CONSAVE Background Scenario Quantification

Arnulf Grübler

International Institute for Applied Systems Analysis
A-2361 Laxenburg Austria

Final Report to

CONSAVE Project

In pursuing contractual obligations for
WP 2 (Quantification of background scenarios) and
Pos. 002 Support to quantification of selected scenarios (for WP2)

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The purpose of this paper is to provide some initial, global quantifications of the CONSAVE scenarios as proposed within the storylines for Qualitative Background Scenarios on the Future of Air Transport and its Emissions. Therefore the present paper should be read in conjunction with the paper describing the qualitative CONSAVE scenario storylines. The numbers presented have to be considered as preliminary as elaborated prior to detailed modeling exercises (whereas in an ideal world these two project steps should be iterated a number of times[1]). They therefore serve only as a yardstick guide for the subsequent detailed quantifications with the AERO model, aiming at assisting the adoption of corresponding model input parameter values.

For the purposes of scenario and modeling economy, the number of originally proposed background scenarios has been reduced from 6 to 4 scenarios, regrouped into three overall scenario families that differ with respect to their broad macro-trends for demographics, economic growth, geopolitics as well as technology (see the discussion on scenario taxonomy in the "sister" scenario storylines document mentioned above). Wherever possible the number of different background scenario assumptions have been minimized, to reduce the number of individual model runs required. For instance, two scenario families (High Growth, and Down to Earth) share the same low population projection. The two scenarios are thus identical in terms of demographic outcomes, however, not in their underlying driving forces. Also for reasons of scenario economy, as far as possible, existing quantifications, in particular those developed for the IPCC-SRES scenarios were adopted. Suggestions on their modifications are made where necessary in view of the underlying scenario storylines.

In a first step, initial **global** yardstick quantifications are proposed for the scenarios variables: population, GDP, (primary) energy use, air transport demand, and general level of air transportation constraints. The suggested quantitative, global scenario values are given below in tabular form and in form of snowflake diagrams for the years 2020, 2050, and 2100 and are compared to the range of scenarios available in the literature obtained from the IPCC SRES and aviation reports respectively. 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 the

[1] This iterative scenario development process was not possible due to time constraints.

number of scenarios describing more moderated, "middle of the ground"[2] developments is limited. 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.[3] 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 in view of limited time and resources available for (expensive) model runs 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.

After giving a global quantitative snapshot overview of the scenarios, more detailed guidance is given on various background scenario variables with respect to data sources, suggested modifications, and explaining their spread across scenarios. These information aims at assisting in the development of appropriate, corresponding input assumptions for the AERO model for the detailed scenario quantifications of the four final scenarios retained for the CONSAVE project. Whenever possible, additional guidance is given of which (combination of) original background scenario variable quantifications from the IPCC-SRES report fit best the corresponding CONSAVE background scenarios.

Finally in a last step, the suggested global scenario background values are disaggregated into the 14 IATA world regions as used by the AERO model for population and economic growth (GDP expressed both at market exchange rates and at purchasing power parities). Corresponding tables are provided as appendix to this document. These numbers intend to assist in the development of regionally disaggregated scenario input assumptions for the AERO model. These regional disaggregations have been prepared especially for this CONSAVE project based on unpublished data underlying the IPCC-SRES report as well as consulting with various IPCC modeling teams.

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[2] Two additional scenarios describing these developments and corresponding to the IPCC-SRES-B2 scenario family are no longer included in the final set of CONSAVE scenarios. Their suggested draft quantification is available upon request from the author.

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

Nonetheless, these data should only be considered as illustrative and not be attributed in any way to, or considered as endorsed by, the IPCC.

Quantitative CONSAVE Scenario Taxonomy for 2020, 2050, and 2100 (global values).

As outlined in the background scenario storyline document the final CONSAVE scenarios retained consist of 4 scenarios regrouped into three scenario families. These are:

High Growth (very high economic and air transport growth)
Fractured World (geopolitically fragmented world with severe constraints on interregional trade and air transport)
Down to Earth (high human development, but with emergence of post-material lifestyles and vigorous environmental conservation and regulation leading to an absolute decline in air transport demand).

In addition, the High Growth scenario family is differentiated further into two subscenarios, reflecting policy constraints on air transport
"Unlimted Skies" (weak constraints)
Regulatory Push&Pull (strong regulatory constraints).
These two sub-scenarios share otherwise the same overall scenario background macro-variables like population or GDP growth, characteristic for the High Growth scenario family.

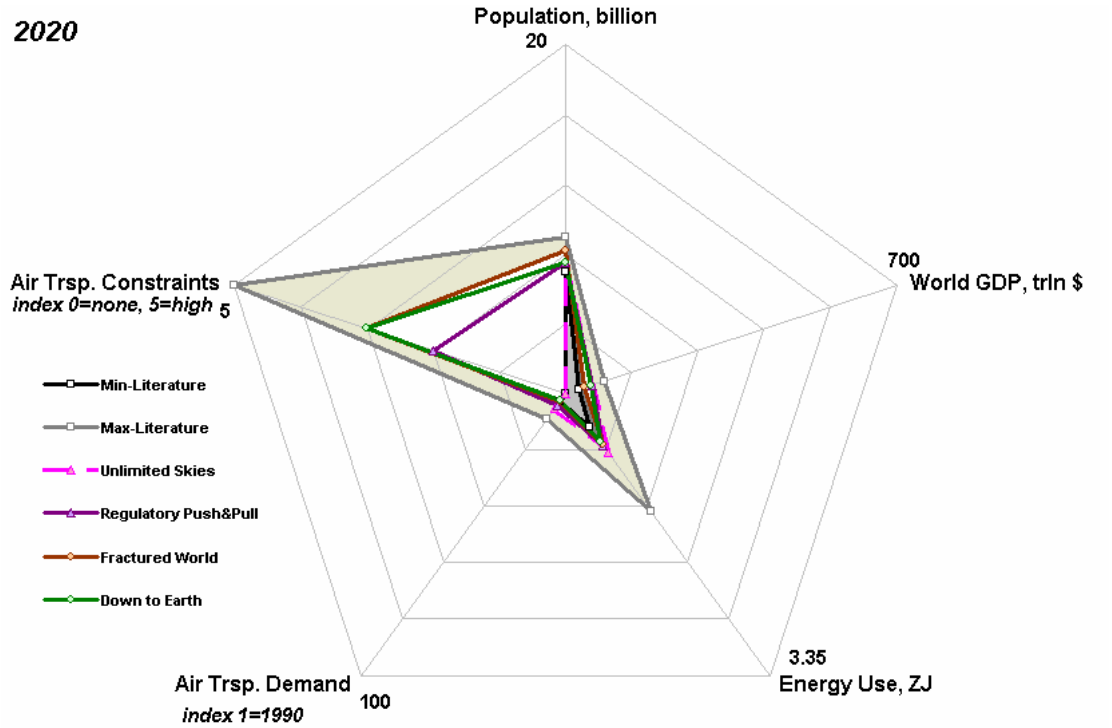
Table 1 summarizes the quantitative scenario taxonomy and Figure 1 illustrates the evolution of the scenarios at the global level for the years 2020, 2050, and 2100. Each (sub-)scenario is represented by a different color code, with grey shades indicating differences between the CONSAVE scenario set to the entire range as available in the published scenario literature.

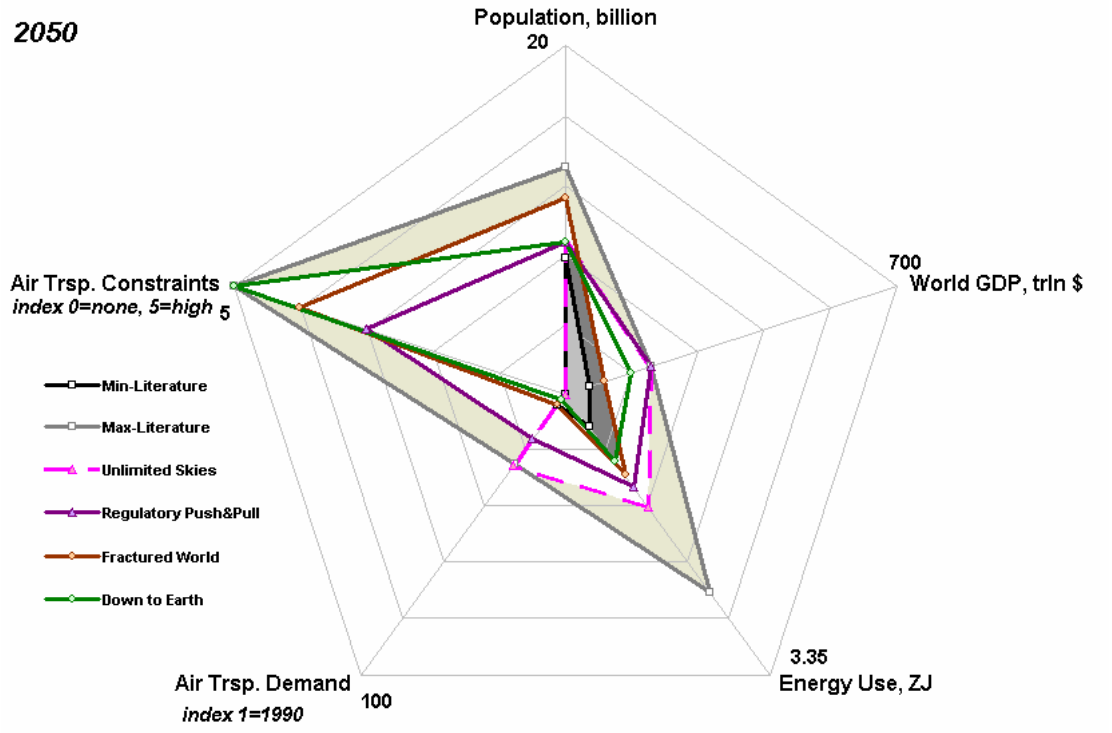
	Population billion			World GDP-mer trillion $		
	2020	2050	2100	2020	2050	2100
Min-Literature	7	7.8	6	30	50	65
Max-Literature	9	13	20	80	180	700
High Growth						
Unlimited Skies	7.5	8.7	7.1	57	180	528
Regulatory Push&Pull	7.5	8.7	7.1	57	180	528
Fractured World	8.2	11.3	15.1	40	82	243
Down to Earth	7.5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

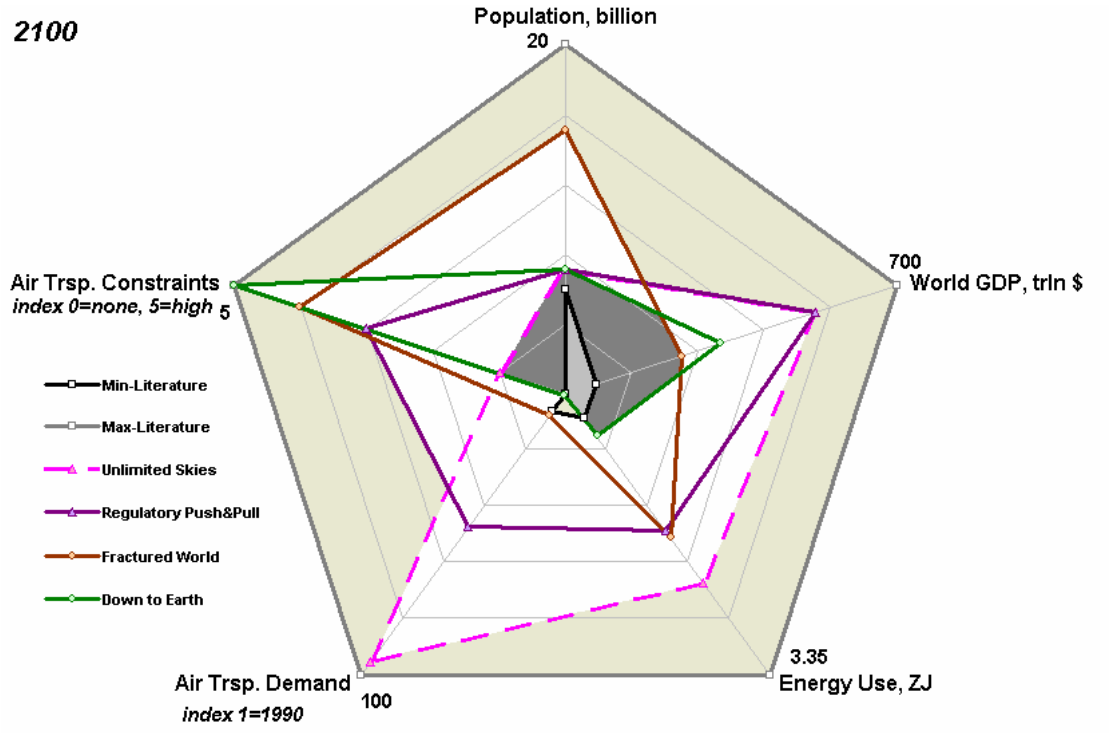
	Energy use ZJ		
	2020	2050	2100
Min-Literature	400	400	293
Max-Literature	1400	2360	3350
High Growth			
Unlimited Skies	700	1350	2250
Regulatory Push&Pull	610	1100	1630
Fractured World	600	970	1720
Down to Earth	580	810	510

	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

	Air transport constraints Index 0=none, Index 5=high		
	2020	2050	2100
Min-Literature	0	0	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


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



Comments on Scenario Quantifications.

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 should be drawn as much as possible from the original IPCC scenario data.

Population:
The final CONSAVE scenarios include two (low/high) demographic projections. 2 scenario families with either high income or high ecological consciousness share the same (low) projection. Global and regional values for the 14 IATA regions used by the AERO model are given in 10-year time intervals in the appendix to this document. 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).

Note that there is no equivalence between the medium population projection of the IPCC-SRES-B2 scenario and the CONSAVE scenario set.

Economic Growth:
For GDP, three scenarios are suggested, with two CONSAVE scenarios (Unlimited Skies, Regulatory Push&Pull) sharing the same GDP projection as their respective (unconstrained) "mother" (High Growth) scenario. In a final model quantification, the GDP of the constrained scenarios might turn out to be slightly lower than in the unconstrained scenarios, but this is likely to be less than 10 percent difference, and hence rather negligible for the uncertainties explored over such a long time horizon.
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.[4]

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 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,

[4] 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.

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 no regional disaggregation is necessary (and no regional values are given in the numerical appendix below). Corresponding more detailed numerical global values can be derived directly from the IPCC-SRES report if need arises.

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

“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).
As this variable, seems not to enter the AERO model directly, no regional disaggregations are provided in the numerical appendix. Should the need for such regional detailed data arise, the published four regional original SRES data should be rescaled to the 14 IATA regions used by the AERO model in proportion to the GDP scenario disaggregations given in the numerical appendix below.

Resource scarcity:
Instead of total “call on resources”, annual extraction (primary energy supply) is proposed 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[5]
"Down to Earth": IPCC-SRES B1: 1.5/1.5-1.8/0.4-0.8[6]

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, it is suggested to substantially increase the import price for oil in the Fractured World scenario to reflect increasing trade restrictions.

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

Energy prices, especially oil:
Unless specified otherwise, the unconstrained CONSAVE scenario should 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 are suggested. Tentative quantifications are suggested below. 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 are presented here (and no regionalization is provided in the data appendix). For reasons of scenario economy it is suggested to limit the number of different oil price scenarios to 4 different 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)

Quantification of Air Transport Demand

As opposed to the previous IPCC aviation scenarios, the CONSAVE scenarios should 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. Below discussion offers some suggestions in terms of modeling and comparable aviation scenarios.

"Unlimited Skies": IPCC model[7] applied to the (high) GDP growth rates suggested above at the global level. This should result in a very high air transport demand scenario highlighting the challenges ahead for the global aviation industry. Equivalent quantifications include for instance the EDF Ech Scenario discussed in the IPCC Aviation report, 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

[7] *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.

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).

"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.[8]

	Period Elasticities		
	1990-2020	2020-2050	2050-2100
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**

Other Quantification Issues

Regionalization of "Fractured World"

The corresponding qualitiative background scenario storyline 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 an Himalayan divide within Asia.

The following regional "blocks" are suggested for the modeling work with the AERO model (including their corresponding IATA regions as used in the model):[9]

[8] 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).

NAFT (North America, Central America)
Eurasia (EU, Former Eastern Block)
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 is suggested 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, inter-regional 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)

Global Climate Policies in "Down to Earth"

The qualitative background scenario storylines describes 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.

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[9] *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).

It is suggested that in the scenario quantification in addition and above the energy price scenario suggested above an additional global carbon tax is assumed that would amount to some 50-100 $/tonC by 2020, 250-500 $/tC by 2050, finally rising to 2000 $/tC by 2100.[10] This evidently would lead to further energy price increases and act as additional restraint on energy-intensive air transportation.

Numerical Appendix: Quantitative background scenario data from the original IPCC-SRES scenarios and downscaled estimates for the AERO model's 14 IATA World Region

[10] These numbers are derived from model simulations performed within IPCC TAR for a stabilization at 450 ppmv and using the IPCC-SRES-B1 scenario as refrerence case.