Scenario Storylines
for Qualitative Background Scenarios
on the Future of Air Transport and its Emissions

Final Report to CONSAVE Project

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Background

The objective of this document is to present qualitative scenario storylines that describe overall background scenarios for the development of "macro-trends" that are important for the future evolution of air transport demand, aircraft technologies and operations, and their combined impacts on the environment (emissions) as part of the CONSAVE project. These scenario storylines provide contextual information to guide the adoption of ranges of input variables in subsequent quantitative modeling with the AERO model.

The scenario storylines draw on two external inputs. One, is a set of scenarios developed for the IPCC Special Report on Emission Scenarios (SRES), and the second is a set of scenarios developed within precursor (AERONET) workshop activities to the current CONSAVE project. In a scenario workshop at IIASA on January 22-24, 2003, the original AERONET scenarios were discussed and modified and 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. These draft scenarios were subsequently reviewed by the CONSAVE partners and a decision was reached to retain three of the four original draft scenario families, with one scenario family (High Growth) consisting of two sub-scenarios to explore in more detail the implications of a stiffer regulatory environment on the future of air transport in a scenario of very high growth in air transport demand.

Following this decision by the CONSAVE partners to reduce the number of scenarios to a more manageable size, the following text presents the final, revised scenario storylines for the CONSAVE project, integrating in particular the comments provided by the CONSAVE partners on the initial, draft scenario storylines. The scenario storylines 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 trends.

Altogether there are three scenario storylines representing three different scenario families of alternative future developments in terms of demographics, economy, geopolitics, as well as technology amongst other variables. One of this scenario storyline (High Growth) is further differentiated to describe two sub-scenario 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, which is a core objective of the CONSAVE project.

Scenario Taxonomy

Following the IPCC-SRES scenarios, a simplified scenario taxonomy 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 2x2 = 4 scenarios describe the scenario space along these two dimensional axis (see top of Figure 1). Three of the four original scenario families from the IPCC-SRES exercise were retained for the CONSAVE project (The "middle of the ground" IPCC-SRES scenario family B2 was excluded[1] for the CONSAVE project scenarios and is hence not further described here). As additional dimensions, the scenarios can be regrouped along the dimensions of growth in air transport volume (low/high) as well as consider additional constraints on the future of air transportation (low/high, see Figure 1). Some of them are embedded within the overall scenario storyline, but additional ones are explored in two sub-scenarios within the High Growth scenario storyline, that branches out into two subscenarios, labeled "Unlimited skies" (few constraints), and "Regulatory Push&Pull" (strong constraints) respectively. Hence, there are 3 main CONSAVE scenarios and (including the two subscenarios of the High Growth scenario family) 4 individual scenarios altogether.

Table 1 and Figure 1 provide an overview of the CONSAVE scenario taxonomy and their relation to the IPCC-SRES scenarios 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 and also not further elaborated in the text below are indicated by light-grey fonts. Considering the need for a limited number of scenarios and their long-tern nature (2050 and beyond), the scenarios are stylized in the sense that they describe the boundary conditions of uncertain future developments both in terms of scenario background information (demographics, economic growth, etc.) as well as the boundary conditions in which future air transportation and its technologies could evolve. From this perspective the scenarios represent extremes of possible developments rather than simple gradual variations along "business as usual" development pathways. Evidently, this does not imply that these scenarios should be considered equally likely than scenarios in which their respective tendencies would play out more moderately. But in order to explore the long-term uncertainties and challenges surrounding air transportation, the CONSAVE group considered it more 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.

[1] The corresponding CONSAVE scenario family is labeled "Middle of the Ground" and originally consisted of two subscenarios, varied with respect to air transport constraints: "Dynamics-as-Usual" (moderate/medium level constraints) and "Zero-Risk-Tolerance" (high constraints). These more intermediary scenarios are no longer further explored in the CONSAVE project for reasons of scenario and modeling economy, but might be take up again in future sequel activities to the project.

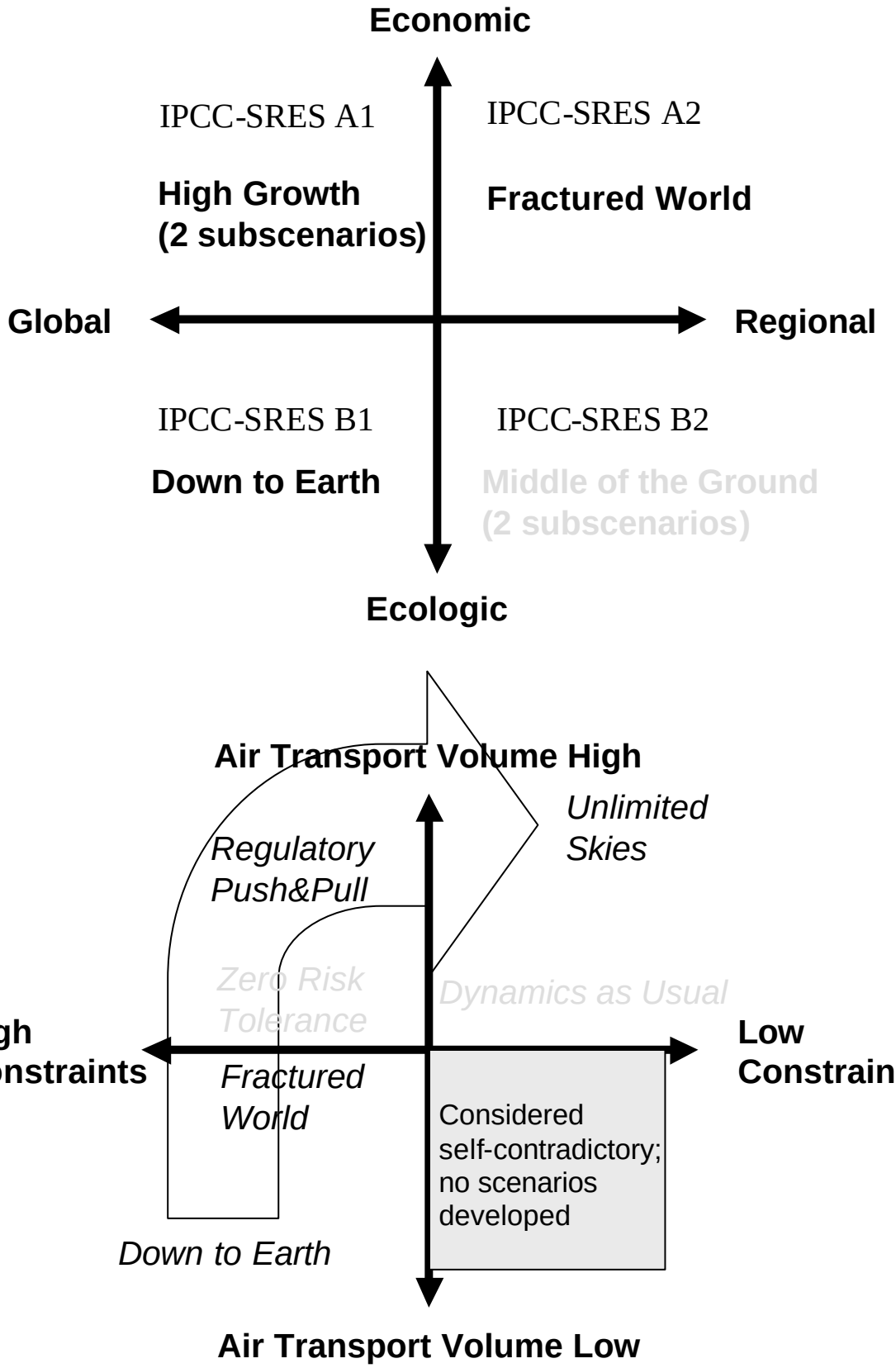
Economic
IPCC-SRES A1
High Growth
(2 subscenarios)
IPCC-SRES A2
Fractured World
Global
Regional
IPCC-SRES B1
Down to Earth
IPCC-SRES B2
Middle of the Ground
(2 subscenarios)
Ecologic
Air Transport Volume High
Unlimited Skies
Regulatory Push&Pull
Zero Risk Tolerance
Dynamics as Usual
High Constraints
Low Constraints
Fractured World
Considered self-contradictory; no scenarios developed
Down to Earth
Air Transport Volume Low

Figure 1

Table 1

	Scenario Dimensions														
			Orientation			**Focus**			**Air Transport Volume**				**Air Transport Constraints**		
			Global	Regional		Economic	Ecologic		Low	Medium	High		Low	Medium	High
	Scenario Family	Sub-scenario													
	High Growth		X			X									
1		Unlimited Skies									X		X		
2		Regulatory Push&Pull								X					X
3	**Fractured World**			X		X			X					X	
4	**Down to Earth**		X				X		X						X
	Middle of the Ground			X			X								
5		Dynamics-as-Usual								X			X		
6		Zero Risk Tolerance							X						X

Scenario Storyline “High Growth"

The scenario describes 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, largely following the “Western” model. 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.

The principal scenario 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 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’s) 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 are 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 much lower than previously anticipated and the high income societies of the future can easily adapt to it. Hence, also global environmental issues are 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

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 an considerably "graying" 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[2] 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 "byproduct" 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 traveling 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

[2] 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.

century sense). Nonetheless, traditional consumerism might not grow linearly with affluence indefinitely. As evidenced in food habits and expenditures, saturation 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 traveling) 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, that trigger both conservation innovations as well as novel, 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 megacities. 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 2052-2058. 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 are 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 sulfur 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 transparence. Product responsibility is also valued high, litigation and compensation for externalities imposed are 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 Transportation

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 zero globally. One hand side 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 3%/yr GDP assumed for the “High Growth” scenario).

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 trains, maglev's, ultimately fusing short- and long-distance transport technologies (metro's) into single interconnected Infrastructures making current distinctions between short- and long-distance travel 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 traveling *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 megacities, 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 fueled 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).

Scenario Storyline “Fractured World”

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 adopted 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.

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 and China, Japan and the rest of Asia). 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 neighboring 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 quo pro* mode, largely based on barter trade of surplus production, with little regard to international division of labor 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

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 by 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 inter-continental 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 spinoffs 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 traveling 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-defense 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 traveling to Siberia and the Southern European rim, as for shorter distances rapid rail systems are favored by both policy and consumer demand.

Scenario Storyline “Down to Earth”

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 favoring 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 favoring the dis-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 a 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 favor 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 traveling 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. Labor 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.

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. Transboundary 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. 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[3] 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 a few exception of 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 centering around 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 choices, as well as high

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

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 depleteable 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 labor productivity. The latter is essential to support the rapid growth in personal income, given that a major increase in labor 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 Transportation

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 decentrally to avoid obtrusive large energy infrastructures.