminish?

- How will slot allocation be organised in a situation of constraints caused by scarcity of airport or airspace capacity and/or environmental regulations?

- What could be the role of (an open or closed system for) emission trading?

- What will be the development during the next decades in airline service concerning
  - route network
  - frequencies
  - fleet mix
  - alliances?

- What will be the relative importance of hub & spoke versus point-to-point connections? What will be the related impact on the fleet mix? What will be the relative importance of turboprops versus jets, long range aircraft versus short range aircraft etc?

- To what extent will economical “burdens” influence the demand for air transport?

- What could be the role of airlines to contribute to a general effort to attain sustainability?

Air transport research

- Should aviation be looked upon in splendid isolation when considering sustainability or does the concept of sustainability lead us above and beyond one single mode of transport?

- Which options do the stakeholders in air transport have to attain sustainability?

- What are the key fields/factors for air traffic demand? What are typical timescales for changes in key fields/ key factors? Are there important factors which can be supposed to remain constant / nearly constant for the considered time horizon? How to include „sudden events“ into the consideration? What will be a suitable regionalisation for the scenarios?

  - What are the most important effects on aviation (demand, supply side) from the expected long-term development in economy, total transport, technology, energy, environment, etc. (sectors which are known to be the frame-setting fields for the aviation system)?
  - What will be the enablers of air transport and what will limit the growth in air traffic?
  - What are the drivers for widening the gap between demand (for unlimited mobility) and the protection of environment? Which will be the opportunities and threats to a sustainable development of air transport?
  - What are the indicators for a saturation of air transport markets? Do we expect for Europe or other parts of the world a saturation of the air transport market during the next decades?
  - How will mobility develop within the given time frame and which will be the role of air transport?
  - To which extent will the relative importance of prices increase?
  - How could aviation evolve in the (newly defined) IPCC SRES world?
  - How will an optimal integration of transport modes affect air transport?

- Which developments will influence business or personal travel? How much will passengers and shippers use air transport services in the considered time horizon?

- Is long term substitution by alternative modes likely to happen? Will use of internet/ videolinks etc. reduce travel (business, private) demand (current evidence available and long term projection)?

- What is the projected long term development in regulatory terms? How will environmental legislation on air transport develop over the next decades?

- To which extend will a shortage in environmental capacity and/or economical burdens restrict growth in air traffic?

- How can mobility benefit from a sustainable environment and vice versa?

- How to qualify and quantify benefits to society from civil aviation?

General remarks

This list is a collection of proposals without any ranking and open for further additional issues.

The discussion on these topics should include recent information and results from IPCC, ICAO/CAEP and from different AERONET workshops in years 1999 and 2000 on air transportation, ATM system developments, aviation fuels and emissions.

Annex 2

Key fields and factors affecting the long-term development in aviation and its emissions

Mainly considered with respect to: G = General Aspects, T = Traffic, A = Aviation

I. Demography (G,T)

- Population development (world, regions) incl. fertility, mortality
- Age distribution
- Household structures
- Employment
- Migration

II. Macroeconomics (G,T,A)

- Economic Development
  - GDP growth or GDP/capita growth (world, regions)
  - income distribution, disposable income
  - differences among regions

Leisure time => IV: Social Trends, Mobility Patterns

- World Trade Development
  - world trade development
  - globalisation of markets, companies, division of labour
  - remaining barriers

Employment => I: Demography

III. Energy / Resources (G,T,A)

- New energy alternatives
- Change in total energy consumption
- Resulting shares of energy sectors

Availability and prices of fuel and resources, relevant for aviation => XI: Aviation – Special System Aspects

IV. Social Trends, Mobility Pattern (G,T,A)

- Intensity and level of cultural and social interactions
- Level of problem-solving (local, regional, global)
- Ranking of social values:
  Welfare, mobility, safety/health, clean environment, contacts, sustainability
- Leisure time
- Life-styles

Travel time budget, travel cost budgets => V: Transport

V. Transport (T,A)

- Travel time budgets, travel costs budgets, etc.
- Infrastructure, intermodal connections
- Growth of total passenger, freight traffic (world, regions)
- Resulting modal split (world, regions)

Intermodal cooperation, competition => IX: Air Transport - Supply Side

VI. Aviation Effects on Ecology (A)

- Risk for sustainability by emissions from aviation
    - global, regional, local relevance
    - noise effects vs. climate change effects vs. air quality effects
- (Other) Health risks from emissions of aviation
- Aircraft emissions of interest in the time span until 2050
- Eco-efficiency of aviation
- Efficiency of aviation on regional planning

Special aspect: Hints, requirements for mitigation options

Energy, resources for aviation => XI: Air Transport – Special System Aspects

VII. Technology (G,T,A)

a) Non Transport Technologies, general

- Rate and direction of technology change

b) Non-Transport Technologies with potential to substitute traffic / air traffic

- Telecommunication, information technology (main effects on business trips)
- Computer technology, virtual reality (main effects on personal trips)

c) Transport Technologies

- New engines
- New airframes
- New CNS/ATM
- Alternative fuels
- New airport design
- Technologies of alternative modes (especially high speed trains)

Aspects: noise, emissions, efficiency, costs, service / demand characteristics, others

VIII. Policy / Standards, Regulations (A)

Global, regional, local

- Planning and financing of infrastructure
- Technological stringencies, regulations
- Market access and operating regulations
- Liberalisation, privatisation, subsidies

- Levies (taxes, charges – noise, emissions)
- Emission trading
- Voluntary options (agreements with aviation industry)
- Restrictions / caps

Aspects: Ecology, regional planning, safety, economical issues, social issues

IX. Air Transport – Supply side

- Services characteristics
  - network/ infrastructure added (distribution of airports, hub-and-spoke, point-to-point)
  - routes
  - frequencies
  - ticket prices
  - safety, security
  - comfort
  - marketing

- Fleet characteristics
  - load factors
  - aircraft capacity / frequency growth
  - aircraft utilization
  - average stage length
  - fleet mix (generic seat categories)
  - turboprops vs. jets (etc.)

- Infrastructure constraints
  - CNS / ATM => VII, VIII
  - airports => VIII
  - intermodal connections => V

- Market aspects (most emphesis on airlines)
  - market access => VIII
  - market structure
  - emerging markets
  - market maturity
  - consumer tastes ^ => IV, V
  - policy regulations, voluntary commitments => VIII
  - competition / alliances between airlines
  - intermodal cooperation, competition (technology aspects => VII)

- Operating economics
  - operating costs
    -- DOC (fixed and variable direct costs)
    taking into account e.g.
      * prices of airframes
      * engine prices
      * fuel prices => XI
      * taxes / charges => VIII
      * capital costs

    -- IOC (indirect operating costs as administration or servicing costs)
  - revenues, yield

X. Air Transport – Demand

- Features relevant for trip generation, modal split => Inputs from field categories I – IX
- Elasticities
- Long-term development of demand by air transport sectors (world, regions)
    - passenger transport by travel purpose (business, private/tourism)
    - freight transport
    - military movements
    - others

Special aspect: short-, medium-, long-haul traffic

XI. Aviation - Special System Aspects

- Energy / Resources
    - fuel availability
    - fuel prices
    - resource availability
    - resource prices

- Key elements which determine the amount and distribution of emissions, as
    - engine-
    - airframe-
    - ATC-
    - flight-characteristics

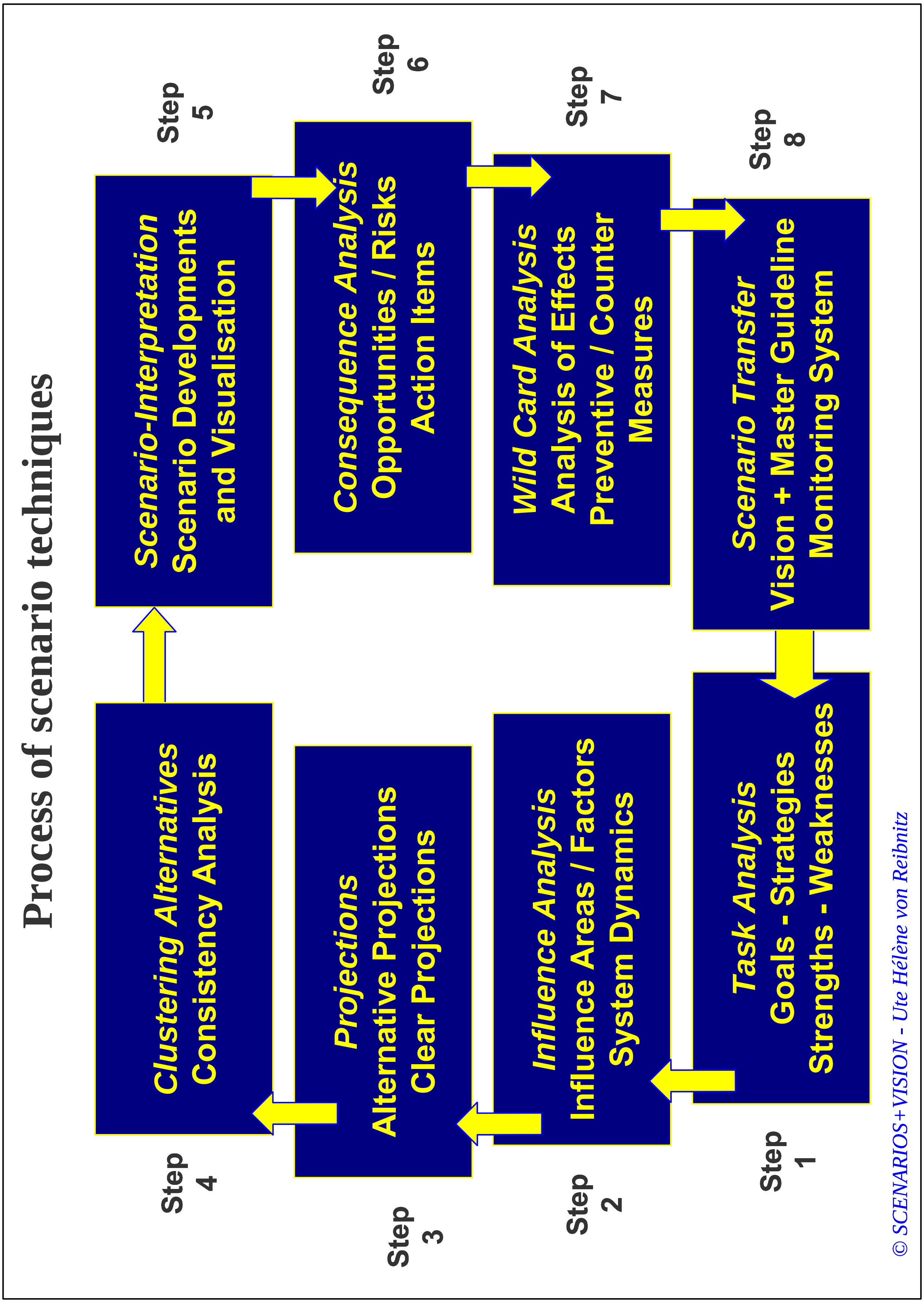
Inputs from: VII, IX

Emissions (Noise, exhausts)

- change/growth of magnitude
- distribution

Emissions of interest => VI: Aviation Effects on Ecology
Sources / causes of emissions => VII: Technology, IX: Air Transport – Supply Side
Mitigation => VIII: Policy / Standards, Regulations

ANNEX 3


Process of scenario techniques
Step 1
Task Analysis
Goals - Strategies
Strengths - Weaknesses
Step 2
Influence Analysis
Influence Areas / Factors
System Dynamics
Step 3
Projections
Alternative Projections
Clear Projections
Step 4
Clustering Alternatives
Consistency Analysis
Step 5
Scenario-Interpretation
Scenario Developments
and Visualisation
Step 6
Consequence Analysis
Opportunities / Risks
Action Items
Step 7
Wild Card Analysis
Analysis of Effects
Preventive / Counter
Measures
Step 8
Scenario Transfer
Vision + Master Guideline
Monitoring System
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ANNEX 4

Comparison of assumptions made for different scenario studies plus two results (demand growth factor (1990), CO2 emissions)

Scenario Drivers	CONSAVE Scenarios 2020				ICAO 2004 (1)	ACARE/ ASTERA (2)	Airbus 2003 (3)	Boeing 2004 (4)	Eurocontrol 2004 (5)	AERO2k 2004 (6)	WBCSD 2004 (7)	ICAO CAEP/4 - FESG 1998 (8) Year 2020			ICAO CAEP/4 - FESG 1998 (8), Year 2050		
	High Growth		FW	DtE													
	ULS	RPP										IS92c	IS92a	IS92e	IS92c	IS92a	IS92e
Population [billion]	7.5		8.2	7.5	k.A.	n.a.	n.a.	n.a.	7.8	n.a.	8.2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Economic growth rates (p.a.)	3.9%	3.8%	2.3%	3.3%	2.5%	n.a.	n.a.	3.0%	2.9%	n.a.	3.0%	2.0%	2.9%	3.5%	1.2%	2.3%	3.0%
World GDP-mer (trillion $)	57	56.4	40	53	k.A.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Energy use [EJ]	700	610	600	580	k.A.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ratio of global oil production (1990=1)	1.3		2.2	1.5	k.A.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Crude oil price (1990=1)	1.5	2	4	2	k.A.	n.a.	n.a.	n.a.	CONSAVE-assumptions	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zero-carbon energy rate	15%	20%	regional differences	20%	k.A.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Air Transport Demand Index (1990=1)	3.2	2.6	2.0	1.9	2.7	n.a.	4.24	4.09	only flights in Europe	only capacity (in ASK) projection: 4,23% p.a.	4	2.4	3.1	3.9	3.7	6.5	10.3
Fuel Efficiency Change	-10 to -20% below 2000 level (-0.75% p.a.)		2020: -10 to -20% below 2000 level (-0.75% p.a.); N.America: -2% p.a. after 2020; Eurasia & Far East: -1% p.a.	+10% c.f. 2000 levels (+0.5% p.a.)	k.A.	n.a.	n.a.	n.a.	n.a.	-20% of specific fuel consumption between 2002 and 2025	n.a.	n.a.	n.a.	n.a.	Technology Scenario 1: -40 to -50%; Technology Scenario 2: -30 to -40% (relative to 1997)		
LTO NOx Levels	45% of 2000		N.America: +11.5% p.a.; Eurasia & Far East: 2020 levels; Middle East: 2010 to 2020 levels; Subcontinent+Unaligned Regions: post-2000 levels	30% of 2000	k.A.	-80% per passenger km for new ac	n.a.	n.a.	n.a.	CAEP4-64% for new aircraft (similar to the vision 2020 targets)	n.a.	n.a.	n.a.	n.a.	Technology Scenario 1: -10 to -30% below CAEP/2 limit, Technology Scenario 2: -50 to -70% below CAEP/2limit		
Noise Reduction	10 dB reduction by 2020				k.A.	reduction to one half of the level in 2001	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fleet Lifespan (in years)	<30	<25	NAmerica, Eurasia, Far East <20; All other regions >30	<20	k.A.	n.a.	n.a.	n.a.	n.a.	narrow-bodied ac: 27, wide-bodied ac: 35	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Aircraft Size Growth	large		large	large	0,2% p.a.	n.a.	1% p.a.	low	1% p.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CO2 Emissions [billion kg pa] (ICAO/CAEP=2050)	906.5	748.9	622.6	624.9	k.A.	-50% per passenger km for new ac	n.a.	n.a.	n.a.	1029	n.a.	n.a.	n.a.	n.a.	Fc1: 845,5, Fc2: 874,1	Fa1: 1485,4, Fa2: 1537,8	Fe1: 2347, Fe2: 3434,6

Sources:

(1) ICAO 2004: Outlook for Air Transport to the Year 2015
(2) European Aeronautics: A Vision for 2020
(3) Airbus 2003: Global Market Forecast 2022
(4) Boeing 2004: Current Market Outlook 2023
(5) Eurocontrol 2004: Long-term Forecast 2025
(6) AERO2k: Global Aviation Emissions Inventories for 2025
(7) WBCSD 2004: Mobility 2030
(8) ICAO CAEP/4-FESG 1998: Long-Range Scenarios 2050

ANNEX 5

Detailed Scorecards of CONSAVE Results

Effect	Unit	1992	2000	2005
Air transport and aircraft operation				
Passenger demand				
First/business	billion pax-km pa	62.7	94.6	116.2
Economy	billion pax-km pa	211.4	333.1	410.7
Discount	billion pax-km pa	1562.5	2459.9	3056.4
Total scheduled	billion pax-km pa	1836.5	2887.6	3583.2
Total non-scheduled	billion pax-km pa	243.4	420.6	507.8
Total	billion pax-km pa	2079.9	3308.2	4091.0
Cargo demand	billion tonne-km pa	70.2	127.5	179.1
Revenue tonne-Km	billion RTK pa	278.2	458.3	588.2
Flights				
Technology age > 12 years	million flights pa	11.4	15.8	19.5
Technology age <= 12 years	million flights pa	11.7	15.0	17.4
Total	million flights pa	23.0	30.7	37.0
Aircraft km				
Technology age > 12 years	billion ac-km pa	10.8	15.7	19.6
Technology age <= 12 years	billion ac-km pa	11.2	15.4	18.4
Total	billion ac-km pa	22.1	31.0	38.1
Effects on airlines				
Direct operating costs	billion 1992 US $	96.68	141.60	182.79
Operating costs	billion 1992 US $	234.31	324.02	417.56
Operating revenues	billion 1992 US $	234.56	351.77	417.67
Operating results	billion 1992 US $	0.25	27.75	0.11
Contribution to gross value added	billion 1992 US $	108	182	202
Airlines related employment	1000 employees	1824	2481	3123
Economic effects for other actors				
Change in consumer surplus	billion 1992 US $			0.0
Fleet				
Technology age > 12 years	number of aircraft	8235	10589	13197
Technology age <= 12 years	number of aircraft	7245	8399	9795
Total	number of aircraft	15480	18988	22992
Revenue from taxation/charges	billion 1992 US $			0.0
Effects for a typical major airport				
Pax demand	million pax pa	20.22	33.04	38.88
Cargo demand	million tonne pa	0.63	1.01	1.35
Movements	1000 mov. pa	276.1	393.6	468.4
Aviation employment	1000 employees	65	96	112
Fuel consumption and emissions				
Fuel use	billion kg pa	134.2	168.1	195.9
CO2 emissions	billion kg pa	423.5	530.7	618.5
NOx emissions	million kg pa	1689.1	2227.9	2637.0
NOx emission index	gram / kg fuel	12.6	13.3	13.5
Operating efficiency commercial aviation				
Direct operating costs / RTK	US$/tonne-km	0.35	0.31	0.31
Cost/RTK	US$/tonne-km	0.84	0.71	0.71
Fuel/RTK	kg/tonne-km	0.45	0.34	0.31
Fuel/ATK	kg/tonne-km	0.28	0.23	0.21
Pax km/seat km	factor	0.65	0.72	0.73
Freight-km/cargo-km	factor	0.53	0.60	0.61
RTK/ATK	factor	0.62	0.68	0.68
RTK/aircraft-km	tonne-km/ac-km	12.61	14.77	15.46
Revenues/RTK	US$/tonne-km	0.84	0.77	0.71
Fuel/aircraft-km	kg/ac-km	5.64	5.03	4.80
Reduction indicators				
CO2/RTK relative to 2000	kg/tonne-km	1.31		0.91
CO2/ASK relative to 2000	kg/tonne-km	1.45		0.91
Growth/year CO2 between 1992-2000	%		2.9	
Growth/year CO2 between 2000-2005	%			3.1
NOx/RTK relative to 2000	kg/tonne-km	1.25		0.74
NOx/ASK relative to 2000	kg/tonne-km	1.38		0.74
Growth/year NOx between 1992-2000	%		3.5	
Growth/year NOx between 2000-2005	%			3.4

Table A5-1: Comparison of common scenario development up to 2005

Effect	Unit	2000	2020	2050 landing charge factor 1.1	2050 landing charge factor 10	2050 landing charge factor 20
Air transport and aircraft operation						
Passenger demand						
First/business	billion pax-km pa	94.6	185.3	609.7	606.6	603.4
Economy	billion pax-km pa	333.1	669.7	2493.2	2467.0	2442.0
Discount	billion pax-km pa	2459.9	4934.3	15954.0	15754.0	15539.0
Total scheduled	billion pax-km pa	2887.6	5789.2	19057.0	18827.0	18584.0
Total non-scheduled	billion pax-km pa	420.6	715.9	2128.9	2046.2	1969.8
Total	billion pax-km pa	3308.2	6505.1	21185.0	20874.0	20554.0
Cargo demand	billion tonne-km pa	127.5	422.5	1954.5	1923.4	1881.2
Revenue tonne-Km	billion RTK pa	458.3	1073.0	4073.1	4010.8	3936.6
Flights						
Technology age > 12 years	million flights pa	15.8	31.4	108.6	105.0	102.7
Technology age <= 12 years	million flights pa	15.0	24.1	73.3	70.2	68.1
Total	million flights pa	30.7	55.5	181.9	175.1	170.8
Aircraft km						
Technology age > 12 years	billion ac-km pa	15.7	33.2	117.4	114.8	112.5
Technology age <= 12 years	billion ac-km pa	15.4	27.4	84.7	83.1	81.8
Total	billion ac-km pa	31.0	60.6	202.1	197.9	194.3
Effects on airlines						
Direct operating costs	billion 1992 US $	141.60	391.81	2508.51	2699.19	2880.89
Operating costs	billion 1992 US $	324.02	803.22	4677.70	4834.30	4984.30
Operating revenues	billion 1992 US $	351.77	868.63	4999.50	5087.50	5193.80
Operating results	billion 1992 US $	27.75	65.41	321.79	253.25	209.43
Contribution to gross value added	billion 1992 US $	182	525	3929	3797	3695
Airlines related employment	1000 employees	2481	4919	16610	16302	16015
Economic effects for other actors						
Change in consumer surplus	billion 1992 US $			0.0	-176.8	-387.0
Fleet						
Technology age > 12 years	number of aircraft	10589	21155	66878	64801	63590
Technology age <= 12 years	number of aircraft	8399	13635	38693	37446	36611
Total	number of aircraft	18988	34790	105570	102250	100200
Revenue from taxation/charges	billion 1992 US $			76.8	304.5	510.0
Effects for a typical major airport						
Pax demand	million pax pa	33.04	54.24	169.63	152.01	139.65
Cargo demand	million tonne pa	1.01	2.63	10.09	9.58	9.04
Movements	1000 mov. pa	393.6	608.3	1607.6	1383.2	1226.5
Aviation employment	1000 employees	96	159	446	412	385
Fuel consumption and emissions						
Fuel use	billion kg pa	168.1	287.1	773.4	760.1	746.3
CO_2 emissions	billion kg pa	530.7	906.5	2441.6	2424.8	2399.5
NO_x emissions	million kg pa	2227.9	3494.5	7312.6	7262.9	7186.2
NO_x emission index	gram / kg fuel	13.3	12.2	9.5	9.5	9.5
Operating efficiency commercial aviation						
Direct operating costs / RTK	US$/tonne-km	0.31	0.37	0.62	0.67	0.73
Cost/RTK	US$/tonne-km	0.71	0.75	1.15	1.21	1.27
Fuel/RTK	kg/tonne-km	0.34	0.25	0.18	0.18	0.18
Fuel/ATK	kg/tonne-km	0.23	0.17	0.11	0.11	0.11
Pax km/seat km	factor	0.72	0.75	0.69	0.69	0.69
Freight-km/cargo-km	factor	0.60	0.62	0.60	0.60	0.60
RTK/ATK	factor	0.68	0.69	0.65	0.64	0.64
RTK/aircraft-km	tonne-km/ac-km	14.77	17.70	20.15	20.27	20.26
Revenues/RTK	US$/tonne-km	0.77	0.81	1.23	1.27	1.32
Fuel/aircraft-km	kg/ac-km	5.03	4.40	3.55	3.56	3.56
Reduction indicators						
CO_2/RTK relative to 2000	kg/tonne-km		0.73	0.52	0.52	0.53
CO_2/ASK relative to 2000	kg/tonne-km		0.74	0.49	0.49	0.50
Growth/year CO_2 between 2000-2020	%		2.7			
Growth/year CO_2 between 2020-2050	%			3.4	3.3	3.3
NO_x/RTK relative to 2000	kg/tonne-km		0.67	0.37	0.37	0.38
NO_x/ASK relative to 2000	kg/tonne-km		0.68	0.35	0.35	0.35
Growth/year NO_x between 2000-2020	%		2.3			
Growth/year NO_x between 2020-2050	%			2.5	2.5	2.4

Table A5-2: Unlimited Skies results up to 2050

Effect	Unit	2000	2020	2050	All: fuel tax	All: fuel tax	U+NA: fuel ta
				no tax	1.0$/kg	2.0$/kg	2.0$/kg
Air transport and aircraft operation							
Passenger demand							
First/business	billion pax-km pa	94.6	150.4	412.6	409.1	405.7	409.0
Economy	billion pax-km pa	333.1	545.7	1696.1	1673.1	1649.9	1678.2
Discount	billion pax-km pa	2459.9	3990.6	11044.0	10758.0	10474.0	10827.0
Total scheduled	billion pax-km pa	2887.6	4686.6	13153.0	12840.0	12530.0	12914.0
Total non-scheduled	billion pax-km pa	420.6	597.3	1482.7	1419.2	1354.3	1434.7
Total	billion pax-km pa	3308.2	5284.0	14636.0	14259.0	13884.0	14348.0
Cargo demand	billion tonne-km pa	127.5	351.0	1214.9	1143.8	1069.3	1178.4
Revenue tonne-Km	billion RTK pa	458.3	879.4	2678.5	2569.7	2457.6	2613.2
Flights							
Technology age > 12 years	million flights pa	15.8	26.0	75.5	67.6	61.4	71.9
Technology age <= 12 years	million flights pa	15.0	20.3	50.9	50.7	50.7	50.6
Total	million flights pa	30.7	46.3	126.5	118.3	112.2	122.5
Aircraft km							
Technology age > 12 years	billion ac-km pa	15.7	27.7	80.3	70.8	63.2	74.2
Technology age <= 12 years	billion ac-km pa	15.4	22.8	58.5	60.2	61.3	59.6
Total	billion ac-km pa	31.0	50.5	138.8	131.1	124.6	133.8
Effects on airlines							
Direct operating costs	billion 1992 US $	141.60	372.85	2407.13	2869.68	3303.61	2602.01
Operating costs	billion 1992 US $	324.02	775.68	4351.20	4771.60	5162.40	4527.40
Operating revenues	billion 1992 US $	351.77	814.85	4540.30	4819.80	5125.40	4655.20
Operating results	billion 1992 US $	27.75	39.17	189.13	48.25	-37.03	127.76
Contribution to gross value added	billion 1992 US $	182	490	3433	3176	2987	3312
Airlines related employment	1000 employees	2481	4566	13065	12510	12007	12745
Economic effects for other actors							
Change in consumer surplus	billion 1992 US $			-9.3	-446.7	-928.1	-222.5
Fleet							
Technology age > 12 years	number of aircraft	10589	17771	47220	40900	36243	44057
Technology age <= 12 years	number of aircraft	8399	11507	27126	27215	27332	26967
Total	number of aircraft	18988	29278	74346	68114	63575	71024
Revenue from taxation/charges	billion 1992 US $			83.1	670.7	1196.0	348.5
Effects for a typical major European airport							
Pax demand	million pax pa	33.04	43.93	107.49	104.94	102.23	103.23
Cargo demand	million tonne pa	1.01	2.19	5.80	5.52	5.18	5.47
Movements	1000 mov. pa	393.6	511.2	1105.9	1047.3	999.0	1016.4
Aviation employment	1000 employees	96	135	293	284	275	281
Fuel consumption and emissions							
Fuel use	billion kg pa	168.1	237.2	523.9	495.1	470.4	505.2
CO2 emissions aviation	billion kg pa	530.7	748.9	1653.8	1563.1	1484.9	1595.0
NOx emissions aviation	million kg pa	2227.9	2871.4	4913.8	4650.1	4418.6	4829.3
NOx emission index	gram / kg fuel	13.3	12.1	9.4	9.4	9.4	9.4
Operating efficiency commercial aviation							
Direct operating costs / RTK	US$/tonne-km	0.31	0.42	0.90	1.12	1.34	1.00
Cost/RTK	US$/tonne-km	0.71	0.88	1.62	1.86	2.10	1.73
Fuel/RTK	kg/tonne-km	0.34	0.25	0.18	0.17	0.17	0.17
Fuel/ATK	kg/tonne-km	0.23	0.17	0.12	0.11	0.11	0.11
Pax km/seat km	factor	0.72	0.75	0.70	0.70	0.70	0.70
Freight-km/cargo-km	factor	0.60	0.62	0.60	0.59	0.58	0.60
RTK/ATK	factor	0.68	0.69	0.65	0.65	0.64	0.65
RTK/aircraft-km	tonne-km/ac-km	14.77	17.42	19.30	19.61	19.73	19.54
Revenues/RTK	US$/tonne-km	0.77	0.93	1.70	1.88	2.09	1.78
Fuel/aircraft-km	kg/ac-km	5.03	4.32	3.42	3.42	3.40	3.42
Reduction indicators							
CO_2/RTK relative to 2000	kg/tonne-km		0.74	0.53	0.53	0.52	0.53
CO_2/ASK relative to 2000	kg/tonne-km		0.74	0.51	0.50	0.49	0.50
Growth/year CO_2 between 2000-2020	%		1.7				
Growth/year CO_2 between 2020-2050	%			2.7	2.5	2.3	2.6
NOx/RTK relative to 2000	kg/tonne-km		0.67	0.38	0.37	0.37	0.38
NOx/ASK relative to 2000	kg/tonne-km		0.68	0.36	0.35	0.35	0.36
Growth/year NOx between 2000-2020	%		1.3				
Growth/year NOx between 2020-2050	%			1.8	1.6	1.4	1.7

Table A5-3: Regulatory Push & Pull results up to 2050: all kerosene fleet

Effect	Unit	2000	2020	2050
				fleet roll-over
Air transport and aircraft operation				
Passenger demand				
First/business	billion pax-km pa	94.6	150.4	398.9
Economy	billion pax-km pa	333.1	545.7	1632.8
Discount	billion pax-km pa	2459.9	3990.6	10476.0
Total scheduled	billion pax-km pa	2887.6	4686.6	12508.0
Total non-scheduled	billion pax-km pa	420.6	597.3	1378.3
Total	billion pax-km pa	3308.2	5284.0	13886.0
Cargo demand	billion tonne-km pa	127.5	351.0	1101.9
Revenue tonne-Km	billion RTK pa	458.3	879.4	2490.6
Flights				
Technology age > 12 years	million flights pa	15.8	26.0	7.8
Technology age <= 12 years	million flights pa	15.0	20.3	109.5
Total	million flights pa	30.7	46.3	117.2
Aircraft km				
Technology age > 12 years	billion ac-km pa	15.7	27.7	10.0
Technology age <= 12 years	billion ac-km pa	15.4	22.8	117.6
Total	billion ac-km pa	31.0	50.5	127.6
Effects on airlines				
Direct operating costs	billion 1992 US $	141.60	372.85	2818.56
Operating costs	billion 1992 US $	324.02	775.68	5321.30
Operating revenues	billion 1992 US $	351.77	814.85	5109.10
Operating results	billion 1992 US $	27.75	39.17	-212.19
Contribution to gross value added	billion 1992 US $	182	490	3476
Airlines related employment	1000 employees	2481	4566	12004
Economic effects for other actors				
Change in consumer surplus	billion 1992 US $			-724.1
Fleet				
Technology age > 12 years	number of aircraft	10589	17771	5419
Technology age <= 12 years	number of aircraft	8399	11507	62538
Total	number of aircraft	18988	29278	67957
Revenue from taxation/charges	billion 1992 US $			76.1
Effects for a typical major airport				
Pax demand	million pax pa	33.04	43.93	99.17
Cargo demand	million tonne pa	1.01	2.19	5.35
Movements	1000 mov. pa	393.6	511.2	1032.2
Aviation employment	1000 employees	96	135	273
Fuel consumption and emissions				
Fuel use	billion kg pa	168.1	237.2	210.7
CO2 emissions	billion kg pa	530.7	748.9	75.8
NOx emissions	million kg pa	2227.9	2871.4	1382.0
NOx emission index	gram / kg fuel	13.3	12.1	6.6
Operating efficiency commercial aviation				
Direct operating costs / RTK	US$/tonne-km	0.31	0.42	1.13
Cost/RTK	US$/tonne-km	0.71	0.88	2.14
Fuel/RTK	kg/tonne-km	0.34	0.25	0.12
Fuel/ATK	kg/tonne-km	0.23	0.17	0.08
Pax km/seat km	factor	0.72	0.75	0.70
Freight-km/cargo-km	factor	0.60	0.62	0.59
RTK/ATK	factor	0.68	0.69	0.65
RTK/aircraft-km	tonne-km/ac-km	14.77	17.42	19.52
Revenues/RTK	US$/tonne-km	0.77	0.93	2.05
Fuel/aircraft-km	kg/ac-km	5.03	4.32	2.71
Reduction indicators				
CO_2/RTK relative to 2000	kg/tonne-km		0.74	0.03
CO_2/ASK relative to 2000	kg/tonne-km		0.74	0.03
Growth/year CO_2 between 2000-2020	%		1.7	
Growth/year CO_2 between 2020-2050	%			-7.3
NOx/RTK relative to 2000	kg/tonne-km		0.67	0.11
NOx/ASK relative to 2000	kg/tonne-km		0.68	0.11
Growth/year NOx between 2000-2020	%		1.3	
Growth/year NOx between 2020-2050	%			-2.4

Table A5-4: Regulatory Push & Pull results up to 2050: kerosene to hydrogen roll-over

Effect	Unit	2000	2020	2050
Air transport and aircraft operation				
Passenger demand				
First/business	billion pax-km pa	94.6	119.0	205.4
Economy	billion pax-km pa	333.1	450.8	782.4
Discount	billion pax-km pa	2459.9	3146.8	5422.4
Total scheduled	billion pax-km pa	2887.6	3716.6	6410.2
Total non-scheduled	billion pax-km pa	420.6	440.1	580.0
Total	billion pax-km pa	3308.2	4156.7	6990.2
Cargo demand	billion tonne-km pa	127.5	229.6	325.1
Revenue tonne-Km	billion RTK pa	458.3	645.3	1024.1
Flights				
Technology age > 12 years	million flights pa	15.8	26.4	61.7
Technology age <= 12 years	million flights pa	15.0	21.7	36.4
Total	million flights pa	30.7	48.1	98.2
Aircraft km				
Technology age > 12 years	billion ac-km pa	15.7	24.1	47.2
Technology age <= 12 years	billion ac-km pa	15.4	20.1	30.0
Total	billion ac-km pa	31.0	44.2	77.2
Effects on airlines				
Direct operating costs	billion 1992 US $	141.60	352.48	1215.36
Operating costs	billion 1992 US $	324.02	665.27	1960.60
Operating revenues	billion 1992 US $	351.77	704.75	2079.20
Operating results	billion 1992 US $	27.75	39.47	118.64
Contribution to gross value added	billion 1992 US $	182	366	1105
Airlines related employment	1000 employees	2481	3515	5906
Economic effects for other actors				
Change in consumer surplus	billion 1992 US $			-78.2
Fleet				
Technology age > 12 years	number of aircraft	10589	18663	37863
Technology age <= 12 years	number of aircraft	8399	12553	19208
Total	number of aircraft	18988	31216	57070
Revenue from taxation/charges	billion 1992 US $			45.7
Effects for a typical major European airport				
Pax demand	million pax pa	33.04	33.76	43.10
Cargo demand	million tonne pa	1.01	1.51	1.78
Movements	1000 mov. pa	393.6	432.0	607.0
Aviation employment	1000 employees	96	106	128
Fuel consumption and emissions				
Fuel use	billion kg pa	168.1	197.2	302.5
CO2 emissions	billion kg pa	530.7	622.6	955.0
NOx emissions	million kg pa	2227.9	2361.4	3459.3
NOx emission index	gram / kg fuel	13.3	12.0	11.4
Operating efficiency commercial aviation				
Direct operating costs / RTK	US$/tonne-km	0.31	0.55	1.19
Cost/RTK	US$/tonne-km	0.71	1.03	1.91
Fuel/RTK	kg/tonne-km	0.34	0.28	0.24
Fuel/ATK	kg/tonne-km	0.23	0.18	0.15
Pax km/seat km	factor	0.72	0.71	0.69
Freight-km/cargo-km	factor	0.60	0.56	0.53
RTK/ATK	factor	0.68	0.65	0.63
RTK/aircraft-km	tonne-km/ac-km	14.77	14.62	13.27
Revenues/RTK	US$/tonne-km	0.77	1.09	2.03
Fuel/aircraft-km	kg/ac-km	5.03	4.04	3.21
Reduction indicators				
CO_2/RTK relative to 2000	kg/tonne-km		0.83	0.81
CO_2/ASK relative to 2000	kg/tonne-km		0.79	0.74
Growth/year CO_2 between 2000-2020	%		0.8	
Growth/year CO_2 between 2020-2050	%			1.4
NOx/RTK relative to 2000	kg/tonne-km		0.75	0.69
NOx/ASK relative to 2000	kg/tonne-km		0.72	0.64
Growth/year NOx between 2000-2020	%		0.3	
Growth/year NOx between 2020-2050	%			1.3

Table A5-5: Fractured World results up to 2050

Effect	Unit	2000	2020	2050	2050 landing charge *3
Air transport and aircraft operation					
Passenger demand					
First/business	billion pax-km pa	94.6	112.7	121.3	121.0
Economy	billion pax-km pa	333.1	392.9	420.4	418.3
Discount	billion pax-km pa	2459.9	2921.9	3141.6	3123.8
Total scheduled	billion pax-km pa	2887.6	3427.5	3683.3	3663.1
Total non-scheduled	billion pax-km pa	420.6	492.3	480.3	472.9
Total	billion pax-km pa	3308.2	3919.8	4163.5	4136.0
Cargo demand	billion tonne-km pa	127.5	235.9	279.8	277.5
Revenue tonne-Km	billion RTK pa	458.3	627.9	696.1	691.1
Flights					
Technology age > 12 years	million flights pa	15.8	19.6	20.7	20.3
Technology age <= 12 years	million flights pa	15.0	16.5	16.2	15.8
Total	million flights pa	30.7	36.0	36.9	36.1
Aircraft km					
Technology age > 12 years	billion ac-km pa	15.7	20.3	22.3	22.1
Technology age <= 12 years	billion ac-km pa	15.4	17.7	18.3	18.2
Total	billion ac-km pa	31.0	38.0	40.7	40.3
Effects on airlines					
Direct operating costs	billion 1992 US $	141.60	273.20	593.86	607.99
Operating costs	billion 1992 US $	324.02	552.11	1049.30	1059.90
Operating revenues	billion 1992 US $	351.77	564.21	1069.80	1077.80
Operating results	billion 1992 US $	27.75	12.11	20.58	17.95
Contribution to gross value added	billion 1992 US $	182	321	722	713
Airlines related employment	1000 employees	2481	3183	3487	3456
Economic effects for other actors					
Change in consumer surplus	billion 1992 US $			-13.7	-30.4
Fleet					
Technology age > 12 years	number of aircraft	10589	13605	14145	13982
Technology age <= 12 years	number of aircraft	8399	9353	9280	9148
Total	number of aircraft	18988	22958	23425	23130
Revenue from taxation/charges	billion 1992 US $			16.7	36.0
Effects for a typical major airport					
Pax demand	million pax pa	33.04	36.56	35.05	34.09
Cargo demand	million tonne pa	1.01	1.46	1.36	1.33
Movements	1000 mov. pa	393.6	441.8	480.0	462.9
Aviation employment	1000 employees	96	110	106	104
Fuel consumption and emissions					
Fuel use	billion kg pa	168.1	198.0	227.9	226.5
CO2 emissions	billion kg pa	530.7	624.9	719.4	714.9
NOx emissions	million kg pa	2227.9	1898.2	1113.1	1106.2
NOx emission index	gram / kg fuel	13.3	9.6	4.9	4.9
Operating efficiency commercial aviation					
Direct operating costs / RTK	US$/tonne-km	0.31	0.44	0.85	0.88
Cost/RTK	US$/tonne-km	0.71	0.88	1.51	1.53
Fuel/RTK	kg/tonne-km	0.34	0.28	0.24	0.24
Fuel/ATK	kg/tonne-km	0.23	0.20	0.17	0.17
Pax km/seat km	factor	0.72	0.74	0.74	0.74
Freight-km/cargo-km	factor	0.60	0.64	0.62	0.62
RTK/ATK	factor	0.68	0.70	0.69	0.69
RTK/aircraft-km	tonne-km/ac-km	14.77	16.52	17.12	17.16
Revenues/RTK	US$/tonne-km	0.77	0.90	1.54	1.56
Fuel/aircraft-km	kg/ac-km	5.03	4.69	4.18	4.19
Reduction indicators					
CO_2/RTK relative to 2000	kg/tonne-km		0.86	0.89	0.89
CO_2/ASK relative to 2000	kg/tonne-km		0.88	0.90	0.90
Growth/year CO_2 between 2000-2020	%		0.8		
Growth/year CO_2 between 2020-2050	%			0.5	0.4
NOx/RTK relative to 2000	kg/tonne-km		0.62	0.33	0.33
NOx/ASK relative to 2000	kg/tonne-km		0.64	0.33	0.33
Growth/year NOx between 2000-2020	%		-0.8		
Growth/year NOx between 2020-2050	%			-1.8	-1.8

Table A5-6: Down to Earth results up to 2050

PART II - MATERIALS

Annex 1 Periodic Report I (Deliverable D1)
Dissemination level: CO

Annex 2 Periodic Report II: Mid-Term Progress Report (Deliverable D2)
Dissemination level: CO

Annex 3 Periodic Report III (Deliverable D3)
Dissemination level: CO

Annex 4 Periodic Report IV
Dissemination level: CO

Annex 5 Catalogue of key factors to be quantified for CONSAVE (Deliverable D5)
Dissemination level: RE

Annex 6a Representative set of qualitative "background" scenarios, Version I (inclusive storylines) (Deliverable D6)
Dissemination level: RE

Annex 6b Representative set of qualitative "background" scenarios modified Version (inclusive storylines) (Deliverable D6/M)
Dissemination level: RE

Annex 7 Quantification of "background" scenarios: data and report (Deliverable D7), Dissemination level: RE

Annex 8 Quantification of scenarios on aviation and its emissions – Preliminary results for review (Deliverable D8)
Dissemination level: RE

Annex 9 Quantification of scenarios on aviation and its emissions – Final results (Deliverable D9)
Dissemination level: RE

Annex 10 Findings and proposals from the review process and the related concluding workshop (Deliverable D10)
Dissemination level: RE

Annex 11 Report on the contact to external activities (Deliverable D11)
Dissemination level: RE