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The evolution of the IPCC's emissions scenarios

Bastien Girod [a,*], Arnim Wiek [a,b], Harald Mieg [c], Mike Hulme [d,e]

[a] Institute for Environmental Decisions, Natural and Social Science Interface, ETH Zurich, Universitaetstrasse 22, 8092 Zurich, Switzerland
[b] Institute for Resources, Environment, and Sustainability, University of British Columbia, 2202 Main Mall, Vancouver V6T 1Z4, Canada
[c] Institute of Geography, Humboldt University Berlin, Unter den Linden 6, 10099 Berlin, Germany
[d] School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, United Kingdom
[e] Tyndall Centre for Climate Change Research, UK

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ABSTRACT

The IPCC's emissions scenarios form the basis for the majority of long-term climate change projections, including those of the current Fourth Assessment Report. The main characteristics of the IPCC's three scenario series – published in 1990, 1992 and 2000 – have changed significantly over time: titles, classification, assumptions and methods have all changed. This article analyses the evolution of the structure, description, process development and context of the IPCC's emissions scenarios, identifying the most important changes and their scientific and political causes. These changes are evaluated against the criteria of saliency, credibility and legitimacy. Our analysis indicates, first, enhanced credibility through an improved scenario construction methodology (multiple baseline scenarios; storylines), even though these achievements are diluted by particularities of the scenario approach used. Second, a reduced saliency through absence of titles, an inappropriate classification and the relatively high number of baseline scenarios, limits and weakens their wider applicability. These latter trends were due in part to concessions made to the intergovernmental nature of the construction process (trade-offs). The article concludes by proposing for the future the employment of a more formal qualitative construction approach as well as revisions to scenario labelling and classification practices.

1. Introduction

The emissions scenarios of the Intergovernmental Panel on Climate Change (IPCC) quantifying global greenhouse gas emissions up to the year 2100 have significantly changed during their evolution from the First (1990, SA90), through the Second (1995, IS92), to the Third Assessment Report on Climate Change (2000, SRES) (IPCC, 1990b, 1995, 2001a). The latest series from 2000, published in the Special Report on Emissions scenarios (SRES) (IPCC, 2000a), has not yet been updated—it was used as the basis for the Fourth Assessment Report (IPCC, 2007b). Diverging from the general IPCC mandate, the emissions scenarios represent original work rather than an assessment of existing research (Alcamo et al., 1995; IPCC, 1990b, 1992b, 2000a).

The IPCC's emissions scenarios are intended to guide scientific investigations, as well as political endeavours, as pointed out in the SRES: "We recommend that the new scenarios be used not only in the IPCC's future assessments of climate change, its impacts, and adaptation and mitigation options, but also as the basis for analyses by the wider research and policy community of climate change and other environmental problems" (IPCC, 2000a, p. vii). In accordance with these intentions, the emissions scenarios have been widely used as the basis for scientific studies (e.g., Arnell et al., 2004; Knutti et al., 2002; Nicholls and Tol, 2006) and as reference point for the

* *Corresponding author*. Tel.: +41 44 632 63 13; fax: +41 44 632 10 29.
E-mail address: bastien.girod@env.ethz.ch (B. Girod).
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political and societal discourse on climate change (e.g., Rosenthal and Revkin, 2007; UK Government, 2007).

Much of the criticism on the IPCC's emissions scenarios is directed at specific components of the scenarios (e.g., van Vuuren and Alfsen, 2006) and at the underlying assumptions (e.g., Webster et al., 2003; Pielke et al., 2008). Some of the literature deals with an individual IPCC scenario series – IS92 or SRES – from a broader evaluative perspective (e.g., van Vuuren and O'Neill, 2006). The IPCC has reacted to the critical discussions by acknowledging the need for new emissions scenarios that ought to be available before completion of the Fifth Assessment Report which is scheduled to be finalized in 2014 (IPCC, 2008). The development of new scenarios is coordinated by the IPCC and the scenarios are planned to being published in 2010 (IPCC, 2008).

Despite the broad discussion, there has been no systematic study on the evolution of the three sets of IPCC's emissions scenarios and their main components. Relevant questions therefore remain unanswered—for example about the absence of intervention scenarios in the IS92 and SRES scenario series, about the reason for the similar projected emissions range for 2100 between IS92 and SRES, and about the interactions between scientific and governmental agents in the review procedure for the IS92 and SRES scenario series.

The study presented in this article deals with the main changes from the SA90 to the SRES series, the reasons for these changes, and the question whether these changes were beneficial or detrimental to the purposes of the scenarios as set out by the IPCC. We put special emphasis on the more or less obvious interplay between scientific and non-scientific (broader societal) interests in the evolution of knowledge on climate change. We contend that the IPCC's emissions scenarios are hybrid constructs and boundary objects that result from extensive construction and negotiation processes among numerous scientists and governmental agents (cf. Hulme and Dessai, 2008). As such, they represent very interesting cases for analyzing and critically reflecting on the science-policy interface in climate change politics.

2. Conceptual approach and methods applied

We applied a simple conceptual approach to analyze and evaluate the main characteristics of the scenario series, their changes over time and possible reasons for these changes. Regarding each of the three IPCC's emissions scenarios series, we distinguished between the verbal *description* (words) of the scenarios and their underlying numerical *structure* (numbers) in the report. With respect to the *development process*, we analyzed the changes in the primary process (leading to preliminary documents) and the changes in the subsequent process (from preliminary documents to the final documents). Regarding the *context*, we analyzed changes in the *scientific setting* (e.g., methodology and participating scientists) and in the *triggers* (e.g., Terms of References which guide the work of the IPCC teams), as well as the changing *applicability* for scenario users (e.g., decision- and policy-makers, climate change scientists).

2.1. Analysis of changes

To capture the relevant changes during the evolution of the IPCC scenarios, we applied document analysis in studying the relevant IPCC's documents (Alcamo et al., 1995; de Vries et al., 2000; IPCC, 1990a,b, 1992a,b,c, 2000a,b,c,d,e; Jiang et al., 2000; Kram et al., 2000; Mori, 2000; Riahi and Roehrl, 2000; Roehrl and Riahi, 2000; Sankovski et al., 2000).

For the description of the IPCC's emissions scenarios, we refer to the official IPCC documents (IPCC, 1990a, 1992a, 2000a). We did not consider the post SRES scenarios of the Mitigation Report (IPCC, 2001b) as the SRES scenarios are the "official" IPCC's emissions scenarios, standing in line with the SA90 and the IS92 scenarios and being used centrally in the Fourth IPCC Assessment Report (IPCC, 2007b).

We used the Kaya identity on the global level for the comparison and evaluation of the structure of the three series. The Kaya identity was proposed by Japanese energy economist Yoichi Kaya to analyze the key components of the emissions scenarios and was used in the IPCC's evaluation of the IS92 scenario series (Alcamo et al., 1995) as well as in the SRES report (IPCC, 2000a):

$$\mathrm{CO_2\ emissions} = \mathrm{population}\underbrace{\left(\frac{\mathrm{GDP}}{\mathrm{population}}\right)}_{\text{income}}\underbrace{\left(\frac{\text{energy use}}{\mathrm{GDP}}\right)}_{\substack{\text{energy}\\ \text{intensity}}}\underbrace{\left(\frac{\mathrm{CO_2\ emissions}}{\text{energyuse}}\right)}_{\substack{\text{carbon}\\ \text{intensity}}}$$

As done in the SRES, GDP was measured in prices and exchange rates from 1990 in US-Dollars (US$ 1990). For the energy use the total primary energy consumption was considered (J), and for the CO_2 emissions the carbon emissions from energy use were considered (gC). A harmonization of these variables for scenarios drawn from the published literature is provided by the Emission Scenario Database (ESD), which was set up to compare the SRES with scenarios from literature (Morita, 1999).

In addition, we conducted 11 expert interviews with academic scholars from various institutions in Europe involved in the construction of the emissions scenarios, namely: Arnulf Grubler, Bert de Vries, Bert Metz, Keywan Riahi, and Nebojsa Nakicenovic (SRES lead authors); Mike Chadwick (SRES review editor); Rob Swart, William Pepper and Jane Leggett (authors of the IS92 and SA90 scenarios); Detlef van Vuuren (Netherlands Environmental Assessment Agency) and Leonardo Barreto (Paul Scherrer Institute). All statements used from the interviews were authorized by the interviewees and are published in Girod (2006).

2.2. Evaluation of changes

We assessed how the analyzed changes score against the criteria of saliency, credibility and legitimacy (Cash et al., 2003; Hulme and Dessai, 2008; Siebenhüner, 2003). Saliency refers to the relevance and comprehensibility of the scenarios for political decision-makers and other scenario users (including scientists). Credibility is concerned with the scientific adequacy of the technical component of the scenarios spelt out in the literature (including publications *after* 2000, as it had been

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Table 1 – Criteria and their operationalization for the evaluation of the evolution of the IPCC's emissions scenarios.

Element (framework)	Criteria	Operationalization
Description	Saliency Credibility	(i) Comprehensibility for scenario users (ii.a) Accurate verbalization (ii.b) Accordance with the literature (content-wise)
Structure	Credibility	Accordance with literature (content-wise)
Development process	Legitimacy	(i) Transparency (ii) Broad and balanced participation of governmental agents
Scientific setting and Triggers	Credibility Legitimacy	(i) Accordance with literature (methodological) (ii.a) Transparency (ii.b) Broad and balanced participation of scientists
Applicability	Saliency	Capability for evaluation climatic consequences of non-intervention futures and intervention futures

decided that the SRES scenarios would also be used for the Fourth Assessment Report). Legitimacy refers to transparency, participation and fairness of the scenario construction process.

The evaluation criteria are presented in Table 1. The changes in the *description* of the scenarios were evaluated against the criteria of saliency and credibility. Credibility is operationalized as (a) accurate verbalization of the underlying characteristics, as well as (b) consistency with emissions scenarios (content-wise) analyzed in large reviews such as the Millennium Ecosystem Assessment Report (Raskin et al., 2005) and the IPCC's Mitigation Report (IPCC, 2001b). Changes in the *structure* were evaluated against the criterion of credibility. Regarding consistency with the literature (content-wise), we included comparisons to scenarios collected in the ESD (Morita, 1999). Deviations from the literature were accepted if they had been sufficiently justified. The evaluation of the *development process* applied the criterion of legitimacy, considering the breadth and balance of participation as well as its transparency (Eckley, 2002; Lemos and Morehouse, 2005). We paid special attention to changes that scored poorly against the criteria of saliency and credibility and to changes that were politically motivated. Regarding the *context* aspects, changes in the *scientific setting* as well as in the *triggers* were evaluated against the criteria of credibility, i.e., consistency with the methodological literature (e.g., Godet, 2000; Robinson, 2003; Swart et al., 2004; Wiek et al., 2006), and legitimacy, operationalized as transparent scenario construction process with broad and balanced participation of scientists. The evaluation of *applicability* relied on the criterion of saliency and was operationalized by a functional concept proposed by Alcamo et al. (1995) and Alcamo (2001).

3. Changes over the three scenario series

3.1. *Changes in the description of the scenarios*

Four main changes in the description of the scenarios can be identified (Table 2). First, comparing the titles and descriptions of intervention characteristics of the scenario series reveals that they changed from a single ''Business as usual'' (BaU) scenario and a number of intervention scenarios (SA90) to a series of non-intervention baseline scenarios (SRES).[1] Second, the implicit and explicit storyline axes of the scenario series changed from energy mix and efficiency (SA90), to population, income and fossil fuel resources (IS92), and ended up with the explicit storyline axes ''regional vs. global'' and ''economic vs. environmental'' (SRES series).[2] Third, comparing the description of probability characteristics reveals that the SA90 scenarios were considered as predictions whereas the IS92 report and the SRES reject predictions and instead adopt the term 'projections'. However, two scenarios of the IS92 series (IS92a and b) were presented as updates of the earlier SA90-BaU scenario (IPCC, 1992b). Fourth, the scenarios have communicated increasingly less about the climatic implications of the emissions trajectories, so that in the SRES there is no information about consequences.

3.2. *Changes in the structure of the scenario series*

Four main changes in the structure of the scenario series can be observed (Table 3). First, the number of scenarios increased from 4 (SA90) to 6 (IS92) to 40 with 6 illustrative scenarios (SRES). If only the scenarios communicated as non-intervention scenarios are considered, the number even changed from 1 to 5 to 40 (6). Second, the structure of the scenario spectrums, considering the development path of the projected CO_2 equivalent emissions, changed from two main emissions paths with one stream comprising off-bending lower emissions scenarios (SA90), to a central emissions path with spectral scenarios (IS92) and finally criss-crossing emissions pathways in the case of the SRES series. Considering the six key variables of the scenarios (Table 3), two additional changes can be observed. While the GDP range increased from SA90 to the IS92 series and then decreased in the SRES series, the decarbonisation range decreases from the SA90 to the IS92 and then increases in the SRES series. If only the SA90-BaU is considered, a continuous increase in the range of

[1] We rely on standard definitions of the relevant technical terms. A non-intervention scenario is ''an emission scenario that does not make any assumption about climate policy to reduce greenhouse gases'' (Alcamo et al., 1995, p. 258). An intervention scenario is ''an emission scenario that makes assumptions about climate policies to reduce greenhouse gases. Policies must be directed towards mitigation'' (Alcamo et al., 1995, p. 258). A baseline scenario is ''a non-intervention scenario used as a reference in the analysis of intervention scenarios'' (IPCC, 2001b, p. 709).

[2] The term ''implicit storylines'' refers to the key variables used in the scenario description which could be used as storyline axes.

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Table 2 – Main changes in the description of the three scenario series regarding titles, intervention characteristics, probabilities and impact communication.

Aspect	SA90-Scenarios (IPCC, 1990a)	IS92-Scenarios (IPCC, 1992a)	SRES-Scenarios (IPCC, 2000a)
Titles	Scenario A (Business as Usual), B–D	IS92a–f	A1B, A1T, A1FI, A2, B1, B2
Implicit and explicit storyline axes	Energy supply mix and efficiency (p. xxxiv)	Population, income growth and fossil fuel resources (p. 11, Table 1)	Storylines: regional vs. global, economic vs. environmental (p. 4, Box SPM-1)
Intervention characteristics	''[...] under the other IPCC emissions scenarios which assume progressively increasing levels of control, rates of increase in global mean temperature...'' (p. xi)	''Six alternative IPCC scenarios (IS92 a–f) now embody a wide array of assumptions [...] affecting how the future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted.'' (p. 10)	''As required by the Terms of Reference, the scenarios in this report do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention for Climate Change (UNFCCC) or the emissions targets of the Kyoto Protocol. However, GHG emissions are directly affected by non-climate change policies designed for a wide range of other purposes. Furthermore government policies can, to varying degrees, influence the GHG emission drivers such as demographic change, social and economic development, technological change, resource use, and pollution management. This influence is broadly reflected in the storylines and resultant scenarios.'' (p. 3)
Probabilities	''Based on current models we predict: [...]'' (p. xi)	''The reader should be cautioned, however, that none of the scenarios depicted in this section predicts the future.'' (p. 75) ''The premises for the 1992 IPCC Scenarios a and b most closely update the SA90 scenario from IPCC (1990).'' (p. 76) ''Four additional scenarios have been constructed to examine the sensitivity of future greenhouse gas emissions to a wider range of alternative input assumptions for key variables.'' (p. 79)	''There is no single most likely, ''central'', or ''best-guess'' scenario, either with respect to SRES scenarios or to the underlying scenario literature. Probabilities or likelihood are not assigned to individual SRES scenarios. None of the SRES scenarios represents an estimate of a central tendency for all driving forces or emissions, such as the mean or median, and none should be interpreted as such. The distribution of the scenarios provides a useful context for understanding the relative position of a scenario but does not represent the likelihood of its occurrence.'' (p. 11)
Implications of scenarios	Temperature change communicated with the emissions scenarios (p. xi)	Temperature change communicated in the same report (p. 18, Fig. 2)	No implications communicated in the SRES. Implications communicated in the Third Assessment Report.

decarbonisation rates can be observed. Despite the similar growth rate ranges for CO_2 emissions the input uncertainties for income and decarbonization (decrease of carbon emissions per GDP) increased from the SA90 to the SRES scenarios (Fig. 1).

3.3. *Changes in the development process of the scenario series*

Six main changes in the development process of the scenario series from the draft to the final version of the report can be identified (Table 4). First, the review process was intensified from an informal review to an extensive three-phase review process, involving a broad range of scientists and governmental agents, and including a documentation of the comments made during the review. Second, while the developers of the SA90 series had no restrictions, the developers of the IS92 series were obliged to update the earlier scenario series, and to exclude intervention scenarios (IPCC, 1992c). For the SRES team, the procedure was spelled out in ''Terms of Reference'' (IPCC, 2000a). Third, while in 1990 the number of scenarios was reduced from the draft to the final report (from 9 to 4), during this same stage of the process the number of scenarios was increased for the IS92 and the SRES series. Fourth, for SA90 more descriptive titles, i.e., ''2030 High Emissions'' and ''2060 Low Emissions'', were translated into BaU and intervention scenarios, respectively. There were no changes in the IS92 series. In the SRES series, however, some of the modelling teams proposed titles describing the main assumption of the storylines, but these were not included in the final version. Fifth, the description of the scenarios changed from featuring the central scenarios to an equal treatment of all scenarios. While the preliminary report of the SA90 scenarios had two non-intervention scenarios, the final report used the 2030 High Emissions scenario to ''predict'' future climate change. In contrast, for the IS92 and SRES equal treatment was given to all scenarios. Sixth, while for the SA90 and IS92 scenarios the climatic implications were included in the final report, and the preliminary publica-

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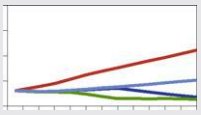
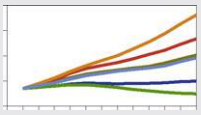
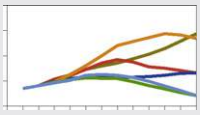
Table 3 – Main changes in the structure of the three scenario series regarding the number of scenarios, the spectrum of the series and the projections of the key variables.

Aspect	SA90-Scenarios (IPCC, 1990a)	IS92-Scenarios (IPCC, 1992a)	SRES-Scenarios (IPCC, 2000a)
Number of scenarios	4, incl. 1 non-intervention	6, incl. 5 non-intervention[a]	40, with 6 illustrative scenarios all non-intervention
Structure of scenario spectrum (based on projected CO2 equivalent emissions from 1990 to the year 2100)			
Projections of key variables (units)	Range of projections (growth rate 1990–2100 in percent per year)		
Population (cap.)	0.7	0.2–1.1	0.3–1.0
Income (US$ 1990)	1.5	1–2.3	1.3–2.7
GDP (US$ 1990)	2.2	1.2–3	2.2–3.0
Energy intensity (J/US$ 1990)	−1 to −1.6	−0.8 to −1.2	−0.8 to −2.2
Carbon intensity (gC/J)	0.1 to −1.2	−0.2 to −0.7	0.0 to −1.9
CO_2-Emissions (gC)	1.3 to −0.6	1.6 to −0.25	1.5 to −0.3

[a] The IS92b scenario is a modification of the IS92a scenario, based on the assumption that current commitments by many OECD member countries have a small impact on the greenhouse gas emissions over the next few decades. Therefore, the IS92 scenarios have in fact only five different non-intervention scenarios.

tions to the SRES also included some implications, all implications were removed in the final version of SRES.

3.4. *Changes in the context*

Finally, three main changes in the context of the scenario development process were observed (Table 5). First, the main triggers for generating new scenario series were the need for more detailed emissions profiles for climate modelling, and the consideration of increasingly complex interrelations of key drivers for calculating the emissions projections. The SA90 series provided more detailed emissions profiles to assess future climate change, which replaced the former and often used simple doubling assumption for CO_2 emissions (WMO/UNEP, 1988). The IS92 series was intended to update the SA90 series in the light of ''recent developments and newly adopted policies'' (IPCC, 1992a). The SRES series was not only conducted to update the IS92 series, but also to consider procedural and structural recommendations advocated by the IPCC's evaluation of the IS92 series (Alcamo et al., 1995).

Methodological developments of scenario techniques led from a backward (SA90) to a projective (IS92) approach and finally to the use of explicit storylines (SRES). Moreover, the number of underlying quantitative models as well as the number of participating scientists significantly increased up to the SRES series. The development process of the SRES series also included a broad scientific review even during the scenario construction, the so-called ''open-process'' (IPCC, 2000a, p. 67).

Finally, the applicability of the scenarios changed from series to series. While the SA90 series could directly be used to evaluate the consequences of interventions to reduce CO_2 emissions, the IS92 and the SRES series could only be used to evaluate the consequences of non-intervention futures and increased the number of recommended baseline (reference) scenarios to be used for such evaluations.

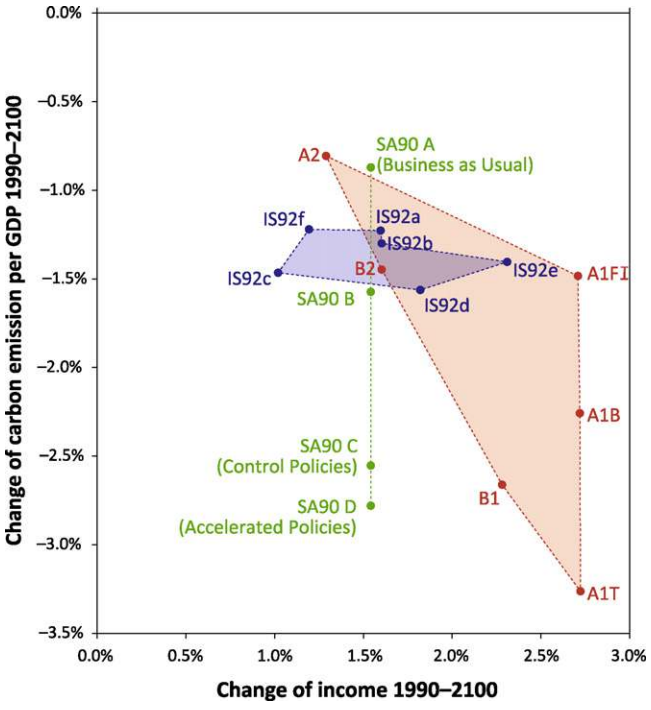


Fig. 1 – Input assumptions corresponding to the storyline axes of the SRES series (carbon emissions per GDP for the "environmental vs. economic"-axis and income for the "regional vs. global"-axis). Carbon emissions per GDP is measured in gC per 1990 US$, income is measured in 1990 US$ per capita (IPCC, 1990a, 1992a, 2000a).

4. Evaluation of changes over the series

We pay special attention to the SRES series as it is the most recent and as it is used in the Fourth Assessment Report (IPCC, 2007b). The applied evaluation criteria have already been introduced above (Section 2.2).

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Table 4 – Main changes in the development process of the scenario series.

Aspect	SA90-Scenarios Main report (IPCC, 1990a); Preliminary report (IPCC, 1990b)	IS92-Scenarios Main report (IPCC, 1992a); Preliminary report (IPCC, 1992b)	SRES-Scenarios Main report (IPCC, 2000a); Previous publications (de Vries et al., 2000; Jiang et al., 2000; Kram et al., 2000; Mori, 2000; Riahi and Roehrl, 2000; Roehrl and Riahi, 2000; Sankovski et al., 2000); Final Draft (IPCC (2000e))
Form of review	Informal	Informal	Formal and documented
Participants	Scientists	Scientists and governmental agents	Scientists and governmental agents
Terms of Reference	–	Update of existing scenarios; no new intervention scenarios	New emissions scenarios that assume no additional climate policy initiatives
Changes in number of scenarios	9 to 4 Note: All scenarios were previously modeled with a high and low economic growth rate. The RIVM team proposed an additional intervention scenario.	(1 to) 6 to 6 Note: According to two developers, a single non-intervention scenario was proposed in the draft (Girod (2006), p. 69).	Scenarios groups: 4 (+3) to 6 Scenarios: 40 to 6 Note: The groups A1C, G, B and T where upgraded and A1C and A1G were merged to A1FI. Instead of all 40 scenarios, the values of six illustrative scenarios were presented.
Changes in titles	2030 High Emission to BaU; 2060 Low Emission to Intervention Scenario B	–	Catch up/High Growth/A1–A1 Domestic supply/Regionalzation/A2–A2 Shortcut/Sustainability/B1–B1 Regional Equity/Regional Stewardship/B2–B2 Proposed by ASF-, AIM–teams (Jiang et al., 2000; Sankovski et al., 2000)
Changes in emphasis on single scenarios	''These scenarios were not intended to be a forecast of possible development …'' (IPCC, 1990b, p. 1) to ''Based on current model results, we predict under the IPCC Business-as-Usual (Scenario A)…'' (IPCC, 1990b, p. xi)	From ''Scenarios IS92c through f explore the sensitivity of results to several sets of alternative, interdependent input assumptions to key variables'' (IPCC, 1992b, p. 1) to ''Six alternative IPCC scenarios (IS92 a – f) now embody a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies…'' (IPCC, 1992a, p. 10)[a]	''We illustrate the sensitivity of projected future GHG emissions and resulting climate change to alternative development in energy systems technologies'' (Roehrl and Riahi, 2000, p. 1) to ''There are six scenario groups that should be considered equally sound that span a wide range of uncertainty, as required by the Terms of Reference.''(IPCC, 2000a, p. 6)[b]
Changing indication of implications	No implications in the preliminary report. Various implications in the final report.	No implications in the preliminary report. Various impacts in the final report.	Temperature increase in some preliminary publications (de Vries et al., 2000; Riahi and Roehrl, 2000; Roehrl and Riahi, 2000; Sankovski et al., 2000). Radioactive forcing in the final draft. No implications in the final report.

[a] However, careful reading reveals that the ''four additional scenarios have been constructed to examine the sensitivity of future greenhouse gas emissions to a wider range of alternative input assumptions for key variables'' (IPCC, 1992a, p. 79).
[b] However, careful reading reveals that ''the team decided to carry out sensitivity tests within some of the storylines by considering alternative scenarios with different fossil-fuel reserves, rates of economic growth, or rates of technical change within a given scenario family. For example, four scenario ''groups'' within the A1 scenario family were explored'' (IPCC, 2000a, p. 27).

4.1. *Description*

Avoiding to label a single scenario as BaU scenario in the IS92 and the SRES series increased credibility of these scenarios because the use had been inappropriate in the SA90 series where there were two non-intervention scenarios (IPCC, 1990b). It also increased saliency because labeling only one of the scenarios as BaU scenario disregards the inherent uncertainty of future developments (e.g., Robinson, 2003). Yet the absence of illustrative names for the SRES scenarios was a deficiency because this made them less comprehensible for policy-makers and other scenario users (saliency) and because, apart from the SRES scenarios, other storyline scenarios in recent literature have illustrative names (Raskin et al., 2005, p. 42; de Vries, 2005, Fig. 19.1) (credibility).

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Table 5 – Main changes in the context regarding the construction and recommended use of the scenarios.

Aspect	SA90-Scenarios (IPCC, 1990a,b)	IS92-Scenarios (IPCC, 1992a)	SRES-Scenarios (IPCC, 2000a)
Trigger	Develop net emission profiles for several scenarios of future global climate change	Update of SA90 scenarios since World Bank revised population and economic growth forecast. War in Persian Gulf. More optimistic assessment of economic availability of renewable resources.	Evaluation of IS92: explore scenario with closing of income gap – explore different trends in technological change – ''open process'' and harmonization of input assumptions''
Scientific setting			
Methodology	Backward	Projective	Projective, Storylines
Models			
ASF (US)	X	X	X
IMAGE (NL)	X	–	X
AIM (ASIA), MARIA (JAPAN), MiniCAM (US)	–		X
Experts	2 expert groups	6 leading authors	28 lead authors
Applications			
Purpose (Alcamo et al., 1995)			
1: Input to evaluate the consequences of non-interventions	Yes	Yes	Yes
2: Input to evaluate the consequences of interventions	Yes	No	No
Recommended use and use in the report	No explicit recommendation. BaU scenario used as baseline.	No explicit recommendation. IS92a scenario used as baseline.	''...the writing team recommends that the smallest set of scenarios used should include the four designated marker scenarios and the two additional illustrative scenarios selected from the scenario groups in the A1 family...'' (p. 46, Box TS-4)

The analyzed implicit *storylines* of the SA90 and IS92 series are adequately described the scenario axes as suggested in the literature (Swart et al., 2004). Although the explication of the SRES storylines by scenario axes is favourable because the main uncertainties are illustrated (saliency), the specific application, however, is flawed. Because the axes titles 'globalisation' and 'sustainability' ''are not necessarily viewed by everyone as being value-free'', the two dimensions were alternatively rephrased as ''more global or more regional'' and ''more economic or more environmental'' (IPCC, 2000a, p. 173). The labelling ''more economic vs. more environmental'' (IPCC, 2001a) contrasts with the definition of sustainability as a guiding concept that intergenerationally balances economic, ecological, and social needs (WCED, 1987). This labelling is also misleading for the SRES B scenario families positioned at the environmental pole of the ''economic vs. environmental''-axis. The B scenario families explicitly rely on ''economic, social and environmental sustainability'', emphasizing not only the relevance of environmental issues, but also oriented toward social equity and economic growth (de Vries et al., 2000; Riahi and Roehrl, 2000), leading to higher income growth than in the A2 scenarios (see Fig. 1). A further weakness is the asymmetric representation of the scenario axes in the SRES scenarios. For instance, sustainability is included very differently in the B families although they are both positioned at the environmental/high sustainability pole. While in the B1 family the transition towards sustainability is assumed to be nearly completed at the end of the 21st century (de Vries et al., 2000), the B2 scenario assumes comparatively little emphasis on sustainability (Riahi and Roehrl, 2000).

The change of *intervention characteristics* from the SA90 to the IS92 series is favourable (credibility and saliency) because the final SA90 report described the SA90-2060low as an intervention scenario although it was described as a non-intervention scenario in the previous report (IPCC, 1990b). A comparison between the ''non-intervention'' SRES scenarios (de Vries et al., 2000; IPCC, 1990b, 1992b; Jiang et al., 2000; Kram et al., 2000; Mori, 2000; Riahi and Roehrl, 2000; Roehrl and Riahi, 2000; Sankovski et al., 2000) with global, long-term and multidimensional scenarios categorized in the IPCC's Mitigation Report (IPCC, 2001b) indicates, however, that the allegedly ''non-intervention'' SRES scenarios would occur in various clusters, including overlaps with *intervention* scenarios. While the A1F1 scenario and the A2 scenario can accurately be assigned to the classes of non-intervention scenarios (pessimistic scenarios or current trends scenarios), the B1 and B2 scenarios fit best to the group of scenarios that need interventions or even a ''great transition'' towards sustainable

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development (Raskin et al., 2005), which is strongly interlinked with climate policy (IPCC, 2001b).[3]

Assigning probabilities to scenarios has been controversially discussed since the 1970s. In accordance with methodological contributions (e.g., Robinson, 1990), the IPCC's authors of the IS92 and SRES series refused to assign probabilities to the scenarios (IPCC, 2000a, p. 27). The change from 'predictions' (SA90 series) to 'projections' (IS92 and SRES series) scores highly against the criterion of credibility. However, new methodological insights, for instance, on integrating discontinuities run counter to the decision "that possible 'surprises' would not be considered" in SRES (IPCC, 2000a, p. 27). Following new approaches (e.g., van Notten et al., 2005), discontinuities and surprises can be adequately included in scenarios and extend their benefits.

The *decreased indication of possible climatic implications* differs from the scenario reports reviewed in the Millennium Ecosystem Assessment Report. All analyzed scenarios include the resulting implications and even draw policy advice in the same report (Gallopin and Rijsberman, 1999; Raskin et al., 2002, 2005) which increases applicability and saliency.

4.2. *Structure*

The rejection of a single BaU scenario acknowledges the high uncertainty of future developments (Robinson, 1990) (scoring highly against credibility). However, the *increased number of baseline scenarios* tends to counteract this benefit. Apart from the IS92 and the SRES series, only one out of 62 emissions scenario series with a timescale up to 2100 (collected in the ESD until 2000) proposes three baselines; all other series propose fewer baselines (Morita, 1999). The increased number of baseline scenarios in IS92 (5) and SRES (40 with 6 illustrative) also has critical implications for their applicability (Section 4.4).

The increased complexity of the *structure of the scenario spectra* reflects advancements in analyzing complex dynamics such as technological change, equity path and different economic developments (Alcamo et al., 1995; IPCC, 2000a) (credibility).

Comparing the IPCC's emissions scenarios with the scenarios from the ESD (Morita, 1999), an *increased range* for population and income projections can be recognized,[4] which reflects inherent uncertainty of future developments (credibility). The smaller GDP range of the SRES series compared to the IS92 series resulted from coupling low income grow and high population growth and vice versa (indicated by the negative correlation between income and population growth in the SRES scenarios) which was based on new findings from Barro (1997). Focusing on the projected decreases in carbon intensity and energy intensity (i.e., efficiency gains; Fig. 2), the analysis indicates that the A1B, A1T and B1 SRES scenarios are similar to ESD *intervention* scenarios. This decrease in carbon and energy intensity is based on incentives for non-fossil fuels and sustainable development emerging for reasons other than climate policy. What is critical, however, is that the change of input assumptions for SRES was not stated explicitly (similar

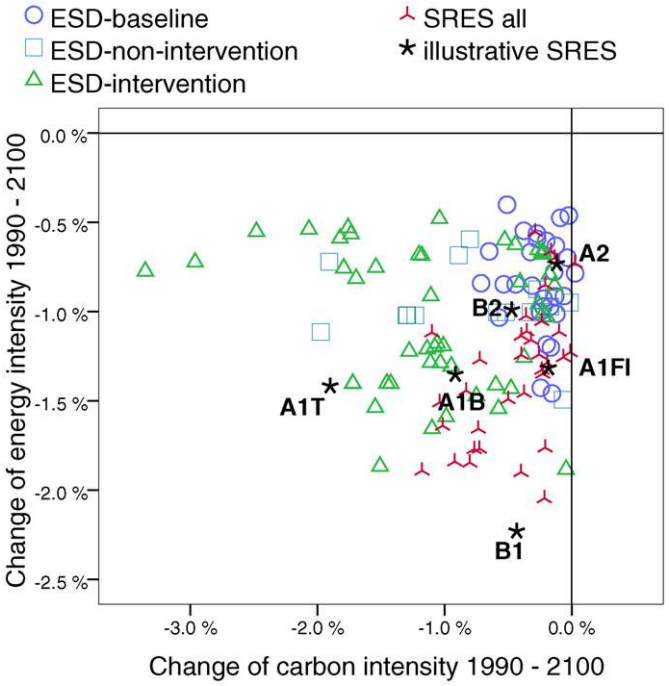

Fig. 2 – Projected annual change of energy and carbon intensity from 1990 to 2100 of SRES, ESD-baseline, ESD-non-intervention and ESD-intervention scenarios. Energy intensity is measured as primary energy consumption per GDP (J/1990 US$), carbon intensity is measured as carbon emissions per primary energy consumption (gC/J).

output range for the SRES and the IS92 series) and that the SRES scenarios were categorized as *non*-intervention scenarios (as were the IS92 scenarios).

4.3. *Development process*

The *intensified review procedure* from SA90 to SRES scores highly against the legitimacy criterion of broad participation, since more experts and policy-makers have been involved. However, it scores poorly against the legitimacy criterion of balanced participation, since those countries which had threatened not to approve the report, in particular Saudi Arabia and USA, were more successful with their requests for changes (Table 6).

The request to exclude policy scenarios in the *Terms of Reference* for SRES reflects the increased external, especially governmental, influence on the scenario construction process. According to one of the authors involved in all three of the IPCC's emissions scenario series, "the First IPCC Assessment Report eventually led to the United Nations Framework Convention on Climate Change in 1992. "Only by then the political relevance increased and several countries (USA, OPEC) resisted any discussion on legally binding emissions reductions as pushed by the EU. Hence, the Second and the Third Assessment Report excluded specific climate policies (Girod, 2006, p. 69). The evaluation of the IS92 scenarios suggested to include intervention scenarios: "because the IS92 scenarios were not designed and are not suitable [to evaluat-

[3] See Supplementary Table S1.
[4] See Supplementary Fig. S1.

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Table 6 – Important requests during the review of the SRES.

Aspect	Comments from agents of the different countries on the SRES drafts	Final Report
Titles	*Switzerland* asks for titles that reflect the storylines (IPCC, 2000c).	No labels
Structure and number of scenarios	Comments on second draft (IPCC, 2000c): *Saudi Arabia* criticizes that the A2 scenario family combines extreme assumptions. The *USA* demands (i) splitting the A1 scenario family into two families (continuous trends versus significant shifting in energy supply) and (ii) an intermediate storyline between A1 and A2. Comments on final draft (IPCC, 2000d): *Saudi Arabia* states that it is unacceptable that the text seeks to give status to the three subgroups in the A1 family (A1C, A1G, and A1T) that is equal to the four marker scenarios (A1, A2, B1, and B2). The *USA* states that it can only accept the Report if the following changes are made: (i) the report identifies a specific representative scenario for each of the seven scenario groups, (ii) the report gives equal treatment to each of the seven representative scenarios, and (iii) the report must explicitly recommend that analysts use the full set of seven representative scenarios in subsequent climate change assessments.	Merge of A1C and A1G to the A1FI scenario Upgrade of A1 groups Selection of illustrative scenarios
Implications	*Saudi Arabia* states that the inclusion of implications of the scenarios is a sufficient reason for the SRES not to be accepted (IPCC, 2000c). *China* requests the removal of the section on radiative forcing (IPCC, 2000d). *Austria* states that additional information on the impact of scenarios would be appreciated. (IPCC, 2000d)	No implications in terms of atmospheric concentration, radiative forcing or temperature projections
Policy assumption	*The UK* sees the greatest shortcoming in not characterizing properly the impact of climate change policies that are implicit in the scenarios. (IPCC, 2000c). *Austria* asks that the many measures for moving towards sustainable development of the B1 scenario family are described more clearly (IPCC, 2000c). According to the *Netherlands*, the B1 scenario family obviously breaks away from business-as-usual. (IPCC, 2000c). The *USA* states that even if no additional *climate* policies are assumed, policy interventions are assumed that lead to significant penetration of non-fossil energy technologies, which reflect an interest in greenhouse gas reductions. (IPCC, 2000c)	Policy assumption of B1 not explicitly indicated. The SRES only states: ''However, GHG emissions are directly affected by non-climate change policies designed for a wide range of other purposes.''(IPCC, 2000a, p. 3).

Note: A more detailed summary of the comments of the governments including arguments for their requests are provided in Supplementary Table S2.

ing the environmental/climatic consequences of intervention to reduce greenhouse gas emissions], new scenarios may be needed to fulfill these purposes'' (Alcamo et al., 1995, p. 279). Hence, the request to exclude intervention scenarios undermines balanced participation because it was requested by the minority of governments and had a negative influence on the saliency of the final report as it led to reduced applicability. Beside the exclusion of intervention scenarios, the Terms of Reference for the SRES (IPCC, 2000a, p. 323) score highly regarding transparency since the findings from the evaluation of the IS92 (Alcamo et al., 1995) were mostly addressed and an increasing transparency of the development process was guaranteed (e.g., by the ''open-process'' concept).

An unbalanced participation can also be tracked for the *construction and selection process of the scenarios* for the final report. One of the authors of the IS92 series remembered that ''serious changes had to be made to the IS92 scenarios after requests—the most important ones coming from the USA'' (Girod, 2006, p. 69). And two authors remembered more specifically that ''the IS92 scenarios were initially intended to reflect business-as-usual policies with no limits on CO_2 emissions and only a central scenario was developed in the first draft. There was strenuous demand that the IS92 scenarios reflect uncertainty in the key drivers of emissions and the scenarios were expanded to include five scenarios with varying, but internally consistent, assumptions about how the future may unfold without explicit climate change policy. A sixth scenario was included which was a variation of the IS92a scenario that did include existing commitments to CO_2 emissions reductions at the time of the report'' (Girod, 2006, p. 69). In the Technical Summary of the final draft of the SRES it is stated that ''the writing team recommends that the smallest set of scenarios used should include the four designated marker scenarios'' (IPCC, 2000e). In the final report this recommendation was extended by the phrase ''[...] and the two additional illustrative scenarios selected from the scenario groups in the A1 family'' (IPCC, 2000a). This upgrade was requested by the USA (see Table 6). The increase to six baseline scenarios scores poorly against the legitimacy criterion of balanced participation because it was requested by those countries which opposed legally binding agreements to reduce CO_2 emissions (interventions).

Two interviewed authors justify the absence of *scenario titles* in the final report with the following reasons: (i) different words mean different things to different people, (ii) titles are likely to be insufficient to capture the complex characteristics of the storylines and (iii) it would be very difficult to agree on titles in an intergovernmental approval process on the

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Table 7 – Proposed titles for marker scenarios.

SRES	AIM modeling team[a] (Jiang et al., 2000)	ASF modeling team[a] (Sankovski et al., 2000)	Jim Shrouds (USDT/USA)[a] (IPCC, 2000b)	Switzerland (IPCC, 2000c)
A1	Catch up (Scenarios C)	High Growth	Global Affluence	Convergence
A2	Domestic Supply (Scenario D)	Regionalization	Regional Identities	Fragmentation
B1	Shortcut[b] (Scenario S)	Sustainability	Global Solutions	Dematerialization
B2	Regional Equity (Scenarios E)	Regional Stewardship	Local Initiatives	Local Solutions

[a] U.S. Department of Transportation (USDT), Asian Pacific Integrated Model (AIM), Atmospheric Stabilization Framework (ASF).
[b] ''Shortcut'' because the quality of the environment is improved in the developing Asia-Pacific countries before reaching levels as critical as those in OECD countries during their development period.

Summary for Policymakers (Girod, 2006, p. 69). However, Table 7 shows that the titles proposed in previous publications, as well as the titles proposed by reviewers, are very similar although they come from different sources. Moreover, the proposed titles are similar to the titles of the storyline scenarios reviewed in the Millennium Ecosystem Assessment Report (Raskin et al., 2005, p. 42). This report also indicates that scenario studies with similar complexity do use scenario titles. The third reason seems to be the best explanation for the absence of scenario names which, nevertheless, is detrimental to credibility and balanced participation.

The *increased emphasis on scenarios exploring the sensitivity* of particular key drivers to baseline scenarios corresponds to a change of the goals, i.e., from policy advice to exploration, and different uncertainty management concepts. The latter changed between SA90 and SRES because uncertainties had become a broadly and controversially discussed issue (Ha-Duong et al., 2007). Whether emissions scenarios are constructed for policy advice or as an exploration tool depends on the function of the scenario study (cf. Wiek et al., 2006). The analyzed change contradicts the original goal that the IPCC should identify ''information needed to evaluate policy implications of climate change and response strategies'' (IPCC, 2004).

The removal of the climatic *implications* from the scenario report scores poorly against the legitimacy criterion of balanced participation because some countries requested that implications ought to be included, while Saudi Arabia and China requested successfully the deletion of the section on radiative forcing (see Table 6).

4.4. *Context*

The main *triggers* for updating the IPCC emissions scenarios were the need to consider more complex dynamics and new uncertainties, as well as methodological improvements in the construction procedure. Since this allows for keeping the IPCC's emissions scenarios up to date, this change scores highly against the criterion of credibility.

The changes of the *scientific settings* were beneficial because they incorporated new achievements in modelling and scenario construction methodology and extended the scientific support in the construction process (''open process''). According to experts involved, the team of authors agreed on four basic storylines after intensive discussions (Girod, 2006, p. 61). However, the construction process of the storylines is not transparently described in the SRES (IPCC, 2000a). Considering recent literature on qualitative scenario construction, there are further potentials for improvement in terms of formal storyline construction, narrative coherence and consistency analysis (Godet, 2000; Wiek et al., 2006; Weimer-Jehle, 2006), as well as greater reflection on normative aspects (Robinson, 2003; Swart et al., 2004). In addition, new methodological insights allow the consideration of discontinuities (van Notten et al., 2005).

We evaluate *applicability* of the IPCC's emissions scenarios against the two purposes proposed by Alcamo et al. (1995) and Alcamo (2001), namely providing input to evaluate the consequence of non-intervention (points one and two below) and interventions (points three to five below).[5] First, a large number of scenarios is problematic because climate models have to be run several times; illustrating and applying the resulting climate change becomes increasingly difficult. Second, the coverage of uncertainties in population and income projections is beneficial because the impact of climate change strongly depends on these variables: ''The most vulnerable future worlds to sea-level rise appear to be the A2 and B2 scenarios, which primarily reflects differences in the socio-economic situation (coastal population, Gross Domestic Product (GDP) and GDP/capita), rather than the magnitude of sea-level rise'' (Nicholls and Tol, 2006, p. 1073). The reference uncertainties are the UN medium projections for population (IPCC, 2000a). Since only few income projections out to 2100 are available, the SRES income range is considered as reference (IPCC, 2000a, p. 118). Third, the inclusion of intervention scenarios is beneficial because it allows direct recognition of the reduction achievements of policy interventions. Fourth, explicating policy assumptions allows the exploration of the emissions reduction potentials of policy interventions. Fifth, the number of baseline scenarios recommended for use again becomes critical since a higher number of baseline scenarios leads to confusing proliferation of different emissions scenarios when intervention scenarios are added (Alcamo, 2001). Overall, the applicability of the IPCC's emissions scenarios decreased with the appearance of the SRES series.

It is important to emphasise that we evaluate here the recommended (based on Alcamo et al., 1995; Alcamo, 2001) and not the actual use of the SRES scenarios. For instance, the SRES B1 scenario has indeed been used in similar ways to an intervention scenario (e.g., Robinson et al., 2006). But since a baseline is defined as ''a non-intervention scenario used as a base in the analysis of intervention scenarios'' (IPCC, 2001b, p. 709), and the SRES explicitly states that the emissions

[5] See Supplementary Table S3.

Table 8 – Main findings from the analysis and evaluation of the scenario series.

Changing issue	Evaluation of the changes
Description	
No more illustrative titles	The abandoning of the BaU label scores highly against the criteria of saliency and credibility because the labeling of the SA90-2030 high as BaU scenario was arbitrary and mantled uncertainties of the projections. The absence of illustrative scenario names (SRES) scores poorly against the criteria of saliency and credibility because it reduced the comprehensibility for users and similar scenarios from literature have illustrative labels.
From implicit to explicit storyline axes	The use of scenario axes (SRES) scores highly against the criterion of saliency because main uncertainties were illustrated. The specific application of scenario axes (SRES) scores poorly against the criterion of credibility because of deficits in the description of the axes and the allocation of the scenarios.
From BaU and intervention to non-intervention scenarios	The classification of the IS92 scenarios as non-intervention scenarios scores highly against the criterion of credibility because the SA90 series inappropriately described the SA90-2060low scenario as an intervention scenario. The non-intervention classification of all SRES scenarios scores poorly against the criteria of credibility and saliency because the classification is not in accordance with literature and users can hardly recognize the fundamental differences within the SRES scenarios.
From prediction to projections	This change scores highly against the criterion of credibility because it is in accordance with methodological contributions from the literature. However, recent methodological insights might demand an improved consideration of discontinuities.
Decreasing indication of implications	This change scores poorly against the criterion of saliency because users did not get informed about the implications in the same report.
Structure	
Increased number of baseline scenarios	The rejection of a single baseline scenario scores highly against the criterion of credibility because a single baseline scenario neglects the uncertainties in future developments. Using not less than six baseline scenarios scores poorly against the criteria of credibility and saliency because most of the scenario series from literature use less baselines, and the high number reduces applicability.
From off-bending to criss-crossing spectrum	This change scores highly against the criterion of credibility because it reflects the consideration of new research insights and complex dynamics.
Increased range of input assumptions	The increased range of income and population projections (SRES, IS92) scores highly against criterion of credibility because it put more emphasis on underlying uncertainties. The lower GDP range (SRES) scores highly against criterion of credibility because it integrated new findings form literature. The increased range of energy intensity (J/US$) and carbon intensity ($CO_2$/J) scores poorly against criterion of credibility because (i) the SRES scenarios were categorized as non-intervention scenarios, and (ii) changing input assumptions were not explicated, despite the comparison with the output range of IS92 and ESD scenarios.
Development process	
Intensified review procedure	This change scores highly against the legitimacy criterion of broad participation because more experts and policy-makers have been involved. This change scores poorly against the legitimacy criterion of balanced participation because countries that had threatened not to approve the report (US, OPEC) were more successful.
More detailed guidelines for scenario construction and output	The exclusion of intervention scenarios scores poorly against the legitimacy criterion of balanced participation because it was requested by some countries (US, OPEC). Other requests on the construction procedure (e.g., open-process) score highly against the legitimacy criterion of transparency because the construction process got more comprehensible.
From selecting scenarios to adding scenarios	This change scores poorly against the legitimacy criterion of balanced participation because the increase to six scenarios (IS92, SRES) was requested only by some countries (especially US).
From adding titles to losing titles	This change scores poorly against the legitimacy criterion of balanced participation because scenario names were used by some authors and requested by some reviewers.
From advisory to exploring scenarios (sensitivity)	This change scores poorly against the legitimacy criterions of balanced participation because this change was requested by those governments that oppose legally binding agreements to reduce greenhouse gas emissions.
Removal of implications	This change scores poorly against legitimacy criterion of balanced participation because it was requested by few countries (China, Saudi Arabia) and opposite requests were ignored.
Context	
Triggers: New data requirements and findings for projections	This change scores highly against the criterion of credibility because the up-date allowed further sophistication of the scenarios.
Scientific setting: Advancements in scenario methodology and increased number of involved scientists	This change in general scores highly against the criterion of legitimacy because of the increased number of participating scientists, and against the criterion of credibility because of the incorporation of new modeling and scenario construction methodologies.

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Table 8 (*Continued*)

Changing issue	Evaluation of the changes
Applicability: Increase to six baselines and loss of intervention scenarios	The storyline construction scores poorly against the legitimacy criterion of transparency because a traceable description of the storyline construction is missing. This change scores poorly against the criterion of saliency because the high number of six baseline increases the costs for climate change simulations, reduces illustration options and complicates the evaluation of intervention scenarios.

scenarios must not ''be interpreted as policy recommendations'' (IPCC, 2000a, p. 3), this was clearly not the recommended use.

5. Discussion

The major changes in the structure and description of the IPCC's scenario series (final report) can be explained by the interplay between increasing scientific capacity (scientific setting and triggers) and an intensified intergovernmental process (development process). The results of the presented analysis and evaluation seem to be robust because we have considered different sources of information. For instance, the expert interviews reported the influence of the governments on the exclusion of intervention scenarios and on the increased number of scenarios which is consistent with the document analysis of the SRES review process.

Table 8 summarises the changes that occurred over time and the results of the evaluation against the criteria of legitimacy, credibility and saliency. We will discuss the results for each of the three criteria.

Credibility. Overall, the credibility of the scenarios continuously improved. Developments in scenario construction methodology (from a deterministic backward approach to a projective storylines approach), the institutionalised account for new findings (continuous update) and a more sophisticated understanding of complex dynamics are unquestionable achievements. In the majority of cases, however, apparent improvements were diluted by other shortcomings. A good example of an 'over-compensatory effect' is the absence of scenario names. While the rejection of a single BaU scenario labelling was an achievement (cf. SA90 vs. SRES), the absence of scenario names conflicts with leading scenario literature. Similarly, the methodological achievement of moving away from predictive approaches seems to have resulted in a disregard of more sophisticated probabilistic as well as discontinuity approaches (e.g., van Notten et al., 2005). Ambivalence reigns also with respect to the storylines. The application of storylines in SRES was an improvement over SA90 and IS92. However, poor evaluation scores result from (i) the inadequate description and allocation of the scenarios (especially the sustainability credentials of SRES B1 and B2), and (ii) ignoring literature which provided improved approaches for storyline and scenario construction (cf. Godet, 2000; Swart et al., 2004; Wiek et al., 2006; Weimer-Jehle, 2006).

The classification of the SRES scenarios as 'non-intervention' scenarios is undoubtedly misleading. Comparing the SRES scenarios to the wider literature either the structure or the description scores poorly. If the SRES scenarios are compared to non-intervention baseline scenarios in the literature, the decrease in carbon and energy intensity assumptions of the SRES A1T and B1 scenarios departs from the range of baseline assumptions. If the SRES scenarios are compared to scenarios using similar storylines, the underlying assumptions are well represented, but their description (scenario names, scenario classification) diverges significantly from the literature. Considering the large decrease in carbon intensity compared to baseline scenarios from the literature casts some doubt about the credibility of the SRES scenarios. Pielke et al. (2008) criticize the ''amount of spontaneous technological change and related decarbonization'' in the allegedly non-intervention SRES scenarios (p. 531). The non-intervention classification of the A1T and B1 scenarios (as well as to some extent the A1B and B2 scenarios) seems to ''seriously underestimate the scale of the technological challenge associated with stabilizing greenhouse-gas concentrations'' (Pielke et al., 2008, p. 531).

Saliency. Our analysis indicates that the saliency of the scenarios has rather been reduced over time. Improvements by avoiding BaU scenario labelling and by using scenario axes are countered with several deficiencies in the SRES such as the absence of scenarios titles, an inappropriate scenario classification and the relatively high number of baseline scenarios. However, the large number of scenarios in the SRES would carry less weight in our evaluation if titles or the classification would clearly indicate that only the A1FI and A2 scenarios represent current trends in energy efficiency and energy supply. The ambiguity of the scenario classification stems from the narrow definition of 'intervention' used by the SRES as ''policies and/or measures of which the primary goal is to reduce greenhouse gas emissions'' (IPCC, 2000a, p. 81). This allows for introducing RD&D for renewable energy or sustainable development in non-intervention scenarios because these measures have multiple benefits and can therefore be implemented for other reasons. However, scenario users with a broader climate policy concept than that adopted in the SRES are misled if they do not realise that the low emissions SRES scenarios (A1T and B1) assume such measures that promote efficiency and non-fossil energy technologies (cf. Pielke et al., 2008).

This ambiguity has been recognised by the IPCC, admitting that ''in practice, many policies can both reduce greenhouse gas emissions and achieve other goals'' and that a clear distinction between intervention and non-intervention might be difficult if such policies are assumed (IPCC, 2001b, p. 122). One could argue that the storylines of the scenarios are described in the SRES and that their implications for policies therefore is unambiguous. However, the Fourth Assessment Report presents in the ''Summary for Policymakers'' the SRES climate projections as ''Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies)'' (IPCC, 2007a, Table SPM.5) while the storylines are *not* described in the summary. The referenced main report

provides only a brief description of the scenarios which does *not* allow scenario users to recognize the assumed interventions relevant for carbon emissions in the B1 and A1T scenarios (IPCC, 2007b, p. 44).

Legitimacy. The evaluation of the legitimacy of the series of IPCC's emissions scenarios results in an ambivalent picture. Focusing only on the number of poor and high scores, however, underestimates the undoubted increase in legitimacy in the evolution of the IPCC's emissions scenarios. The high scores include major overall achievements, while the poor scores refer to particular aspects of (il)legitimacy in the SRES scenario series. The development process of the SRES scenarios was, with one exception (storylines), transparently documented (IPCC, 2000d, 2000b, 2000c, 2000e), and the depth and broadness of the participation was improved with respect to both scientists and governmental agents. These aspects had in turn a generally positive influence on credibility and saliency. The broader involvement of scientists fostered the scientific credibility of the scenarios, for instance, in terms of methodological robustness. Requests from governmental agents had positive effects on the saliency and credibility of the scenarios, for instance, the rejection of a single BaU scenario.

However, our analysis revealed a variety of unbalanced governmental influences. A major example is the exclusion of intervention scenarios which was requested by some countries refusing legally binding agreements to cut carbon emissions. Other examples are the increased number of scenarios, the absence of scenario names and the removal of climatic implications. Moreover, ambivalent outcomes resulted from each of the major achievements. Evidently, the IPCC's enforcement of transparency does not 'automatically' lead to thorough fairness (defined as *balance* among all statements)—a situation which is in line with literature on participatory processes in policy and planning (e.g., Smith and McDonough, 2001). The different power positions do not dissolve within the IPCC's review process because countries that had threatened not to approve the report (US, OPEC) were more successful in getting their statements enforced. Transparency is a necessary condition to address these issues.

Finally, our analysis indicates *trade-offs* between the three criteria. This is in line with Cash et al. (2003) who suggest that boundary work at the interface between science and policy needs to balance credibility, salience, and legitimacy of the information produced. The decision procedure within the IPCC's review process allows for deliberating alternative and conflicting views, although ultimately it aims at consensus building (IPCC, 1999). This setting favours more than fewer baseline scenarios and precludes the adoption of illustrative scenario titles. Because the future is inherently uncertain and probability concepts are controversial (Robinson, 2003), it is difficult to reject any given consistent and plausible scenarios. The trade-off results from the fact that a smaller number of baseline scenarios with illustrative titles would indeed increase the saliency of the scenarios. A second, similar trade-off exists between legitimacy and credibility, as demonstrated in the literature. The reviewed literature does favour fewer baseline scenarios and with illustrative titles, but then the legitimacy of the compared scenarios as viewed by the participating governments is significantly lower (e.g., Gallopin and Rijsberman, 1999; Raskin et al., 2005).

The trade-off between legitimacy and saliency could be mitigated by a more accurate scenario classification. Distinctions between 'intervention' scenarios and 'current trend' scenarios could have made for greater comprehensibility (saliency) without undermining legitimacy. An argument for this contention is the comment of the USA (see Table 6) indicating that they would have agreed to a classification of the A1FI (formerly A1G and A1C) scenario as ''continued trends in energy supply'' and the A1B and A1T scenarios as ''significant shifts in energy supply toward renewable and nuclear'' (quasi-intervention scenarios).

We have to emphasise that our analysis and evaluation focused on the structure and description of the IPCC's emissions scenarios as well as on procedural aspects and political influences. Hence, the described and analyzed changes are not comprehensive: various improvements to the quantitative models underlying the scenario constructions (e.g., advanced recognition of different greenhouse gases; better representation of economic, social and technological dynamics) were not analyzed, while our analysis of the scenario structure considered only the global level—improvements on the level of world regions (e.g., interactions between world regions) were not evaluated.

6. Conclusions

Significant enhancement in the *credibility* of the IPCC's emissions scenarios has been achieved between SA90 and SRES. A more formal storyline and scenario construction process for future emissions scenarios would nevertheless foster further sophistication of scenario construction. This would entail a traceable storyline construction process and a consistent translation of storylines into quantitative assumptions. A second concern about credibility, emerging from the assumptions underlying the non-intervention characteristic of the SRES scenarios, should be addressed in future IPCC work by referring to the leading opinions in the literature.

Deficiencies in *saliency* could be overcome by labelling the scenarios according to the underlying storylines and by developing a classification scheme that captures the main distinguishing characteristics of the scenarios (including their interventional characters). A reduction in the number of baseline scenarios to a smaller reasonable set for use in scientific studies and political discourse should also be considered.

Despite significant enhanced *legitimacy* of the IPCC's emissions scenarios between SA90 and SRES, concessions were made to intergovernmental approval. Our analysis indicates that the emissions scenarios did not result solely from synthesising research results, but to a significant extent were influenced through intergovernmental negotiations. The extent to which such co-production (cf. Jasanoff, 2004) can be claimed legitimate depends very largely on the transparency and representativeness of the negotiating processes.

For future scenario exercises, the IPCC has decided to begin with possible evolution patterns for the atmospheric concentration of greenhouse gases (''representative concentration pathways (RCPs)'') which will simultaneously serve for

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the development of new climate model simulations and new socio-economic and emissions scenarios (IPCC, 2008). The challenges for the development of new IPCC's emission scenarios remain: (i) to agree on a salient number of emissions scenarios; (ii) to transparently describe and classify the scenarios (intervention/non-intervention); (iii) to assess which policies are needed to reach the low RCPs/emissions scenarios; and (iv) to transparently and fairly mediate among the scientific and intergovernmental review contributions.

The intergovernmental work of the IPCC, including the review processes, has been groundbreaking in linking climate change science and policy. Our evaluation provides a basis for learning from past experiences based on the specific case of the evolution of the IPCC's emissions scenarios. Yet, the results can be used to inform other ongoing and upcoming initiatives on how to design the institutional settings and rules for 'boundary work' on climate change in order to balance credibility, saliency, and legitimacy at the science-policy interface.

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Supplementary data

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Bastien Girod holds a Master's degree in environmental sciences from the Swiss Federal Institute of Technology (ETH Zurich), Switzerland and is currently pursuing his PhD study at the same institution on a project dealing with carbon emission and rebound effects of households, funded by the Swiss National Science Foundation. Since 2007, Bastien Girod is member of the Swiss National Parliament.

Arnim Wiek is visiting scientist at the Institute for Resources, Environment, and Sustainability at the University of British

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Columbia, and designated Assistant Professor in Sustainability Science at Arizona State University. He has conducted several scenario studies in sustainability research on land-use conflicts, cross-sectoral planning, integrated resource management, and emerging technologies in close collaboration with non-academic partners from government, business and civil society. Wiek holds a PhD in environmental sciences from the ETH Zurich and a Master's degree in environmental sciences from the University of Jena, Germany.

Harald Mieg is Hans-Sauer-Professor of Metropolitan Studies and Innovation at the Department of Geography at the Humboldt University in Berlin, Germany. He holds a PhD in social psychology and philosophy from Mannheim University and a Master's degree in psychology and mathematics from the same institution. Between 1998 and 2004, Mieg was Assistant Professor of Human-Environmental Interaction at ETH Zurich. His areas of interest include sustainable urban development; science-society-cooperation; invention and innovation as expertise-in-context; science and technology parks and urban development.

Mike Hulme is Founding Director of the Tyndall Centre for Climate Change Research at the School of Environmental Sciences at the University of East Anglia, UK. He has published over 100 peer-reviewed journal papers and over 30 book chapters on climate change topics. He has prepared climate scenarios and reports for the UK Government, the European Commission, UNEP, UNDP, WWF-International and the IPCC. He is leading the EU Integrated Project ADAM (Adaptation and Mitigation Strategies) during the period 2006–2009, which comprises a 26-member European research consortium contributing research to the development of EU climate policy. He co-edits the journal *Global Environmental Change*.

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